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Aurore Staes

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Essays on Firms' Private Information

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Résumé

Cette thèse est constituée de trois chapitres et s'organise en deux parties. Chaque partie traite d'un problème théorique particulier relatif à la question de l'information privée des entreprises.

La première partie traite de l'architecture des politiques environnementales et de l'information privée des entreprises. Le premier chapitre analyse la possibilité de mettre en place un accord climatique international quand l'asymétrie d'information touche à la fois les pays et les entreprises domestiques. Nous prenons en compte les contraintes clés dans la modélisation d'un tel accord: hétérogénéité des pays, asymétrie d'information aux niveaux national et international et participation de tous les pays. Nous obtenons l'accord de premier et de deuxième rang. Nous montrons que l'accord optimal ne se caractérise pas nécessairement par un prix unique du carbone. En effet, en présence d'un double niveau d'asymétrie d'information, l'accord de deuxième rang se définit par des prix du carbone qui diffèrent d'un pays à l'autre. Nous mettons ainsi en lumière la sous-optimalité d'un accord qui reposerait sur un prix unique du carbone.

La seconde partie de la thèse, organisée en deux chapitres, s'intéresse à l'interaction entre deux outils de communication le signal par le prix et la divulgation d'information par un tiers qui sont utilisés par les entreprises pour révéler leur information privée aux consommateurs. Le deuxième chapitre s'attache à l'examen d'une divulgation d'information par un tiers sous la forme d'une certification menée par un intermédiaire: un certificateur. Un monopole a le choix entre payer pour cette certification ou utiliser son prix pour signaler sa qualité. Le certificateur est stratégique, soit à la recherche de son propre profit, soit il agit dans l'intérêt du monopole. Je montre tout d'abord que la structure des coûts d'audit engagés par le certificateur détermine le type de monopole qui choisit la certification. Je montre ensuite que les caractéristiques de la certification la probabilité d'audit et les frais de certification varient selon la motivation du certificateur.

Le troisième chapitre étudie une divulgation d'information par un tiers qui se caractérise par deux étapes: la certification et l'obtention d'un label. Celle-ci implique deux intermédiaires: un certificateur et un détenteur du label et deux types de coût: un frais de certification et un prix du label. Un monopole choisit entre payer pour cette divulgation ou signaler sa qualité par le prix. Je caractérise la divulgation quand le certificateur maximise son profit et le détenteur du label est soit à la recherche de son propre profit, soit il agit dans l'intérêt du monopole. Je montre que, quand le détenteur du label défend le monopole, le prix du label ainsi que la répartition du surplus dépendent de la nature de la compétition entre certificateurs. En particulier, si ce détenteur du label souhaite empêcher la capture du surplus par un certificateur, il devra favoriser la compétition entre certificateurs ou, quand cela est impossible, choisir un prix du label élevé.

SUMMARY

This thesis consists of three chapters and is organized in two parts. Each part deals with a particular theoretical issue of firms' private information.

The first part of the thesis is devoted to the architecture of global warming policies and firms' private information. The first chapter analyses which global agreement can be implemented in presence of two-tiers asymmetry of information coming from both countries and domestic firms. We impose several key constraints on the design of such a regulatory policy: heterogeneity of countries, two-tier private information both at domestic and international levels and full participation. We derive the optimal first and second-best agreement. It is shown that the optimal global agreement does not always entail a uniform price for carbon. In presence of private information of domestic firms, the second-best agreement entails prices for carbon that differ from one country to another. We thereby highlight the failure of the *Law of One Carbon Price*.

In the second part of the thesis that comprises two chapters, I study the interaction between two communication tools — price signaling and third-party disclosure — that firms may use to reveal their private information to consumers. The second chapter examines a third-party disclosure that consists in a certification handled by a middleman: a certifier. A monopolist has the choice between paying for that disclosure or using price to signal quality. The strategic certifier is either a for-profit entity or an entity that defends the monopolist' interest. I first show that the structure of audit costs incurred by the middlemen affects the type of monopolist that chooses certification. I then show that the characteristics of the certification —audit probability and certification fee— vary with the motivation of the strategic middleman. More specifically, a for-profit certifier, whenever it is possible, will not audit and put the highest feasible fee while a certifier defending the monopolist will audit with a certain probability and select the lowest possible fee. This

chapter thereby contributes to a better understanding of the certification industry.

The last chapter studies a third-party disclosure that consists of two steps: certification and labeling. It involves two middlemen — the certifier and the owner of the label — and it includes a certification fee and a price for the label. A monopolist has the choice between paying for that disclosure or signaling quality through price. I derive the disclosure when the certifier is a for-profit private entity and the label owner is private either a for-profit entity or an entity that defends the monopolist' interest. I show that, when the label owner defends the monopolist, the price of that label and the sharing of the surplus depend on whether there is competition between the certifiers. In particular, I find that, a label owner defending the monopolist in order to prevent the certifier from capturing the surplus should favor competition between certifiers or, when that is not possible, monetize the label.

Keywords: Asymmetric Information, Regulation, Mechanism Design, Certification, Labeling, Middlemen, Price signaling.

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GENERAL INTRODUCTION

When Peter and Marie play cards, depending on whether or not Peter can observe Marie's hand, they will be playing two very different games. In the first case, Peter has full information about the game while in the second one, Marie holds private information that Peter ignores. It is generally easier for Peter to win in the former game; which is why some people cheat at cards. A similar concept applies when a firm interacts with other economic players: other firms, retailers, regulators or consumers. The firm often has private information about its production and the characteristics of its product. This complicates the game for those players. Let us consider two examples.

A first difficulty arises when governments or other authorities want to correct a market failure, but do not know the critical parameters of the firms they want to regulate. In these cases, devising a suitable regulation is far more complicated than what it would be in a world with full information. A typical example in the environmental literature is a regulator willing to reduce pollutive emissions but ignoring the abatement costs of the firms. If they request this information directly from firms, they may lie if, for instance, they can obtain higher subsidies or pay lower taxes.

A second issue concerns consumers that do not have all the information about the firm's product quality. In particular, this occurs when there are some hidden attributes for which consumers care and are willing to pay for, but that are not observable even after consumption. This is the case with labor conditions (e.g. fair labor), the impact of consumption on health (e.g. non-genetically modified food) and the impact of production on the environment (e.g. green technologies). In such markets, firms will find it difficult to sell products that are costlier to produce, even though they are more valued by consumers. A possible solution is to therefore convince consumers that their products are of high quality. To this end, firms can use a variety of marketing instruments such as warranties, advertising or price signals. The idea is that the cost of acquiring these is lower for

high quality than for low quality, which guarantees credibility. Alternatively, firms may disclose information via the use of an independent third-party — a middleman that audits and reveals their quality to consumers. However, because quality is private information to the producers, this middleman meets a problem: firms may try to pretend to be of a higher quality in order to profit from the consumer's willingness to pay.

These problems have received particular attention in the economic literature. According to the *Theory of Incentives*, a principal — the regulator or the third-party in the two previously mentioned examples — chooses a mechanism that provides the incentives so as to reveal the private information held by an agent: the firm. This type of mechanisms solves the asymmetry of information but it comes at the cost of distortions in decisions, output or actions of the firms with respect to the full information scenario.

The work presented in this thesis relies on the tools of the *Theory of Incentives*. It is composed by two independent parts and each deals with problems related to the firms' private information and investigates how they can be overcome. The first part made up of the first chapter, investigates the design of an efficient International Environmental Agreement in presence of private information of firms. The second part is concerned with the communication tools firms may use to reveal their private information to consumers. The second chapter focuses on third-party disclosure offered by a strategic middleman: a certifier. The third chapter studies a similar problem when disclosure involves not only one but two middlemen: a certifier and a label owner. I briefly introduce each of these chapters below, as well as their main results, to provide the reader with an overview of the topics studied.

The first chapter of the thesis is co-authored by David Martimort and is entitled "The Law of One Carbon Price: A Political-Economy Fallacy". This constitutes the first part of the thesis in which we examine how the presence of firms' private information at domestic scale complicates the designing of an International Environmental Agreement. The designing of regulation to address the problem of global warming is still a challenge for economists. Global warming results from negative *externalities*, namely pollutive emissions linked to production and that are not taken into account by the market. These externalities are *non-excludable*. This means that when polluters emit, they cannot contain pollution within one area but it will have negative effects at a global scale. Global

warming is thus a *global public bad*. This implies that, even though each country has an interest in agreeing to reducing their emissions, any given country calculates that if all the other countries negotiate an agreement, then they are better off not participating. Indeed, by staying out, a country can enjoy the benefit of emission reduction without paying for it. This is called the *free-rider* problem (Olson (2012)) — this illustrates the failure of a Coasian approach in the case of non-excludable externalities and calls for the intervention of the government or some other coercive authority to impose a method for determining pollution reduction. In this context, Baliga and Maskin (2003) advocate for the use of a mechanism design approach. The *free-rider* problem is worsened by the presence of asymmetry of information: countries and firms hold private information about how much it costs them to reduce polluting emission and consumers hold private information about how much they value pollution reduction. In this context, the goal is to find the appropriate mechanism to deal with global warming taking into account the informational constraints. In that direction, Martimort and Sand-Zantman (2013) discuss the feasibility and performance of simple mechanisms to implement international environmental agreements. They take into account two important elements: the asymmetry of information between countries and the participation of sovereign and heterogeneous countries. They derive a simple menu of options that enables all countries to voluntarily contribute to a fund although at different intensities. Only the most efficient ones effectively reduce their pollution below their *business as usual* level. In this chapter of the thesis we follow their approach but we deal with one critical dimension of the problem that has remained largely unexplored: the role that domestic politics plays in shaping international environmental policy. To that end, we develop a model of an Environmental International Agreement with two-tier asymmetry of information: national and international. There is asymmetry of information at each level. The first tier has it between countries that ignore how costly it is for the others to accept the international agreement. The second tier concerns governments that do not have information about how much it costs domestic firms to abate emissions in a way that respects the intentional agreement. As in Martimort and Sand-Zantman (2013), the mechanism should provide incentives to participate and to reduce emissions but, in addition, it should also provide the incentives for domestic firms and consumers to participate. In that context, we study the feasibility and performance of an International Environmental Agreement. We first found that, despite the two-tier

asymmetry of information, an International Environmental Agreement always dominates non-cooperative domestic policies, even in a second-best environment. We then show that the existence of a two-tier asymmetry of information may rule out the possibility of implementing the first-best agreement that entails a unique price for carbon. Indeed, second-best agreement should entail a price for carbon that varies from one country to another. Our results contribute to the academic and public debate over the adoption of a uniform price for carbon.

In the second part of the thesis, I study two channels of communication — price signaling and third-party disclosure — that a monopolist can use to reveal the exogenous quality of their good to consumers. Third-party disclosure can be considered as a decentralized approach ([Gruère \(2013\)](#)). Indeed, it is voluntary and relies on the creation of informational schemes by third-party entities that are mostly either private or non-profits ([Prag, Lyon, and Russillo \(2016\)](#)). This explains why, over the past several years, economists have been increasingly attracted to these informational schemes as an alternative to traditional methods and, in particular, for regulating environmental externalities ([Mason \(2013\)](#)). The use of third-party disclosure, however, raises two main issues: their reliability and their cost. These two problems are intertwined. Indeed, part of the credibility relies on the presence of a middleman which, in turn often increases the cost incurred by firms to obtain those schemes. In my work, third-party disclosure is offered by one or two middlemen and is required to be credible a mechanism in the sense that the firm has no incentive to lie about their quality.¹

In the second chapter, entitled "Third-Party Certification and Price Signaling", I study the interplay between price signaling and third-party certification of product quality. To that end, I follow the theoretical approach of [Daughety and Reinganum \(2008a\)](#). This paper argues that, contrary to what has been extensively done in the literature, for a firm willing to reveal exogenous quality the alternative to disclosure should not be viewed as "non-disclosure" but rather as revealing their type via other channels such as price. Note that, marginal cost should depend on quality, otherwise price signaling is not possible. They show that, the integration of these two alternatives has new implications on disclosure, signaling, firm preferences over type, and the social efficiency of the channel of

¹I however gloss over one part of the credibility problem by assuming that the middlemen are honest. For the incentives to lie for the middleman see for instance [Guerra \(2001\)](#) and [Mahenc \(2017\)](#).

communication employed. In particular, assuming that higher quality is associated with higher marginal costs of production, they show in a continuum-of-types model that there is a range of disclosure costs, such that some types of monopolist will signal and others will disclose. I consider a similar model in which a monopolist can use price signal as an alternative to certification. However, contrary to [Daughety and Reinganum \(2008a\)](#), the certification is endogenous. This setting allows me to provide predictions that contribute to explain some discrepancies observed in certification schemes. I first show that the structure of audit costs incurred by the third-party affects the type of monopolist that chooses certification. I then show that the characteristics of the certification—audit probability and certification fee—vary with the motivation of the strategic middleman. More specifically, a for-profit certifier, whenever it is possible, will not audit and put the highest feasible fee while a certifier defending the monopolist will audit with a certain probability and select the lowest possible fee. This chapter thereby contributes to a better understanding of the certification industry. According to [Liu \(2003\)](#), "the increased use of third-party certification has led to the development of a certification industry, with its own economic interests". Modeling the determinants of certification is all the more important in a context in which the multiplication of informational schemes creates higher compliance costs for producers.²

In the third and last chapter entitled "The Two Middlemen", I examine a similar problem as in the previous chapter but assuming that there are two middlemen. The certification literature is often associated with the labeling literature. This makes sense since certification, in many cases, is a necessary preliminary step to obtain a label. Indeed, as explained by [Delmas and Colgan \(2018\)](#), disclosure strategies often comprise several steps: codification, standardization, certification and labeling. Note that, different intermediaries may be in charge of these steps. It is therefore relevant, though rarely examined, to study disclosure strategies taking these elements into account. In this last chapter, I therefore describe a third-party disclosure that comprises two steps: certification and labeling and involves two strategic middlemen: a certifier and a label owner. The certifier is a for-profit entity and the label owner is a private entity either for-profit or defending the monopolist. In practice, the presence of these two intermediaries aims at strengthen-

²Notice that it became common to pay for several certifications to verify compliance to different standards for the one product. This phenomenon is encouraged by the emergence of labels based on one criteria instead of multi-attributes ([Gruère \(2013\)](#)).

ing the credibility of the label but it also often increases the cost for the firm due to the higher number of intermediaries. I thus investigate the effect of a disclosure composed of labeling and certification on the cost of disclosure and market pricing. I also examine how the surplus is shared between the monopolist and the two middlemen. I show that a private label owner, either for-profit or defending the monopolist, is in a strategic position to capture the surplus that could otherwise be captured by a certifier. This may explain the increasing number of privately owned informational schemes revealed in the study from the OCDE by [Prag, Lyon, and Russillo \(2016\)](#). I also find that the price of the label and the sharing of the surplus when the label owner defends the monopolist depends on the competition between certifiers. A label owner defending the industry can prevent a certifier from capturing the disclosure surplus, either by monetizing the label or making it free and encouraging competition between certifiers.

Chapter 1. The Law of One Carbon Price: A Political-Economy Fallacy ¹

(with David Martimort)

Abstract

This paper studies how global warming, a worldwide *public bad* should be regulated, whether such a regulation can be an International Environmental Agreement and how to do so. We impose several key constraints on the design of such a regulatory policy: heterogeneity of countries, two-tier private information both at domestic and international levels and full participation. We first show that there is a trade-off between a better internalization of the externality under an international regulation, although informatively contracted at the national and international level, and a lesser internalization under non-cooperative domestic regulations with a lesser informational problem. The international agreement always dominates the domestic policies but the existence of a two-tier asymmetry of information may rule out the possibility of implementing the first-best agreement that entails a unique price of carbon for all countries. When this optimal agreement is not possible, we show that the second-best carbon prices should vary from one country to another. We thereby highlight the failure of the *Law of One Carbon Price*.

Keywords: *Asymmetric information, environmental policy, global warming, centralization.*

JEL Classification: Q54, D82, H23.

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Introduction

Movements against global warming are multiplying. Citizens together with NGOs make complains about the lack of action of their governments. In 2018, ten families from Portugal, Germany, France, Italy, Romania, Kenya, Fiji, and the Saami Youth Association Sáminuorra brought a case against the EU in front of the European Court of Justice. These families, supported by NGOs, claim that the EU has failed, and continues to fail, to meet its urgent responsibilities to limit the emission of greenhouse gases. Similar examples of legal cases are flourishing in all around the world.¹ The lack of ambitious regulation can be understood due to the nature of global warming. Global warming is a global *public bad* and as such, any emission reduction realized by one country benefits to all. It follows that every government rather free-ride and let the others bear the cost of ambitious reduction. As every country adopts the same behavior, emissions do not reduce significantly and citizens increasingly suffer from pollution. It is the well-known *under provision of public good*. However, even if a general agreement provides governments with the appropriate incentives to reduce their emissions and avoid free-riding, a second problem still remains. When domestic governments try to implement environmental policies, they often meet resistance from both those that create this pollution and those that suffer from pollution. Recent examples illustrate these oppositions. In Brazil, in May 2019, truck drivers stroked and obtained a suspension of the fuel tax increase. In Europe, many firms or groups of firms lobby in order to limit the scope and the stringency of the European market EU ETS. Finally, in France, in December 2018, an increase in the carbon tax was abandoned following the civil movement of the *yellow vests*. They refuse environmental policies arguing that individual costs, either in terms of profit or purchasing power, are too heavy. Domestic governments can ignore these claims but at the risk of facing strikes and losing popularity.² It thus appears that both international tensions, due to free-riding, and domestic tensions, due to the acceptability of the regulation by firms and consumers, complicate the setting of an International Environmental Agreement. Sometimes, it is not even clear which of

¹For instance, in 2015, 886 Dutch citizens wanted to force the state to reduce emissions from 25% by 2020, in January 2018, the mayor of New-York made a complain against five multinationals and, in December 2018, four NGOs (including Greenpeace and Oxfam) threatened the French government of a lawsuit.

² Many recent examples nevertheless illustrate that governments take this risk. For instance in France, despite many complains on the glyphosate that is suspected to be carcinogenic by the Centre international de recherche sur le cancer (CIRC), the French government postponed its ban initially promised in 2021.

the two problems prevent governments from taking measure for global warming. For instance, the American administration withdrew from the Paris agreement on the grounds that it was unfair to US citizens. This argument can be understood in two ways: either it is unfair because the other countries do not contribute as much as they should, or it is unfair because the cost for the US citizens is too high.

The question of knowing how we can reach an ambitious regulation through an International Environmental Agreement is consequently still high in the agenda. According to economic theory, with perfect information, global warming should be solved by a central institution. The institution would implement a regulation that would fully internalize the global externality. In practice, countries are heterogeneous, and in particular, welfare costs of reducing emissions differ among countries. Domestic governments only know the cost for their own country. The existence of information hidden between countries is a first issue that makes more intricate the free-riding problem when deciding for an international regulation. A second problem arises due to hidden information at domestic scale. An international agreement has to respect countries' sovereignty and cannot force them to accept the regulation. On the other side, governments accept the agreement only if they obtain their citizens' approval. Citizens, and in particular firms, accept or not the regulation depending on their cost for reducing emissions. Governments are often ignorant of firms' individual costs. This asymmetry of information between citizens and domestic government strongly complicates the domestic acceptability of a global agreement. The existence of country and citizens' heterogeneity, asymmetry of information at global and domestic scale, as well as countries' sovereignty are as many barriers to reach an agreement. In this complicated context, the question of whether and how an International Environmental Agreement can be implemented comes back on the forefront of the analysis. Our broader motivation is to better understand the nuts and bolts of the architecture of environmental regulation in an imperfect information environment. In particular, we consider as necessary to take into account the different levels of governance to study the possibility and the implementation of an international regulation.

OUR CONTRIBUTION. Taking into account the heterogeneity of countries and firms, two-tier private information both at domestic and international levels and full participation, we derive first-best and second-best International Environmental Agreements. Our model is, to our knowledge, the first to study global agreements in such a rich environment.

Our model further questions the feasibility and desirability of a unique price for carbon. In a first-best environment, the price for carbon is the same for all countries. However, we show that when the asymmetry of information is too strong, this first-best cannot be implemented. The second-best optimal agreement entails prices for carbon that depend on domestic parameters and, as such, differ in every country. This result goes against an International Environmental Agreement that would consist in a unique price for carbon.

In our model, when countries do not compel to an International Environmental Agreement, they non-cooperatively implement domestic regulations. Countries' decisions to undertake such domestic policies depend on their domestic costs and benefits from pollution reduction. This outside option, that occurs in case of failure of the general agreement, differs from the *Business As Usual* scenario more commonly assumed in the literature. We believe that our assumption may be more realistic. Indeed, in reality, when countries accept an international agreement, their domestic policies aim at respecting it. For countries which refuse it, they can still implement, in a non-cooperative way, some less ambitious environmental domestic regulations.

We first study this *non-cooperative equilibrium* in which countries implement their *domestic regulations*. In each country, there is a continuum of firms which produce and sell their output on competitive domestic markets. Production generates emissions which contribute to a negative worldwide externality. By incurring quadratic abatement costs, a firm can reduce its emissions. These costs depend on a *firm-specific parameter*, capturing the fact that all the firms do not have access to the same technology. Importantly, this efficiency parameter is private information of the firms, it is the *first source of asymmetric information* in our model. To correct pollution, domestic regulators introduce domestic markets for firms to trade pollution permits and they compel firms either to abate or to buy permits for their emissions. Domestic governments not only have to take into account private information of heterogeneous firms but also the participation constraints of firms and consumers that pay a subsidy to firms. We find that, at the first-best, domestic regulations entail a domestic Pigovian price of carbon that is the same in all countries. Although the *Law of One Carbon Price* applies, this price only corrects for the externality that arises at the local level and, which is the same worldwide. This price remains too low because it leaves uncorrected the externality that domestic emissions exert abroad. In addition, when the domestic informational cost is too high, this Pigovian price cannot

be implemented. When this happens, domestic regulators set up second-best domestic regulations. Such regulations are costly for regulators that give up rent to some firms in order to respect incentives and participation constraints. The domestic second-best carbon prices -being lower than in the first-best- correct less the externality. Of importance, the *Law of One Carbon Price* here fails. Indeed, these prices may differ across countries as they depend not only on the local externality but also on country-specific demand parameters.

Once derived what happens when countries do not sign the agreement, we study the *International Environmental Agreement*. A central regulator, embodying an international institution, has the delegated power of implementing regulations in each country. Sovereign countries must find optimal to participate to the agreement. In other words, the regulation must raise greater payoffs than the non-cooperative domestic regulations scenario. To foster cooperation, the central regulator uses lump-sum inter-countries' transfers. Importantly, countries are *heterogeneous with respect to a domestic demand shock*. This shift parameter might embody fluctuations in domestic economic conditions, heterogeneity in consumer tastes across countries and the like. It constitutes *the second source of asymmetry of information* as the shock parameter is not known by the central regulator. Countries heterogeneity and private information, full participation and budget balance are key and stringent constraints. The global Pigovian price that fully internalizes the worldwide externality is the same for every country but it is better than the domestic Pigovian price.

As a first pass, we consider a *complete information scenario* and assume that, although domestic firms in each country keep private knowledge of their abatement costs, the central regulator and all countries know the demand shock parameters that hit those countries. In this case, the force of an International Environmental Agreement is that the set of balanced transfers can be designed to make each country internalize the impact of its own emissions on the rest of the world. It allows for a "pay-the-externality" scheme. We show that, when the global Pigovian price does not satisfy the domestic incentive-feasibility constraint, the carbon price must be reduced to cut down the information rents distributed to domestic firms. In this case, the optimal agreement entails second-best domestic prices that depend on country's demand parameters and are lesser than the global Pigovian price but better than the domestic price chosen in the Bayesian-Nash equilibrium.

We finally examine the International Environmental Agreement in a scenario with a

two-tier asymmetry of information. The countries participating to the agreement now keep private information on their domestic demand. In this case, we envision any global agreement as an incentive mechanism that elicits private information held by countries. We show that the first-best implementation mechanism is constructed so that all countries adopt the same global Pigovian price and receive a fixed compensation whose corresponds to the overall positive externality such emissions reduction brings to the rest of the world. Importantly, this payment being fixed, the mechanism requires no particular knowledge of the realizations of the shock parameter in either country to be implemented. However, whenever this global Pigovian price cannot be implemented, the second-best optimal price should depend on domestic demand shock. This implies that the carbon prices differ among countries. We thus show that the *Law of One Carbon Price* fails due to the asymmetry of information. There is nevertheless scope for putting enforceable uniform prices in place. Imposing the extra constraint of a uniform treatment of all countries, we show that a mechanism can be implemented with a non-linear compensation schedule and a single price that is always lesser than the global Pigovian but better than the domestic Pigovian price. In this case, the worldwide externality is somewhat internalized although imperfectly so.

Our article participates in the study of different levels of governance for an environmental regulation by comparing non-cooperative domestic regulations to an International Environmental Agreement. The international agreement always dominates domestic policies for the correction of the externality even in second-best environments. However, non-cooperative domestic regulations are easier to implement because they deal with a lesser informational problem than an international agreement.

Our article also contributes to the academic and public debate over the adoption of a uniform carbon price. The question of whether or not the carbon price should be uniform was receiving close review during the Paris agreement.³ An uniform price was also more recently presented as an attracting feature of linking different carbon markets. In this paper, we show that, when the asymmetry of information prevents the implementation of the first-best Pigovian price for carbon, the *Law of One Carbon Price* might no longer hold. Indeed, the optimal second-best prices, whether set at the local or at the global level, might

³See for instance the *Call for an ambitious and credible climate agreement in Paris* made by economists from the universities of Paris Dauphine and Toulouse School of Economics or [Barroux \(2019\)](#).

vary from one country to another.

RELATED LITERATURE.

The literature on the architecture of International Environmental Agreement has been flourishing in the last decade. Among others, [Aldy and Stavins \(2007\)](#) discuss its main stakes and call for more research in this area. Our work goes in that direction and attempts to develop a theoretical tool to study and compare different architecture designs to solve the global warming problem. For that purpose, we use the mechanism design approach as advocated by [Baliga and Maskin \(2003\)](#).⁴

In this field, [Baron \(1985\)](#) examines a model in which an environmental agency regulates pollution using abatement standard and emission fee and a public utility commission regulates the price for the monopolist that has private information about the effectiveness of its abatement alternatives. The analysis characterizes the non-cooperative equilibrium between these two regulators and compares it with a cooperative equilibrium. In our model, the central regulator has only one market failure to correct — pollutive externalities — because we consider perfect competition between firms. However, they have to deal with two sources of asymmetry of information: both from domestic firms and countries.

Also, [Spulber \(1988\)](#) studies the problem of domestic regulation in a context where competing domestic firms have private information about their cost of reducing pollution. He highlights the existence of a trade-off between the benefits of pollution abatement and those resulting from the economic activity which generates that pollution as an unwanted by-product. He shows that if the expected informational costs exceed net gains from trade in the product market net of external damages, then the full information optimum is not attainable by direct revelation mechanism. We follow [Spulber \(1988\)](#) in designing a model in which there is asymmetry of information between domestic firms and regulator, but we take it to the next step by integrating the main features of his model within a global agreement model. By keeping the domestic scale, we manage to describe an economy with clear rationale for polluting. The relationship between production and emissions is well specified. This differs from the assumption often met in the international agreement literature that emissions are taken as given.

⁴They survey some of the main findings of this literature and recall the relevance of this approach for the economics of the environment.

The closest article of ours is [Martimort and Sand-Zantman \(2013\)](#). They study the domestic incentive-feasibility and performances of simple mechanisms to implement an International Environmental Agreement to reduce global warming in context of multilateral externalities between countries. They highlight that, in presence of asymmetric information, there is a trade-off between two central goals: participation to the central agreement and incentives to reduce significantly the level of emissions. In this context, market could fail to reach the first best and, in that case, second-best mechanisms would need to be considered. [Martimort and Sand-Zantman \(2013\)](#) underline the one limit of their model is not to include a second level of analysis: the domestic scale. Starting from their work and the assessment that the domestic level is not integrated into the design of global agreement, we develop a model with two level of decisions: national and international. In each level we consider that there is some asymmetry of information. In doing so, we develop a more complete analysis of the design of International Environmental Agreement architecture in incomplete information setting. This also allows us to derive and compare regulations with two different levels of governance.

A part of environment economic literature studies the different levels of governance. Many articles investigate characteristics of a given level of governance. In particular, international and domestic scales have been widely studied. However, fewer papers discuss explicitly the complexity arising from the superposition of these levels of governance. [Marchiori, Dietz, and Tavoni \(2017\)](#) investigate the effect of domestic politics on international environmental policy by incorporating into a classic stage game of coalition formation the phenomenon of lobbying by special-interest groups. They study how domestic politics affect participation and group coalition for environmental agreement. In this sense, they contribute to the integration of the domestic layer into the environmental agreement picture. Our approach is slightly different as we study how domestic politics affect the design of global agreement. [Shobe and Burtraw \(2012\)](#) compare respective advantages and drawbacks of the domestic versus the national regulation in the US. Their arguments are numerous, very interesting and can easily be extrapolated to the case of national versus international governance. Their analytical work however does not present a theoretical model. We try to fill this gap, fully aware that we are only addressing some aspects of the intricate problem of multiple layers of governance.

ORGANIZATION OF THE PAPER. Section [1.1](#) presents the model as well as three relevant

benchmarks: *Business As Usual*, domestic Pigovian price and global Pigovian price. Section 1.2 analyzes the Bayesian-Nash equilibrium in which governments non-cooperatively choose their own domestic regulation taking into account the asymmetry of information on domestic firms. Section 1.3 investigates an International Environmental Agreement set up by a central regulator when countries share information about their demand parameters but the asymmetry of information on domestic firms remains. Finally, section 1.4 examines the case of an International Environmental Agreement in the context of a two-tier asymmetry of information. Proofs are relegated to an Appendix.

1.1. The Model and some Relevant Benchmarks

We consider an economy made of n countries indexed by the subscript $i \in \{1, \dots, n\}$. Each country is viewed as an island, with consumers and firms trading only on the domestic market. The only interaction across countries comes from the worldwide environmental externality that local productions in each country induce.

FIRMS. There is a continuum of firms with mass one in each country i . A firm which produces a quantity q sells this output on the domestic market at the competitive price r_i . One unit of output generates one unit of polluting emissions. Marginal cost is normalized at zero. Instead, the firm faces some abatement costs to reduce emissions. More precisely, these costs write as $\frac{a^2}{2}$ where a is abatement. Thanks to this technology, a firm which produces q units of output and exerts abatements a , produces emissions e such that

$$e = q - a + \theta.$$

The shock θ is a firm-specific parameter, which reflects heterogeneity in abatement technologies. Those parameters are independently drawn from the same common knowledge cumulative distribution $F(\cdot)$ in each country. This distribution has support $\Theta = [\underline{\theta}, \bar{\theta}]$ and we denote its expected value by $\mathbb{E}_\theta(\theta) = \theta_e$. For future reference, let $\Delta = \bar{\theta} - \theta_e$ be a measure of the underlying uncertainty on technology. The complete information scenario could thus be viewed as the special case $\Delta = 0$.

MARKET FOR POLLUTION PERMITS. To correct the negative pollution externality, all firms in country i may trade pollution permits at a price p_i on a domestic market. Beforehand, all

those firms are endowed with the same quantity of permits R_i . We follow here [Martimort and Sand-Zantman \(2013\)](#) in assuming that initial rights are uniformly distributed *ex ante*. Asymmetric information on abatement technologies preclude other choices.⁵ Of course, equilibrium on the market for permits together with the Law of Large Numbers require that the total amount of allocated permits R_i corresponds to the average emissions E_i .

Participation to the market for permits is mandatory. Yet, firms may also receive a lump-sum subsidy τ_i . This transfer stems for all kinds of environmental programs that the domestic government may offer to facilitate adoption of clean standards, permits purchases and cover abatement costs.

Firms in country i choose their production $q_i(\theta)$, their emissions $e_i(\theta)$, and thus their abatements a , so as to maximize overall profits on the markets for product and permits. Taking into account abatement costs and the possibility of trading permits, the profit $U_i(\theta)$ of a type- θ firm in country i can be written as

$$U_i(\theta) = \max_{(q,e)} r_i q - \frac{1}{2}(q - e + \beta_i)^2 - p_i(e - R_i) + \tau_i. \quad (1.1)$$

Because firms adopt a competitive behavior on the market for permits, their marginal costs of abatement are equal to the price of permits.⁶ Competitive behavior on the output market in turn requires that the price on this market is also equal to the price of permits:

$$r_i = p_i = q_i(\theta) - e_i(\theta) + \beta_i. \quad (1.2)$$

From (1.2), and aggregating over the whole continuum of firms in country i , total emissions $E_i = \mathbb{E}_\theta(e_i(\theta))$ and aggregate production $Q_i = \mathbb{E}_\theta(q_i(\theta))$ there satisfy:

$$p_i = Q_i - E_i + \theta_e. \quad (1.3)$$

CONSUMERS/TAXPAYERS. The representative consumer's net surplus in country i is de-

⁵Of course, in a dynamic setting, domestic regulators could use grand-fathering clauses, allocating rights in responses to past emissions in unregulated environments. We leave the analysis of this case to future research.

⁶For simplicity, we also assume that abatement efforts remain non-negative under all circumstances below.

defined as

$$S(Q_i) - (\beta_i + r_i)Q_i - \frac{1}{n} \left(E_i + \sum_{j \neq i} E_j \right) - \tau_i \quad (1.4)$$

where Q_i is domestic consumption, S is the gross surplus function which is increasing and strictly concave ($S' > 0 > S''$). Domestic demand thus writes as $D(r_i + \beta_i)$ where $D = S'^{-1}$ is decreasing and, for technical reasons, convex ($D'' > 0 > D'$). Let E_j denote aggregate emissions from country $j \neq i$ and τ_i is the subsidy from consumers/taxpayers to firms. Importantly, each country suffers from an equal fraction of the worldwide overall externality $\sum_{i=1}^n E_i$.

The shock β_i is a shift parameter which is country i -specific. It captures possible fluctuations in domestic economic conditions, for instance some heterogeneity in consumer's tastes across countries. Later, we will assume that firms, consumers and regulators in country i have private information on this parameter. The rest of the world remains ignorant of the realization of this shock.⁷ Those country-specific parameters are drawn from the same common knowledge cumulative distribution G , with positive density g and compact support $\mathcal{B} = [\underline{\beta}, \bar{\beta}]$. For technical reasons, we will assume that G satisfies the monotone hazard rate property, $\frac{d}{d\beta_i} \left(\frac{1-G(\beta_i)}{g(\beta_i)} \right) < 0$.

The above expression makes clear that consumers in country i suffer not only from domestic pollution E_i , but also from emissions coming from elsewhere, namely $\sum_{j \neq i} E_j$. Consumers take those emissions as given. They ignore the relationship between domestic emissions, domestic production, and thus their own consumption.

Taking then into account (1.2) and (1.3) actually gives the expression of aggregate emissions E_i in terms of the carbon price p_i and the local demand shock β_i as

$$E_i = E(p_i, \beta_i) = D(\beta_i + p_i) - p_i + \theta_e. \quad (1.5)$$

Business As Usual SCENARIO. Suppose there is no public intervention and the *Business As Usual* scenario prevails worldwide. First, firms receive no subsidy from consumers, i.e.,

⁷These assumptions can be understood in the sense that a government has more numerous or updated data about economic conditions and consumer's tastes in their country. They however have less precise data about others countries.

$\tau_i = 0$. Second, there is no market for permits and everything happens as if

$$p_i^b(\beta_i) = 0.$$

As a result, firms do not care about the impact of their own emissions on the rest of society and abatements are zero, $a^b = 0$. The output price is also null since it is equal to the marginal cost of production, $r_i^b = 0$. From (1.5), emissions in country i are thus equal to $E(0, \beta_i)$. With such normalization, firms make zero profit and welfare in country i can finally be written as:

$$S(D(\beta_i)) - \left(\beta_i + \frac{1}{n} \right) D(\beta_i) - \frac{1}{n} \sum_{j \neq i} E(0, \beta_i).$$

WELFARE IN COUNTRY i AND DOMESTIC PIGOVIAN PRICES. Country i 's welfare is the sum of domestic consumers' surplus and local firms' overall profits. Expressed in terms of the price of permits, and inserting (1.2) into (1.1) and (1.5) to obtain the expression of those surplus and profits, welfare can finally be written as:

$$\omega(p_i, \beta_i) - \frac{1}{n} \sum_{j \neq i} (D(\beta_j + p_j) - p_j + \theta_e)$$

where the function $\omega(p_i, \beta_i)$ stands for the welfare in country i in the hypothetical scenario where this country would be alone on earth. A more explicit expression would be

$$\omega(p_i, \beta_i) = S(D(\beta_i + p_i)) - \left(\beta_i + \frac{1}{n} \right) D(\beta_i + p_i) - \frac{1}{2} p_i^2 + \frac{1}{n} p_i - \frac{1}{n} \theta_e.$$

Differentiating, we immediately find

$$\frac{\partial \omega}{\partial p_i}(p_i, \beta_i) = \left(p_i - \frac{1}{n} \right) (D'(\beta_i + p_i) - 1), \quad \frac{\partial^2 \omega}{\partial p_i \partial \beta_i}(p_i, \beta_i) = \left(p_i - \frac{1}{n} \right) D''(\beta_i + p_i).$$

From the first property, it follows that $\omega(p_i, \beta_i)$ is strictly quasi-concave with respect to p_i . The second property together with the assumption $D'' > 0$ implies that $\omega(p_i, \beta_i)$ has increasing (resp. decreasing) differences when $p > \frac{1}{n}$ (resp. $p < \frac{1}{n}$). These technical properties will be used repeatedly in the sequel.

Consider a scenario where the domestic regulator has complete information on domestic firms' technologies. Thanks to the quasi-concavity of $\omega(p_i, \beta_i)$, welfare in country i would be maximized at the domestic Pigovian price:

$$p^n(\beta_i) = p^n = \frac{1}{n} \quad \forall(i, \beta_i).$$

The *Law of One Carbon Price* applies here but with a vengeance. Although this price is the same in all countries, it only corrects for the externality that arises at the local level and, which is the same worldwide. This domestic Pigovian price remains too low. Indeed, it leaves uncorrected the externality that domestic emissions exert abroad.

Emissions in country i are now given by $E(p^n, \beta_i)$. The quantity of pollution permits distributed varies from one country to the other because demand shocks may differ across those countries. Emissions are of lower magnitude when countries are hit by less favorable demand shocks.

WORLDWIDE WELFARE AND GLOBAL PIGOVIAN PRICE. Suppose now that countries can reach an overall agreement on how to regulate the worldwide externality. This scenario implicitly requires that subsidies across countries are feasible. We will come back on the nature of these compensatory payments later when considering more complex informational scenarios. Since the markets for permits in each country are segmented, a worldwide welfare-maximizing regulation could a priori specify different carbon prices on each country-specific market.

Worldwide welfare is now defined as the sum of domestic welfares, namely

$$\sum_{i=1}^n \left(\omega(p_i, \beta_i) - \frac{1}{n} \sum_{j \neq i} (D(\beta_j + p_j) - p_j + \theta_e) \right) = \sum_{i=1}^n \tilde{\omega}(p_i, \beta_i)$$

where the worldwide contribution of production and pollution in country i writes as

$$\tilde{\omega}(p_i, \beta_i) = \omega(p_i, \beta_i) - \frac{n-1}{n} (D(\beta_i + p_i) - p_i + \theta_e).$$

Note that the difference between $\tilde{\omega}$ and ω comes from the impact that i 's production has on the welfare of all other countries $j \neq i$.

It is straightforward to check that

$$\frac{\partial \tilde{\omega}}{\partial p_i}(p_i, \beta_i) = (p_i - 1)(D'(\beta_i + p_i) - 1), \quad \frac{\partial^2 \tilde{\omega}}{\partial p_i \partial \beta_i}(p_i, \beta_i) = (p_i - 1)D''(\beta_i + p_i).$$

Thus $\tilde{\omega}(p_i, \beta_i)$ has decreasing differences when $p_i < 1$. It is also strictly quasi-concave with respect to p_i , so that optimal prices are now obtained as

$$p^g(\beta_i) = p^g = 1 \quad \forall (i, \beta_i).$$

The carbon price is thus the same across all markets while emissions $E(1, \beta_i)$ are not the same in all countries since they depend on demand shocks. The carbon price is now of course higher.

Under asymmetric information on costs and demand shocks, the second-best prices, whether set at the local or at the global level, might also depend on local demand parameters. The *Law of One Carbon Price* might no longer hold under those conditions. We now turn to the characterization of those second-best prices.

1.2. Domestic Regulation under Asymmetric Information

Consider the scenario where the government in country i is uninformed on both the cost parameters of domestic firms and the demand parameters of other countries $\beta_{-i} = (\beta_1, \dots, \beta_{i-1}, \beta_{i+1}, \dots, \beta_n)$. We now look for a Bayesian-Nash equilibrium in which countries non-cooperatively choose their own domestic regulation. Remind that such a regulation consists of a price p_i at which permits are traded on the domestic market, a quantity of such permits (which of course is equal to the total emissions $R_i = E_i$), and a subsidy τ_i . Those instruments are chosen so as to maximize domestic welfare given the set of regulatory instruments chosen elsewhere.

1.2.1. Domestic Incentive-Feasibility

Firms are privately informed on their abatement cost parameter β_i . Because of arbitrage on the market for permits, all firms have to trade permits at the same price and thus no screening is possible. A firm whose parameter is θ can thus pretend to have the worst effi-

ciency parameter $\bar{\theta}$. Doing so, it produces and emits the same amount than this inefficient type, pockets the same subsidy but reduces its abatement effort by $\bar{\theta} - \theta$. Adopting this strategy, this firm earns some information rent worth $(\bar{\theta} - \theta)p_i$. For future reference, we notice that, aggregating over the whole distribution of domestic firms, the total amount of information rent left to domestic producers in country i is worth

$$\Delta p_i.$$

A domestic regulation (p_i, R_i, τ_i) must also ensure that all types of firms obtain more by running their business under those regulatory constraints than what they get in the *BAU* scenario. With our previous normalization, this reservation payoff is normalized at 0. This participation constraint is of course more stringent for the least efficient firms $\bar{\theta}$. This participation condition determines the level of subsidies that firms receive. Of course, firms with more efficient abatement technologies would be ready to participate rather than opting for the *BAU* scenario even with lower subsidies. Imposing participation for all possible values of the abatement costs thus requires:

$$U_i(\bar{\theta}) = \max_{(q,e)} r_i q - \frac{1}{2}(q - e + \bar{\theta})^2 - p_i(e - R_i) + \tau_i \geq 0.$$

Using the expressions of the volume of pollution permits and the domestic price given in (1.2), (1.3) and (1.5), this condition becomes:

$$p_i(D(\beta_i + p_i) - \Delta) - \frac{1}{2}p_i^2 + \tau_i \geq 0. \quad (1.6)$$

To be acceptable, a domestic regulation must also give more surplus to domestic consumers than what they get in the *BAU* scenario. This condition puts an upper bound on the subsidy that can be distributed to the firms, namely

$$\begin{aligned} & S(D(\beta_i + p_i)) - (\beta_i + p_i)D(\beta_i + p_i) - \frac{1}{n}E(p_i, \beta_i) - \frac{1}{n}\mathbb{E}_{\beta_{-i}} \left(\sum_{j \neq i} E(p^n(\beta_j), \beta_j) \right) - \tau_i \\ & \geq S(D(\beta_i)) - (\beta_i)D(\beta_i) - \frac{1}{n}E(0, \beta_i) - \frac{1}{n}\mathbb{E}_{\beta_{-i}} \left(\sum_{j \neq i} E(p^n(\beta_j), \beta_j) \right) \end{aligned}$$

where $E(p^n(\beta_j), \beta_j)$ denotes country j 's emissions when the demand shock there is β_j .

Thanks to the additive separability between environmental damage and surplus, we obtain a simpler condition which is independent of foreign emissions and permits:

$$S(D(\beta_i + p_i)) - (\beta_i + p_i)D(\beta_i + p_i) - \frac{1}{n}E(p_i, \beta_i) - \tau_i \geq S(D(\beta_i)) - \beta_i D(\beta_i) - \frac{1}{n}E(0, \beta_i).$$

Expressing this condition in terms of the local part of domestic welfare, we get:

$$\omega(p_i, \beta_i) + \frac{1}{2}p_i^2 - p_i D(\beta_i + p_i) - \tau_i \geq \omega(0, \beta_i). \quad (1.7)$$

Finally, summing up (1.6) and (1.7) gives us an aggregate domestic incentive-feasibility condition, Condition (1.8) below, that must be satisfied by any implementable regulation (p_i, R_i, τ_i) . Reciprocally, this condition is also sufficient. Any price p_i that satisfies condition (1.8) is part of a regulation that can be accepted by both local consumers and firms provided that the subsidy τ_i is chosen to be neither too small neither too large to satisfy the participation constraints of firms and that of consumers/taxpayers respectively.

Lemma 1. *A domestic regulation that implements a carbon price p_i is domestic incentive-feasible if and only if:*

$$\omega(p_i, \beta_i) - \omega(0, \beta_i) \geq \Delta p_i. \quad (1.8)$$

As a first pass, it is worth observing that, under complete information, the term Δp_i would disappear and the so simplified domestic incentive-feasibility condition, namely $\omega(p_i, \beta_i) \geq \omega(0, \beta_i)$, would be trivially satisfied by the domestic Pigovian price p^n .

The domestic incentive-feasibility constraint (1.8) is thus a fundamental requirement on any domestic regulation which is constrained by asymmetric information. It characterizes the condition under which such regulation is collectively accepted by both firms and consumers at the domestic level.⁸ More precisely, a price p_i for permits can be implemented if and only if the benefits from pollution reduction that it induces, namely the

⁸Readers accustomed with the mechanism design literature will have recognized here the similarity between the aggregate-feasibility condition (1.8) and other similar conditions that have flourished in the literature to describe feasible allocations in bargaining models asymmetric information. See Myerson and Satterthwaite (1981) and Cramton, Gibbons, and Klemperer (1987), Mailath and Postlewaite (1990) for general models while Rob (1989), Spulber (1988) and Martimort and Sand-Zantman (2016) have presented such conditions in the field of environmental economics.

difference $\omega(p_i, \beta_i) - \omega(0, \beta_i)$, outweighs the informational costs Δp_i of implementing such policy. Asymmetric information may now hinder the implementation of the domestic Pigovian price. Intuitively, domestic consumers have to pay for the informational cost Δp_i that is needed to unlock domestic negotiations with privately informed firms. Transferring wealth from consumers to the firms makes it more difficult to induce acceptance of such domestic regulation by consumers themselves.

To better understand the importance of the domestic incentive-feasibility constraint (1.8), Figure 1.1 below represents the set of feasible prices under asymmetric information. When the Pigovian price is not feasible, the second-best optimal price is the highest feasible price and it thus remains below $p^n = \frac{1}{n}$. This second-best price $p^n(\beta_i)$ is obtained when the linear function Δp_i intersects the incremental surplus function $\omega(p_i, \beta_i) - \omega(0, \beta_i)$.⁹ Notice that $\omega(p_i, \beta_i) - \omega(0, \beta_i) - \Delta p_i$ is quasi-concave in p_i , worth 0 for $p_i = 0$, and negative for p_i large enough and positive in a right-neighborhood of 0 for all β_i when

$$\frac{1}{n} (1 - D'(\bar{\beta})) > \Delta,$$

and assumption that is made throughout. Therefore, there exists a unique positive solution $\hat{p}(\beta_i)$ to

$$\omega(\hat{p}(\beta_i), \beta_i) - \omega(0, \beta_i) = \Delta \hat{p}(\beta_i).$$

The set of feasible prices that satisfy (1.8) is thus an interval of the form $[0, \hat{p}(\beta_i)]$. Moreover, observe that $\hat{p}(\beta_i)$ is decreasing in β_i when $\hat{p}(\beta_i) \leq p^n = \frac{1}{n}$ since ω has decreasing differences over the domain $p \leq p^n = \frac{1}{n}$.

THE BAYESIAN-NASH EQUILIBRIUM. A symmetric Bayesian-Nash equilibrium is a collection of mappings $\{(p(\cdot), R(\cdot), \tau(\cdot))\}$ that associate to each realization of the domestic demand parameter β_i , a market price $p(\beta_i)$, a quantity of permits $R(\beta_i)$ and a subsidy $\tau(\beta_i)$. These mappings must form an equilibrium fixed point; if all countries except i adopt such regulation, country i does as well doing so.¹⁰ More precisely, expressing domestic emis-

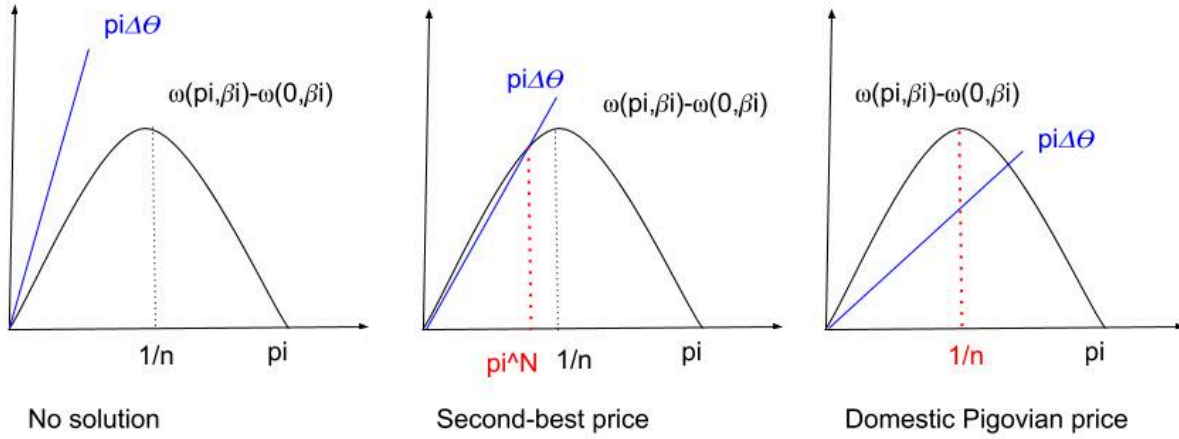
⁹Note that the feasible set of prices has a non-empty interior only when

$$\frac{\partial}{\partial p_i} (\omega(p_i, \beta_i) - \omega(0, \beta_i)) |_{p_i=0} > \Delta \Leftrightarrow -\frac{1}{n} (D'(\beta_i) - 1) > \Delta.$$

This condition will be supposed to hold throughout.

¹⁰Since countries are symmetric up to their demand shock parameters, we are able, for the sake of clar-

Figure 1.1: The domestic incentive-feasibility set.



sions $E(\beta_i) = R(\beta_i)$ in terms of $p(\beta_i)$ by means of (1.5) and observing that the domestic transfers $\tau(\beta_i)$ cancel out in the objective of a domestic regulator, $p(\beta_i)$ must solve

$$p(\beta_i) \in \arg \max_{p_i \text{ s.t. (1.8)}} \omega(p_i, \beta_i) - \frac{1}{n} \mathbb{E}_{\beta_{-i}} \left(\sum_{j \neq i} (D(\beta_j + p(\beta_j)) - p(\beta_j) + \theta_e) \right). \quad (1.9)$$

Two important facts determine the structure of the solution. First, the externality term coming from other countries' emissions enters additively into the regulator's objective function. Second, the domestic incentive-feasibility condition (1.8) only depends on domestic instruments. Henceforth, the optimal choice in country i does not depend on other countries's own regulatory choices. The unique Bayesian-Nash equilibrium is achieved with simple dominant strategies; an important feature that simplifies much of the analysis in the sequel.

1.2.2. Equilibrium Characterization

Had domestic regulation taken place under complete information on the firms' technologies, the domestic incentive-feasibility condition (1.8) would be absent of this optimiza-

ity, to drop the indexes i in the expressions of price, quantity of permits and transfers at the equilibrium. Remark, that in a more sophisticated version of our model, countries may differ in terms of their demand functions or cost considerations. Extending our analysis to such cases is straightforward.

tion problem. The equilibrium price would then be equal to the domestic Pigovian price $p^n = \frac{1}{n}$ in all countries. Under asymmetric information, this local Pigovian price might not always be implementable because it may fail to satisfy the domestic incentive-feasibility condition (1.8).

IMPLEMENTABILITY OF THE LOCAL PIGOVIAN PRICE. Condition (1.8) illustrates an important trade off between the domestic regulator's desire to correct externalities and the fact that doing so requires giving up information rents to domestic firms which hardens the domestic incentive-feasibility condition. Investigating whether the local Pigovian price $p^n = \frac{1}{n}$ can be implemented boils down to checking whether (1.8) holds for that price; a condition which writes as

$$\omega(p^n, \beta_i) - \omega(0, \beta_i) \geq \frac{\Delta}{n} \Leftrightarrow \hat{p}(\beta_i) \geq p^n. \quad (1.10)$$

RUNNING EXAMPLE. To illustrate, consider the case of a quadratic surplus $S(Q) = aQ - \frac{1}{2}Q^2$ for some parameter a (the inverse demand intercept) large enough. Demand is linear, $D(\beta_i + p_i) = a - \beta_i - p_i$, and the domestic incentive-feasibility condition boils down to

$$\frac{1}{n} \geq \Delta.$$

The magnitude of the domestic externality must be greater than the informational rent to ensure implementability of the Pigovian price in a second-best environment.¹¹ Of course, this condition fails as soon as n is large enough. For that knife-edge example, the second-best price is $p^n(\beta_i) = \frac{2}{n} - \Delta$ which remains independent of β_i . Henceforth, with quadratic surplus and linear demand, *The Law of One Carbon Price* remains valid. \square

SECOND-BEST DOMESTIC REGULATION. When the Pigovian price does not satisfy the domestic incentive-feasibility condition (1.8), the carbon price must be reduced to decrease the information rent captured by producers and make it easier to implement that price.

¹¹In the case of a linear demand, the domestic incentive-feasibility condition does not depend on the realization of the domestic shock β_i . With more general demand functions, the domestic incentive-feasibility condition would depend on the shock β_i , and as such, differs among countries. There may be cases in which the domestic incentive-feasibility condition holds for some countries but not for others. Countries hit by small demand shocks implement the domestic first-best regulation, while countries hit by higher shocks cannot.

Proposition 1. *In the unique Bayesian-Nash equilibrium, with the BAU scenario as fall-back option, the second-best domestic price $p^n(\beta_i)$ is less than the local Pigovian price:*

$$p^n(\beta_i) = \min \{p^n; \hat{p}(\beta_i)\} \quad \forall \beta_i \in \mathcal{B}. \quad (1.11)$$

Under asymmetric information, the second-best domestic price may be downward distorted below the domestic Pigovian price to limit the information rents of domestic firms. The magnitude of the distortion may *a priori* depend on the distribution of the firms' efficiency parameters but also on the domestic demand shock β_i . While under complete information, the domestic Pigovian price only depends on the domestic externality; the second-best price now also depends on demand.

REMARK. This result of course bears some resemblance with the well-known Ramsey-Boîteux pricing distortion which is familiar from the Public Economics literature. In this setting, the absence of lump-sum subsidy to help covering its fixed cost forces a monopolist to raise its price. In a very similar vein, the domestic incentive-feasibility condition (1.8) shows that the surplus gain from opening the market for permits must exceed the cost of information rents. Of course, there are some differences between the Ramsey-Boîteux model of monopoly regulation and our context. First, the cost of asymmetric information is not a fixed cost. It actually varies with the price on the market for permits. Second, this cost is here compared with a surplus gain, and not with a monopoly profit. Yet, the same logic applies. As in Ramsey-Boîteux model, the domestic incentive-feasibility condition is now satisfied by introducing a wedge between the price of permits and the level of the domestic externality. Price distortions also depend on demand considerations. The domestic regulator's information on demand shocks now matters to evaluate those distortions. Importantly, any International Environmental Agreement among countries that would improve on this Bayesian-Nash equilibrium has thus to also collect such information on demand shock. \square

The *Law of One Carbon Price* fails under asymmetric information. Indeed, the second-best prices for carbon may differ across countries in response to the different realization of the demand shock that those countries may face. When (1.10) does not hold, the domestic incentive-feasibility constraint (1.8) is actually binding and the second-best price

in country i satisfies

$$p^n(\beta_i) = \hat{p}^n(\beta_i).$$

In sharp contrast with the complete information scenario, having a worldwide market on which permits would be traded at a unique price is no longer optimal. It would indeed amount to moving into a third-best scenario where the prevailing price would satisfy the domestic incentive-feasibility condition (1.8) for *all possible realizations* of the demand shock. Since $p^n(\beta_i)$ is decreasing in β_i , this uniform third-best price is the lowest possible one, namely $p^n(\bar{\beta})$. In other words, insisting on a single price at which permits would be traded on different markets no longer makes any sense in a second-best world.

Turning now to the value of domestic subsidies necessary to enforce these second-best prices, observe that those subsidies must compensate firms with the worst abatement cost parameter $\bar{\theta}$ for the cost of complying with the regulation. Yet, subsidies are costly to taxpayers/consumers and must thus be reduced up to the point of leaving those inefficient firms (1.6) just indifferent between accepting the regulatory contract or opting for the *BAU* option. This gives the following expression of the subsidy in country i :

$$\tau^n(\beta_i) = \frac{1}{2}(p^n(\beta_i))^2 + p^n(\beta_i) (\Delta - D(\beta_i + p^n(\beta_i))). \quad (1.12)$$

1.3. International Environmental Agreement: Information Sharing

Taking a normative perspective, we now examine the design of an international regulation. The goal of such hypothetical mechanism would be to make it possible for each country to internalize the impact of its own emissions on the rest of the world. Such an international regulation should be viewed as a proxy for the best outcome that any International Environmental Agreement between countries could reach given the existing informational constraints that prevail both within and across countries.

More precisely, an hypothetical central regulator supersedes domestic regulators in each country by recommending a collection of domestic regulatory mechanisms $(p_i, E_i, \tau_i)_{i \in \{1, \dots, n\}}$.

For each country, such a regulation stipulates a price p_i at which permits are traded on the local market for pollution permits, a number of permits E_i that are distributed equally among domestic firms, and as before a lump-sum subsidy τ_i which is paid by domestic consumers to those firms.

The novel instrument available to foster worldwide cooperation and make each country internalize the impact of its own emissions on others is a set of budget balance compensatory transfers *from* and *towards* each country. Those transfers stem for all kinds of financial compensations that a given country may receive for implementing the requested price for carbon. The possibility of incorporating monetary contributions into environmental treaties is, indeed, often made explicit. To illustrate, Article 11 of the Kyoto Convention allows for the possibility of transfers from developed to developing countries under the aegis of an International Green Fund. Compensatory payments may also be given a broader interpretation and be viewed as the benefits or costs that countries experience when climate negotiations are linked to negotiations on other issues such as R&D technology transfers, sovereign debt, and trade agreements (Barrett, 2003).

We first envision a complete information scenario and assume that, although domestic firms in each country keep private knowledge of their abatement costs, the central regulator and all countries know the whole collection of demand shock parameters $\beta = (\beta_1, \dots, \beta_n)$ that hit those countries. In other words, an international agreement makes it possible for all countries to credibly disclose information on what they know on local conditions. Although highly hypothetical, this scenario allows us to investigate the highest bound on welfare that such an agreement could achieve.

This informational structure has two consequences. First, any domestic regulation, even if suggested by this central regulator, is still bound to satisfy the domestic firms' incentive constraints and the requirement for acceptance by both domestic consumers and domestic producers. Henceforth, a by-now familiar domestic incentive-feasibility constraint will apply in each country. This condition is similar to that which applies when only domestic regulations are possible. It is also different because the fall-back option is no longer the *BAU* scenario as before but instead what happens when each country is free to choose a regulation on its own without any constraint being imposed externally by an agreement. Second, the central regulator can now condition the domestic regulation

in country i on demand shocks that affect emissions abroad to facilitate coordination if needed. Indeed, international coordination may certainly benefit from such information sharing.

COMPENSATORY TRANSFERS. At the Bayesian-Nash equilibrium of domestic regulations, country i 's emissions were shown to be $E(p^n(\beta_i), \beta_i)$. This quantity takes into account the local negative externality suffered in country i , but ignores the negative externality exerted on other countries $j \neq i$. Those countries may want to pay country i so that it reduces its own emissions. To illustrate, if country i reduces its emissions to $E(p_i, \beta_i) = D(\beta_i + p_i) - p_i + \theta_e$ instead of $E(p^n(\beta_i), \beta_i)$, country j 's welfare (for $j \neq i$) increases by $\frac{1}{n}(E(p^n(\beta_i), \beta_i) - E(p_i, \beta_i))$. Country j is thus ready to pay i up to that amount so as to have i reduce its emissions. Overall, country i thus receives from all other countries $j \neq i$ an aggregate contribution worth

$$\frac{n-1}{n} (E(p^n(\beta_i), \beta_i) - E(p_i, \beta_i)). \quad (1.13)$$

By the same token, country i pays j an amount worth

$$\frac{1}{n} (E(p^n(\beta_j), \beta_j) - E(p_j, \beta_j)). \quad (1.14)$$

Of course, the set of bilateral transfers so constructed is necessarily budget balanced since what a given country receives is what others actually give to that country.

Importantly, this set of bilateral compensatory transfers between countries implicitly defines an initial allocation of rights that prevails before any international agreement is reached. To illustrate, country i has the right to pollute an amount $E(p^n(\beta_i), \beta_i)$ in the first place and reduces its emissions only when it is compensated by other countries for any such reduction.

REMARK. The payments (1.13) and (1.14) are of course reminiscent of the Vickrey-Clarke-Groves transfers that are used in the mechanism design literature (Groves, 1973; Green and Laffont, 1977). Here also, each country “is paid the positive externality” that reducing its own emissions inflicts on others. The information structure that we consider in this section somehow differs from the one that prevails in the mechanism design literature when studying Vickrey-Clarke-Groves mechanisms. Those mechanisms are indeed used in con-

texts where the modeler (or the mechanism designer) insists on dominant strategy implementation; which supposes that each agent playing the mechanism only knows its own type and remains ignorant on those of others. In our context instead, all countries know the whole array of demand realizations and those realizations can be contracted upon. On top, budget balance is generally a serious concern with Vickrey-Clarke-Groves mechanisms (Green and Laffont, 1979, Chapter 5) while it is satisfied by construction here. \square

WITHIN-COUNTRY INCENTIVE AND PARTICIPATION CONSTRAINTS. For the sake of completeness, we now express how a domestic regulation, when decided by the central regulator under the aegis of an International Environmental Agreement, affects the payoffs of domestic consumers and domestic firms. The novelty here comes from the fact that, whenever the international regulation does not satisfy the domestic incentive-feasibility condition, country i refuses to ratify the agreement. Following such refusal, country i implements its Bayesian-Nash equilibrium domestic regulation. Thanks to the additive separability of emissions in the expression of each country's welfare, this Bayesian-Nash domestic regulation is the best strategy irrespectively of what other countries $j \neq i$ are choosing and irrespectively of whether their demand parameters is known or not by i . Therefore, this strategy is consistent with country i holding *passive beliefs* and thinking that other countries still abide to the international agreement even though not being in the agreement anymore severs country i 's access to information on their demand shocks.¹² In addition, we assume that the approval of all countries, whatever the realization of their own demand shock, is necessary to ratify the agreement and implement the international regulation it requests.

When the compensatory transfers (1.14) are used, domestic consumers/taxpayers in country i are paying country $j \neq i$ its benefits from reducing its own emissions so that the net effect of compensating others for emissions reduction is neutral in their payoff. Still denoting by τ_i the domestic subsidy to local producers, we may write the following condition for consumers/taxpayers in country i to accept the international agreement as

$$S(D(\beta_i+p_i)) - (\beta_i+p_i)D(\beta_i+p_i) - \frac{1}{n} \left(\sum_{j=1}^n E_j(p_j, \beta_j) \right) - \frac{1}{n} \left(\sum_{j=1}^n (E(p^n(\beta_j), \beta_j) - E_j(p_j, \beta_j)) \right) - \tau_i$$

¹²Martimort and Sand-Zantman (2016) analyze how the domestic incentive-feasibility of an international agreement depends on the conjecture that a given country makes on the subsequent behavior of others following its own refusal of ratifying this agreement.

$$\geq S(D(\beta_i + p^n(\beta_i))) - (\beta_i + p^n(\beta_i)) D(\beta_i + p^n(\beta_i)) - \frac{1}{n} \left(\sum_{j=1}^n E(p^n(\beta_j), \beta_j) \right) - \tau^n(\beta_i).$$

Expressing this condition in terms of the local part of domestic welfare, we get

$$\tilde{\omega}(p_i, \beta_i) + \frac{1}{2}p_i^2 - p_i D(\beta_i + p_i) - \tau_i \geq \tilde{\omega}(p^n(\beta_i), \beta_i) + \frac{1}{2}(p^n(\beta_i))^2 - p^n(\beta_i) D(\beta_i + p^n(\beta_i)) - \tau^n(\beta_i). \quad (1.15)$$

To be acceptable, an international regulation must also give more surplus to domestic producers than what they get in the Bayesian-Nash scenario. This condition can now be expressed as

$$p_i(D(\beta_i + p_i) - \Delta) - \frac{1}{2}p_i^2 + \tau_i \geq p^n(\beta_i)(D(\beta_i + p^n(\beta_i)) - \Delta) - \frac{1}{2}(p^n(\beta_i))^2 + \tau^n(\beta_i). \quad (1.16)$$

1.3.1. Domestic Incentive-Feasibility

To be accepted by country i , any international regulation must give to domestic firms a greater profit and to domestic consumers a greater net surplus than what they get at the Bayesian-Nash equilibrium with the Bayesian-Nash domestic regulations. Proceeding as before and aggregating those acceptance conditions yields a necessary and sufficient condition that must be satisfied by any implementable international regulation.

Lemma 2. *An international regulation that implements a carbon price greater than in the Bayesian-Nash equilibrium, i.e., $p_i \geq p^n(\beta_i)$, is domestic incentive-feasible if and only if*

$$\tilde{\omega}(p_i, \beta_i) - \tilde{\omega}(p^n(\beta_i), \beta_i) \geq \Delta(p_i - p^n(\beta_i)). \quad (1.17)$$

REMARK. Consider the hypothetical scenario where the central regulator would have perfect information on abatement costs, which amounts to making $\Delta \equiv 0$ in the right-hand side of (1.17). The domestic incentive-feasibility condition becomes

$$\tilde{\omega}(p_i, \beta_i) \geq \tilde{\omega}(p^n(\beta_i), \beta_i).$$

The left-hand side stands for country i 's contribution to worldwide welfare. It is thus maximized for the global Pigovian price $p_i = p^g = 1$. Henceforth, (1.17) always holds under complete information on abatement costs. \square

The domestic incentive-feasibility constraint (1.17) is thus a fundamental requirement that must be satisfied by any international regulation under asymmetric information. Increasing the price for carbon p_i beyond its Bayesian-Nash level is domestic incentive-feasible in country i if the benefits that this country enjoys when reducing emissions thereby outweighs the informational cost of implementing such a policy.

Moving from a Bayesian-Nash domestic regulation to an international agreement affects both sides of this condition. First, thanks to the proposed set of compensatory transfers between countries, each country internalizes the impact of its domestic pollution on others. By observing the demand shock in each country, the central regulator is thus able to condition those transfers that each country receives on how its own emissions are reduced below the Bayesian-Nash scenario. Each country is thus ready to adopt a greater carbon price. At the same time, a higher price for carbon redistributes more information rent to domestic producers. Increasing the carbon price p_i above its Bayesian-Nash level $p^n(\beta_i)$ requires an increase in information rent worth $\Delta(p_i - p^n(\beta_i))$. Therefore, moving away from the Bayesian-Nash *status quo* becomes more difficult. The magnitudes of these two opposite effects determine whether or not an international regulation can be implemented in each country.

1.3.2. Optimal International Environmental Agreement

The optimal international regulation $(p_i, E_i, \tau_i)_{i \in \{1, \dots, n\}}$ should maximize worldwide welfare that, because utilities are transferable, is unambiguously defined as

$$\sum_{i=1}^n \tilde{\omega}(p_i, \beta_i).$$

A priori, the instruments (p_i, E_i, τ_i) could depend on the whole vector of shock parameters $\beta = (\beta_1, \dots, \beta_n)$. Thanks to the additive separability of the domestic welfare between domestic benefits and worldwide externality and the fact that the domestic incentive-feasibility condition (1.17) only depends on local policy instruments and on the domestic shock on demand, there is no loss of generality in restricting the domestic price to depend

only on local demand. Accordingly, we will thus write $p_i = p(\beta_i)$. This price must solve

$$p(\beta_i) = \arg \max_{p_i \geq p^n(\beta_i) \text{ and (1.17)}} \tilde{\omega}(p_i, \beta_i).$$

The analysis is from now on somewhat similar to that of Section 1.2. The sole change comes the difference in the fall-back options that prevail in the two scenarios.

Now, we notice that, $\tilde{\omega}(p_i, \beta_i) - \tilde{\omega}(p^n(\beta_i), \beta_i) - \Delta(p_i - p^n(\beta_i))$ is quasi-concave in p_i , worth 0 for $p_i = p^n(\beta_i)$, eventually negative for p_i large enough, and positive in a right-neighborhood of 0 for all β_i when

$$(1 - p^n(\beta_i))(1 - D'(\beta_i + p^n(\beta_i)) - 1) > \Delta, \quad \forall \beta_i \in \mathcal{B}$$

an assumption that is made throughout. Under those conditions, there exists a unique solution $\tilde{p}(\beta_i)$ greater than $p^n(\beta_i)$ to

$$\tilde{\omega}(\tilde{p}(\beta_i), \beta_i) - \tilde{\omega}(p^n(\beta_i), \beta_i) = \Delta(\tilde{p}(\beta_i) - p^n(\beta_i)).$$

The set of feasible prices that satisfy (1.17) is thus an interval of the form $[p^n(\beta_i), \tilde{p}(\beta_i)]$. Moreover, observe that $\tilde{p}(\beta_i)$ is decreasing in β_i when $\tilde{p}(\beta_i) \leq p^g = 1$ since ω has decreasing differences over the domain $p \leq p^g = 1$.

IMPLEMENTABILITY OF THE GLOBAL PIGOVIAN PRICE. The global Pigovian price $p^g = 1$ satisfies the domestic incentive-feasibility condition (1.17) if and only if

$$\tilde{\omega}(1, \beta_i) - \tilde{\omega}(p^n(\beta_i), \beta_i) \geq \Delta(1 - p^n(\beta_i)). \quad (1.18)$$

Of course, whether this condition holds depends on the relative magnitudes of the local informational problem and the overall benefits obtained by country i when adopting the global Pigovian price p^g and being accordingly rewarded by others.

RUNNING EXAMPLE (CONTINUED). With a quadratic surplus and a linear demand, the domestic incentive-feasibility condition (1.18) is independent of the realization of the demand shock. Suppose now that countries are always able to implement the local Pigovian price, i.e., $p^n(\beta_i) = \frac{1}{n}$ for all β_i which, from our previous analysis, arises when $\frac{1}{n} > \Delta$.

Then, Condition (1.18) writes as

$$\frac{n-1}{n} \geq \Delta.$$

This is now the externality exerted on other countries that must be of a greater magnitude than the local informational problem to ensure implementation of the global Pigovian price. Taken together, these two conditions require $\frac{1}{1-\Delta} < n < \frac{1}{\Delta}$ (and thus we should necessarily have $\Delta < \frac{1}{2}$). On the one hand, n should be small enough so that each country would be able to implement its local Pigovian price at a Bayesian-Nash equilibrium; which requires it bears a significant share of the worldwide externality. On the other hand, n should also be large enough to ensure that the externality that it exerts on the rest of the world and thus the corresponding compensatory payments it receives are sufficiently large to make each country be willing to implement the global Pigovian price. \square

SECOND-BEST INTERNATIONAL REGULATION. When the global Pigovian price does not satisfy the domestic incentive-feasibility constraint (1.17), the carbon price must be reduced to cut down the information rents distributed to domestic firms.

Proposition 2. *The optimal international regulation entails a second-best domestic price $p^g(\beta_i)$ which is less than the global Pigovian price but greater than the domestic price chosen in the Bayesian-Nash equilibrium:*

$$p^g(\beta_i) = \min \left\{ 1; \tilde{p}(\beta_i) \right\} \quad \forall \beta_i \in \mathcal{B}. \quad (1.19)$$

This result is less pessimistic than it appears at first glance. True, the global Pigovian price may not be implementable but the second-best price $\tilde{p}(\beta_i)$ is not so low after all. It is *always* greater than the Bayesian-Nash equilibrium price. The force of an International Environmental Agreement is that, since it allows parties to disclose information, a set of balanced transfers can be designed that makes each country internalize the impact of its own emissions on the rest of the world. The benefit side of the domestic incentive-feasibility constraint is of a much greater magnitude than in the Bayesian-Nash scenario. Our quadratic/linear example nicely illustrates the force of this effect.

RUNNING EXAMPLE (CONTINUED). Consider again quadratic surplus and linear demand and suppose that $p^n(\beta_i) = \frac{2}{n} - \Delta < \frac{1}{n}$ so that the domestic incentive-feasibility constraint is a binding constraint at the Bayesian-Nash equilibrium. Straightforward computations

show that

$$\tilde{p}(\beta_i) = 2 \left(1 + \Delta - \frac{1}{n} \right) > p^g = 1.$$

In other words, while domestic incentive-feasibility is a true constraint at the local level, an international regulation with information sharing generates enough worldwide benefits to overcome the power of domestic producers.□

1.4. International Environmental Agreement: Asymmetric Information

We now consider a scenario in which countries participating to an agreement keep private information on their domestic demand. This two-tier information structure is thus the same as in the Bayesian-Nash scenario. Countries have now not only imperfect information on the abatement costs of their domestic producers but also on the demand shocks elsewhere in the world.

Following the tradition of the mechanism design literature (Myerson, 1982), we thus envision any International Environmental Agreement as an incentive mechanism that elicits private information held by countries. Borrowing an approach that was pioneered by [Myerson and Satterthwaite \(1981\)](#)'s analysis of bargaining problems, such incentive mechanism should be viewed as a metaphor for the dynamic bargaining and communication process that takes place in the framework of international negotiations. While in Section 1.3, the sole role of the central regulator was to coordinate and enforce the cooperative regulation implementing different carbon prices and enforcing compensatory payments across countries, this regulator acts now also as a mediator communicating with privately informed countries and recommending which domestic carbon prices they should adopt. Again following [Myerson and Satterthwaite \(1981\)](#), we assume that the uninformed regulator's objective is to maximize ex ante efficiency, giving thus an equal weight to each country in his welfare criterion.

An allocation that arises at the equilibrium of any bargaining protocol must actually satisfy a set of constraints. First, and as in the analysis of Section 1.3, any mechanism must be accepted by both domestic consumers and producers. It means that such mechanism is bound to respect a domestic incentive-feasibility condition that applies within

each country. Whenever the mechanism is not ratified by country i , this country shifts to its dominant strategy and opt for the Bayesian-Nash domestic regulation.

Second, each country must now also be induced to reveal information on its own demand shock. Such information is necessary to assess the externality that its emissions will exert on the rest of the world and thus the magnitude of any compensation it should receive to reduce such emissions.

INCENTIVE MECHANISMS. The central regulator still proposes a set of domestic regulations that stipulate the price for carbon in each country and the possible compensatory payments that this country receives from others. From the *Revelation Principle* (Myerson, 1982), there is thus no loss of generality in viewing such regulation as a set of direct revelation schemes $\{p_i(\hat{\beta}), z_i(\hat{\beta})\}_{i \in \{1, \dots, n\}}$ with prices and compensatory payments in each country i being *a priori* contingent on the whole vector of announcements $\hat{\beta} = (\hat{\beta}_1, \dots, \hat{\beta}_n)$. In fact, and by the same reasoning as that made in Section 1.3, the separability of the global welfare function into a sum of functions that each only depends on domestic carbon prices and demand shocks implies that there is no loss of generality in looking at simpler mechanisms where the carbon price in country i depends only on this country's announcement $\hat{\beta}_i$, namely $p_i(\hat{\beta}) \equiv p(\hat{\beta}_i)$. Yet, payments may be more general as we will see below.

In order to facilitate comparison with the analysis in the previous section, we will sometimes invoke the *Taxation Principle* (Rochet, 1985) and view a mechanism as a nonlinear schedule that stipulates a compensation payment $Z_i(p_i)$ as a function of the carbon price p_i chosen by country i . The benefit of this approach is that it captures the idea that the choice of those prices can actually be delegated to the level of countries where the relevant information on domestic shocks is known.

Expressing expected payments in terms of the underlying contribution, the following identity should hold

$$Z_i(p_i(\beta_i)) = \mathbb{E}_{\beta_{-i}}(z_i(\beta_i, \beta_{-i})). \quad (1.20)$$

From now on, and because of symmetry, we will omit the subscript i since all countries should *a priori* face the same nonlinear contribution schedule $Z(p_i)$.

REMARK. In sharp contrast with Section 1.3, an International Environmental Agreement no longer specifies the number of permits allocated on each domestic market. There are two motivations for such restriction. The first one is theoretical. The number of permits

also determines domestic emissions as a function of the domestic carbon price and demand shock. Had he still been able to observe and offer regulatory contracts contingent on emissions, the central regulator could infer the realization of domestic demand. We would back to the information sharing scenario investigated in Section 1.3. The second motivation is institutional. Although abiding to the rules of an International Environmental Agreement means accepting to coordinate pricing on all domestic carbon markets, in practice, countries keep control on how much permits they distribute on the domestic markets and on the level of subsidy that domestic producers may receive. An International Environmental Agreement thus requires relinquishing part of this domestic regulatory power but not all of it. \square

BUDGET BALANCE. Contrary to Section 1.3, the central regulator being uninformed no longer knows the externality that each country exerts on others. This makes it impossible to use the “*pay-the-externality*” scheme (1.13) to align each country’s objectives with global welfare. We will thus replace this condition by the weaker requirement that, for all possible realizations of a β , the sum of the contributions left to all countries always matches the overall externality they exert on each other. This requirement amounts to imposing an *ex post* budget balance condition as

$$\sum_{i=1}^n z_i(\beta_i, \beta_{-i}) = \frac{n-1}{n} \sum_{i=1}^n (E(p^n(\beta_i), \beta_i) - E(p(\beta_i), \beta_i)). \quad (1.21)$$

The interpretation here is that contributions are taken from a budget whose size matches the overall emissions reductions that is realized when the mechanism is implemented. The mechanism can redistribute contributions between countries as long as this budget constraint is not violated.

An alternative requirement, much in the spirit of Section 1.3, would be that, *on average* over all possible realizations of the demand shock β_i , country i is compensated for its own reduction of emissions, which means

$$\mathbb{E}_{\beta_i}(Z(p(\beta_i))) = \frac{n-1}{n} \mathbb{E}_{\beta_i}(E(p^n(\beta_i), \beta_i) - E(p(\beta_i), \beta_i)). \quad (1.22)$$

In fact, the two requirements are equivalent as shown in next Lemma.

Lemma 3. Take a direct revelation mechanism $\{p(\hat{\beta}_i), z_i(\hat{\beta})\}_{i \in \{1, \dots, n\}}$ such that (1.21) holds, then $Z(p(\beta_i))$ as defined in (1.20) satisfies (1.22). Reciprocally, for any nonlinear contribution schedule $Z(p(\beta_i))$ such that (1.22) holds, there exist direct transfers $z_i(\beta_i, \beta_{-i})$ such that both (1.20) and (1.21) hold.

REMARK. To better understand the consequences of countries keeping private information asymmetric information, let us for suppose that, as in the information sharing scenario of Section 1.3, country i is compensated for raising its own price from p^n to p^g by means of the “pay-the-externality” scheme (1.13). It thus receives an overall payment

$$\frac{n-1}{n} \left(E(p^n, \hat{\beta}_i) - E(p^g, \hat{\beta}_i) \right)$$

where $\hat{\beta}_i$ is country i 's announcement on its realized demand shock.¹³ Thanks to our assumption on the convexity of demand, this payment is actually decreasing in $\hat{\beta}_i$; which means that all countries would pretend being hit by the lowest demand shock $\underline{\beta}$ while the true impact of reducing emissions is in fact

$$\frac{n-1}{n} \left(E(p^n, \beta_i) - E(p^g, \beta_i) \right)$$

which is of a lower magnitude. This means that, had the International Environmental Agreement naively kept the “pay-the-externality” scheme, the budget balance condition (1.22) would not be satisfied. Reconciling incentive compatibility and budget balance is a difficulty of designing an International Environmental Agreement under asymmetric information. Note that, another issue put aside by these simple computations is that the carbon price must also be acceptable by country i . We will come back to this issue in our characterization of optimal mechanisms below.□

1.4.1. Domestic Incentive-Feasibility under Asymmetric Information

To fix ideas and somewhat save on notational burden, we suppose from now on that, even at the Bayesian-Nash equilibrium, each country is always able to implement the local Pigovian price $p^n = \frac{1}{n}$.¹⁴ In a very similar vein to what we did above, we may then

¹³The reader will have noticed that we momentarily depart from our focus on non-linear price to analyze how a particular direct mechanism may be manipulated.

¹⁴The alternative scenario is omitted but the analysis is similar.

look for the domestic incentive-feasibility conditions that are induced by a given nonlinear schedule $Z(p_i)$. Again, we consider that the ratification of the agreement is under the threat of falling back to the Bayesian-Nash outcome if either domestic consumers or domestic producers refuse that agreement. Of course, such nonlinear schedule aims at implementing a carbon price $p(\beta_i)$ that should be no less than p^n . The difference with the analysis in Section 1.3 is that the contribution can only be made contingent on the domestic carbon price but no longer on domestic demand shock. It leads to the following Lemma whose appearance is now familiar.

Lemma 4. *An international regulation that implements a price $p_i \geq p^n$ is domestic incentive-feasible at β_i if and only if*

$$Z(p_i) + \omega(p_i, \beta_i) - \omega(p^n, \beta_i) \geq \Delta(p_i - p^n). \quad (1.23)$$

The interpretation of Condition (1.23) is straightforward. For a carbon price p_i greater than in the Bayesian-Nash scenario to be domestic incentive-feasible, the domestic benefits of adopting such price must exceed the incremental information rent that then accrues to domestic producers thereby.

Although the interpretation is straightforward, a few technical issues should also be stressed before pursuing the analysis. First, from (1.23) and the fact that p^n is itself always feasible, it first follows that $Z(p^n)$ must be non-negative. From (1.22), it must indeed be that

$$Z(p^n) = 0.$$

Second, the set of domestic incentive-feasible prices depends on an endogenous object, the nonlinear schedule $Z(p_i)$. We now impose some conditions that ensure that the optimization problems below always have a solution.

Assumption 1. *$Z(p_i) + \omega(p_i, \beta_i) - \omega(p^n, \beta_i) - \Delta(p_i - p^n)$ is quasi-concave for $p_i \in \mathcal{P} = [p^n, \bar{p}]$ (where \bar{p} is large enough) with $Z(p_i)$ being continuously differentiable and such that*

$$Z'(p^n) > \Delta.$$

The first of those conditions guarantees that the set of feasible prices is an interval

while the last requirement is nothing else than a Slater's constraint qualification condition that ensures that this interval has a non-empty interior. Intuitively, it means that a small increase in the carbon price above the domestic Pigovian level is domestic incentive-feasible. Finally, differentiability will allow us to use first-order conditions to characterize the domestic optimal prices.

The above characterization of domestic incentive-feasibility condition leads us to define the welfare of country i , say $\mathcal{V}(\beta_i)$, and its chosen carbon price $p(\beta_i)$ as follows.

Definition 1. *An allocation $(\mathcal{V}(\beta_i), p(\beta_i))$ is constrained-implementable if and only if there exists a nonlinear schedule $Z(p_i)$ such that*

$$\mathcal{V}(\beta_i) = \max_{p_i \in \mathcal{P} \text{ and (1.23)}} Z(p_i) + \omega(p_i, \beta_i), \quad (1.24)$$

$$p(\beta_i) \in \arg \max_{p_i \in \mathcal{P} \text{ and (1.23)}} Z(p_i) + \omega(p_i, \beta_i). \quad (1.25)$$

This definition of the payoff profile $\mathcal{V}(\beta_i)$ significantly differs from what is usually found in screening problems¹⁵ because of the additional constraint (1.23) that constrains country i 's choice. Indeed, the set of feasible prices among which country i may choose from now depends on the realized shocks.¹⁶ The analysis of those settings has (to the best of our knowledge) not led to develop any systematic techniques for characterizing the set of implementable payoff profiles $\mathcal{V}(\beta_i)$ that could be imported to analyze the problem under scrutiny.¹⁷ The force of Assumption 1 is that such characterization is available in our specific context as shown by next Lemma.

To prepare for this analysis, we define the enforcement slack variable $v(\beta_i)$ as

$$v(\beta_i) = \mathcal{V}(\beta_i) - \omega(p^n, \beta_i) - \Delta(p(\beta_i) - p^n) \quad \forall \beta_i \in \mathcal{B}, \quad (1.26)$$

¹⁵ Laffont and Martimort (2009) (Chapter 3) for instance.

¹⁶If the feasibility condition was expressed in terms of direct mechanisms, the set of possible reports $\hat{\beta}_i$ that country i could make to the mediator would be type-dependent. We know from the seminal work of Green and Laffont (1986) that such problems raise important difficulties. This type-dependency might limit the validity of the *Revelation Principle* in the first place, which justifies our approach in terms of an indirect instrument, i.e., the nonlinear price $Z(p_i)$.

¹⁷For some preliminary research on this front, see Martimort and Severinov (2020).

Observe that, by definition, $p(\beta_i)$ is feasible and thus the non-negativity condition

$$v(\beta_i) \geq 0 \quad \forall \beta_i \in \mathcal{B} \quad (1.27)$$

just follows from (1.23). Alternatively, we may rewrite (1.27) as

$$\mathcal{V}(\beta_i) \geq \omega(p^n, \beta_i) + \Delta(p(\beta_i) - p^n) \quad \forall \beta_i \in \mathcal{B}. \quad (1.28)$$

For future reference, it is useful to define Ω (resp. Ω^c) the subset of \mathcal{B} where (1.27) is binding (resp. enforcement slack) and by $I\Omega$ (resp. $I\Omega^c$) its interior.

Lemma 5. *An allocation $(\mathcal{V}(\beta_i), p(\beta_i))$ is constrained-implementable if and only if:*

1. $p(\beta_i)$ is non-decreasing and thus a.e. differentiable with at any point of differentiability

$$\dot{p}(\beta_i) \geq 0 \text{ a.e.}; \quad (1.29)$$

2. On Ω^c , $\mathcal{V}(\beta_i)$ is Lipschitz-continuous, and thus a.e. differentiable with at any point of differentiability

$$\dot{\mathcal{V}}(\beta_i) = \frac{\partial \omega}{\partial \beta_i}(p(\beta_i), \beta_i) \text{ a.e. for } \beta_i \in \Omega^c; \quad (1.30)$$

3. On $I\Omega$, at any differentiability point β_i in that set, we have

$$\dot{\mathcal{V}}(\beta_i) = \omega_{\beta_i}(p^n, \beta_i) + \Delta \dot{p}(\beta_i). \quad (1.31)$$

and

$$\dot{\mathcal{V}}(\beta_i) = u(\beta_i) + \omega_{\beta_i}(p(\beta_i), \beta_i) \quad (1.32)$$

where

$$u(\beta_i) \geq 0. \quad (1.33)$$

To understand the scope of this Lemma, we may first think of the case where the allocation $(\mathcal{V}(\beta_i), p(\beta_i))$ is *strictly* domestic incentive-feasible, i.e., the compensatory payments

for reducing emissions are always sufficiently large to make it politically acceptable to increase the carbon price. This condition amounts to $v(\beta_i) > 0$ and by continuity of this value function, we have also $v(\beta_i - d\beta_i) > 0$ for $d\beta_i > 0$ but small enough. A given country which has been hit by a shock β_i , may adopt the same behavior as if it had been instead hit by a lower shock $\beta_i - d\beta_i$ and accordingly choose a price $p(\beta_i - d\beta_i)$. Thanks to the fact that $\omega(p_i, \beta_i)$ has increasing differences, the set of domestic incentive-feasible prices at β_i contains the set of in prices which are also domestic incentive-feasible at $\beta_i - d\beta_i$.¹⁸ This mimicking strategy thus remains domestic incentive-feasible for the β_i -country if it is so for $\beta_i - d\beta_i$ as well. This strategy allows the β_i -country to potentially grasp higher compensations for increasing its carbon price and reducing emissions. To prevent such behavior, the β_i -country must receive an incremental rent beyond what type $\beta_i - d\beta_i$ receives which is worth

$$\omega(p(\beta_i - d\beta_i), \beta_i) - \omega(p(\beta_i - d\beta_i), \beta_i - d\beta_i) \approx \frac{\partial \omega}{\partial \beta_i}(p(\beta_i), \beta_i) d\beta_i.$$

This first effect is captured on the right-hand side of (1.30).

Thanks again to the fact that $\omega(p_i, \beta_i)$ has increasing differences, incentive compatibility also implies that $p(\beta_i)$ is non-decreasing whose differentiable form writes as (1.29).

Condition (1.31) is simply obtained by differentiating (1.26) at any interior point of Ω . More novel is (1.31), which is a one-sided version of (1.30). Indeed, consider a value β_i where (1.27) is binding. For such a β_i -country, mimicking the behavior of a country hit by a lower shock $\beta_i - d\beta_i$ is feasible while the reverse is not. The $\beta_i - d\beta_i$ -country could not choose a price $p(\beta_i)$ since it would not be domestic incentive-compatible.

Observe that the necessary conditions in Lemma 5 not necessarily imply differentiability of $p(\beta_i)$ and $\mathcal{V}(\beta_i)$ on all \mathcal{B} . For technical reasons, we are going to restrict our analysis to case where those functions are piecewise continuously differentiable. It will allow us to use the techniques of optimal control under their easiest form.

1.4.2. International Incentive-Feasibility under Asymmetric Information

In the same spirit as we have derived domestic incentive-feasibility above, we now look for a condition, coined as *international incentive-feasibility*, that aggregates the requirements

¹⁸See the Proof of Lemma 5 in the Appendix.

of *constrained-implementability* as described in Lemma 5 and of budget balance (1.22). Any international regulation is bound to satisfy such condition.

Lemma 6. *For any constrained-implementable allocation $(\mathcal{V}(\beta_i), p(\beta_i))$ with non-negative enforcement slack $v(\beta_i)$, the following international incentive-feasibility conditions must hold:*

$$\mathbb{E}_{\beta_i} \left([\tilde{\omega}(p, \beta_i) - \Delta p]_{p^n}^{p(\beta_i)} \right) = \mathbb{E}_{\beta_i} (v(\beta_i)) \geq 0. \tag{1.34}^{19}$$

Asymmetric information has two impacts on international incentive-feasibility. First, and in comparison with the complete scenario, this condition is now taken in expectation. Second, asymmetric information might require to leave some positive enforcement slack over a possible subset of types with non-zero measure, and the international incentive-feasibility is thereby hardened.

REMARK. At a broader level Condition (1.34) is reminiscent of other incentive-feasibility conditions that have flourished in the mechanism design literature although in slightly different contexts. Among others, Myerson and Satterthwaite (1981), Cramton, Gibbons, and Klemperer (1987) and Makowski and Mezzetti (1994) for bargaining problems and Spulber (1988), Rob (1989), Neeman (1999) and Martimort and Sand-Zantman (2016) for more specific contributions to environmental economics have analyzed the consequences of such conditions for institution design. In those papers, such condition is obtained by aggregating incentive compatibility, budget-balance and participation/veto constraints. Checking whether such condition holds for the first-best allocation is most of the time a straightforward exercise (that we will perform below in our specific context). More complicated is the endeavor consisting in looking for a second-best allocation when the first best cannot be achieved. The reason is that the subset of types (necessarily non-empty) where participation constraints bind is endogenous to the mechanism (see Loertscher and Wasser, 2019, and Pommey, 2020, for some recent contributions along these lines). In our context, the enforcement constraint (1.23) replaces the more traditional participation constraints of the extant literature. Yet, it remains difficult to characterize because the point where the enforcement slack is minimized lies. In the sequel, we will this consider simple

¹⁹Where we use the notation $[f(x)]_z^y = f(y) - f(z)$.

settings where the enforcement constraint binds for the most willing to deviate type had the first-best mechanism been offered. See below for more details. \square

IMPLEMENTABILITY OF THE GLOBAL PIGOVIAN PRICE. To illustrate the importance of the incentive-feasibility condition (1.34), we now investigate whether the global Pigovian price, $p(\beta_i) = p^g = 1$, for all $\beta_i \in \mathcal{B}$, can be implemented with positive enforcement slack, i.e., $v(\beta_i) > 0$ for all β_i .

Proposition 3. *The global Pigovian price, i.e., $p(\beta_i) = p^g = 1$ for all $\beta_i \in \mathcal{B}$ is international incentive-feasible if and only if*

$$\omega(1, \underline{\beta}) - \omega(p^n, \underline{\beta}) \geq \frac{n-1}{n} \Delta + \frac{n-1}{n} \mathbb{E}_{\beta_i} \left([D(p + \beta_i) - p - \theta_e]_{p^n}^1 \right). \quad (1.35)$$

The following nonlinear compensation schedule implements this outcome

$$Z(p) = \omega(1, \underline{\beta}) - \omega(p, \underline{\beta}) + \frac{n-1}{n} \mathbb{E}_{\beta_i} \left([D(p + \beta_i) - p - \theta_e]_{p^n}^1 \right) \quad \forall p \in [p^n, 1]. \quad (1.36)$$

Observe that a $\underline{\beta}$ -country would, under complete information, implement the global Pigovian price if and only if

$$\omega(1, \underline{\beta}) - \omega(p^n, \underline{\beta}) \geq \frac{n-1}{n} \Delta + \frac{n-1}{n} [D(p + \underline{\beta}) - p - \theta_e]_{p^n}^1. \quad (1.37)$$

Condition (1.35) is thus similar but stands as a hardening of the complete information version (1.37) since, when $D'' > 0$, emissions as well have increasing differences in the following sense:

$$\frac{\partial}{\partial \beta_i} [D(p + \beta_i) - p - \theta_e]_{p^n}^1 = [D'(p + \beta_i)]_{p^n}^1 > 0.$$

Turning to the shape of the nonlinear compensation schedule, we observe that

$$Z(1) = \frac{n-1}{n} \mathbb{E}_{\beta_i} \left([D(p + \beta_i) - p - \theta_e]_{p^n}^1 \right). \quad (1.38)$$

The first-best implementation mechanism is thus constructed so that all countries adopt the same global Pigovian price and receive a fixed compensation $Z(1)$ whose corresponds to the overall positive externality such emissions reduction brings to the rest of the world. Importantly, this payment being fixed, the mechanism requires no particular knowledge

of the realizations of the shock parameter in either country to be implemented. As we will see below, things are different when the global Pigovian price can no longer be implemented and second-best prices, contingent on these realizations must be preferred.

ONE CARBON PRICE ONLY. Incentive compatibility is *de facto* satisfied if the mechanism stipulates a single price, $p(\beta_i) = p_0$ for all $\beta_i \in \mathcal{B}$. The benefits of such crude strategy is that incentive compatibility requirements are *de facto* satisfied. The simplicity of such pooling mechanism can be seen as attractive on many grounds. It is easily implementable and saves on administrative costs. It also cuts on the negotiation costs that might arise when discussing details of more complex mechanisms. Finally, having a single price is attractive if carbon markets are not insulated or when firms are footloose and may move to the more attractive regulatory environments to save on costs.

The cost of such a simple mechanism is that, when Condition (1.35) fails and the first-best global Pigovian price can no longer be implemented, optimal carbon prices should depend on local market conditions; a logic which is familiar from our analysis of domestic incentive feasible policies.

Proposition 4. *Suppose that Condition (1.35) fails and that the mechanism stipulates a single price, $p(\beta_i) = p_0$ for all $\beta_i \in \mathcal{B}$. Suppose also that*

$$\frac{n-1}{n} (1 - \mathbb{E}_{\beta_i} (D'(p^n + \beta_i))) > \Delta. \quad (1.39)$$

The optimal single carbon price p_0^ is given by*

$$p_0^* = 1 - \frac{\mu}{1+\mu} \frac{\Delta + (p_0^* - p^n) \mathbb{E}_{\beta_i} \left(\frac{1-G(\beta_i)}{g(\beta_i)} D''(p_0^* + \beta_i) \right)}{\mathbb{E}_{\beta_i} (1 - D'(p_0^* + \beta_i))} \quad (1.40)$$

for some $\mu > 0$.

The optimal price p_0^ is less (resp. greater) than the global (resp. domestic) Pigovian price:*

$$p^n < p_0^* < 1. \quad (1.41)$$

The following nonlinear compensation schedule implements this outcome

$$Z(p) = \begin{cases} \omega(p^n, \underline{\beta}) - \omega(p_0^*, \underline{\beta}) + \omega(p_0^*, \bar{\beta}) - \omega(p, \bar{\beta}) & \text{for } p > p_0^*, \\ \omega(p^n, \underline{\beta}) - \omega(p, \underline{\beta}) + \Delta(p_0 - p^n) & \text{for } p \leq p_0^*. \end{cases} \quad (1.42)$$

The single optimal price p_0^* is always less than the global Pigovian level. There are two reasons for the downward distortions and they can be seen on the right-hand side of (1.40). On the one hand, choosing p_0 above p^n hardens the enforcement constraint for all countries whatever their type since the extra slack $\Delta(p_0 - p^n)$ must always be given up. On the other hand, countries with a favorable shock β_i want to claim that shock is lower to pretend emitting more and being better compensated for reducing their emissions. Reducing these extra informational rents that eschew to the countries themselves requires asking for less ambitious global price. Both the enforcement slack and the information rent hardens the feasibility constraint whose Lagrange multiplier μ is necessarily positive when Condition (1.35) fails.

On a more optimistic stance, p_0^* remains above the domestic Pigovian level. In other words, even under asymmetric information and the extra constraint of a uniform treatment of all countries, the worldwide externality is somewhat internalized although imperfectly so. There is scope for implementing enforceable uniform prices.

The nonlinear schedule is obtained by using simple duality arguments, starting from the payoffs profile $\mathcal{V}(\beta_i)$ induced by a fixed price p_0^* . Of particular importance is the value of that contribution at that price, namely

$$Z(p_0^*) = \omega(p^n, \underline{\beta}) - \omega(p_0^*, \underline{\beta}) + \Delta(p_0^* - p^n) = \frac{n-1}{n} \mathbb{E}_{\beta_i} \left([D(p + \beta_i) - p - \theta_e]_{p_0^*}^{p^n} \right). \quad (1.43)$$

This formula gives us a direct expression (without the Lagrange multiplier of the incentive-feasibility constraint) of the one-price optimum p_0^* . This formula could be compared to the definition of the complete information second-best price $\tilde{p}(\underline{\beta})$ that would solve

$$\omega(p^n, \underline{\beta}) - \omega(\tilde{p}(\underline{\beta}), \underline{\beta}) + \Delta(\tilde{p}(\underline{\beta}) - p^n) = \frac{n-1}{n} [D(p + \underline{\beta}) - p - \theta_e]_{\tilde{p}(\underline{\beta})}^{p^n}. \quad (1.44)$$

Because $D'' > 0$, the right-hand side of (1.43) is greater than that of (1.44). Asymmetric

information requires to lower the price even below the worst second-best price $\tilde{p}(\underline{\beta})$ that would be chosen had country-specific demand shocks been known:

$$p_0^* < \tilde{p}(\underline{\beta}).$$

SECOND-BEST PRICES. Suppose again that Condition (1.35) fails so that the first-best global Pigovian price can no longer be implemented. In the same vein as what we did when local Pigovian price are not domestically feasible, we now investigate properties of the second-best optimal prices. We now make no restriction on the kind of mechanisms that can be offered. Next Proposition summarizes some findings.

Proposition 5. *If the enforcement constraint (1.28) is slack in a left-neighborhood of $\bar{\beta}$ of the form $[\beta^*, \bar{\beta}]$, then the second-best optimal price $p^{sb}(\beta_i)$ is separating on that interval and*

$$p^{sb}(\beta_i) = 1 - \frac{\mu}{1 + \mu} \frac{1 - G(\beta_i)}{g(\beta_i)} \frac{(p^{sb}(\beta_i) - p^n) D''(p^{sb}(\beta_i) + \beta_i)}{1 - D'(p^{sb}(\beta_i) + \beta_i)} \quad (1.45)$$

where $\mu > 0$.

The enforcement constraint (1.28) is binding on an interval Ω with non-empty interior.

The enforcement constraint (1.28) is slack on an interval of the form $[\beta^, \bar{\beta}]$ when*

$$\omega_{\beta_i}(p^{sb}(\beta_i), \beta_i) - \omega_{\beta_i}(p^n, \beta_i) \geq \Delta \dot{p}^{sb}(\beta_i) \quad \forall \beta_i \in [\beta^*, \bar{\beta}] \quad (1.46)$$

where $p^{sb}(\beta_i)$ is given by (1.45).

The condition (1.45) shows that the second-best optimal prices should depend on demand shock. The Law of One Price fails in this context.

1.5. Conclusion

We studied the implementation of an International Environmental Agreement with international budget-balanced transfers in a context where private information takes place at both international and domestic scales and participation constraints of countries, firms and consumers are respected. We showed that the two-tier asymmetry of information may prevent the implementation of the first-best agreement that consists in a unique price of

carbon for all countries. We derived the second-best agreement and showed that, in this case, the carbon price should differ between countries. Our model thereby questioned the feasibility and desirability of implementing a unique price for carbon. We however also examined a second-best agreement with the extra constraint that the price of carbon should be the same for all countries. More broadly, we highlighted the importance of taking into account the asymmetry of information at both domestic and international levels. Our results call for a better consideration of the informational barriers associated to multiple levels of governance to improve the design of International Environmental Agreements.

The limits of our model lie mainly in some of our assumptions. We first assumed linear damages of pollution. A natural extension of our work can be to consider the robustness of our result with convex damages. We also considered that countries are homogeneously affected by pollution. Assuming heterogeneous damages of pollution would in the first place affect the first-best regulations: the optimal price of carbon would no longer be unique. This can be an interesting alley for further research. Also, though we imposed strong requirements on the international agreement, we did not explicitly model the negotiation process leading to it. It would be interesting to understand how the domestic asymmetry of information affects this negotiation process. Finally, we glossed over the existence of international trade.

1.6. Appendix

Proof of Lemma 1. Summing (1.6) and (1.7) and taking into (1.5) immediately yields (1.8). Reciprocally, suppose that (1.8) holds and define τ_i such that (1.7) is an equality. Then, (1.6) is satisfied. \square

Proof of Lemma 2. Summing (1.16) and (1.15) and taking into (1.5) immediately yields (1.17). Reciprocally, suppose that (1.17) holds and define τ_i such that (1.15) is an equality. Then, (1.16) is satisfied. \square

Proof of Proposition 2. The proof is similar to that of Proposition 1 and is thus omitted. \square

Proof of Lemma 3. Necessity. Suppose that (1.21) holds, taking expectations and using (1.20) plus symmetry yields (1.22).

Sufficiency. Take any arbitrary $Z(p(\beta_i))$ that satisfies (1.22). We may write

$$Z(p(\beta_i)) = \frac{n-1}{n} (E(p^n(\beta_i), \beta_i) - E(p(\beta_i), \beta_i)) + \zeta(\beta_i)$$

where, by construction $\zeta(\beta_i)$ satisfies

$$\mathbb{E}_{\beta_i} (\zeta(\beta_i)) = 0.$$

Take now

$$\tilde{z}_i(\beta_i, \beta_{-i}) = \zeta(\beta_i) - \frac{1}{n-1} \sum_{j \neq i} u(\beta_j).$$

By construction, we have

$$\mathbb{E}_{\beta_{-i}} (\tilde{z}_i(\beta_i, \beta_{-i})) = \zeta(\beta_i).$$

and

$$\sum_{i=1}^n \tilde{z}_i(\beta_i, \beta_{-i}) = 0.$$

Define now

$$z_i(\beta_i, \beta_{-i}) = \frac{n-1}{n} (E(p^n(\beta_i), \beta_i) - E(p(\beta_i), \beta_i)) + \tilde{z}_i(\beta_i, \beta_{-i}).$$

Clearly, (1.21) holds. Moreover, taking expectations (1.20) also holds.

To conclude, replacing the nonlinear schedule $Z(p)$ by the payments (1.21) keeps unchanged Bayesian incentive compatibility and domestic-incentive feasibility.²⁰

□

Proof of Lemma 5. Let denote the set of feasible prices at β_i as

$$\mathcal{D}(\beta_i) = \{ p_i \text{ s.t. (1.23)} \}.$$

By Assumption 1, $\mathcal{D}(\beta_i)$ is an interval with p^n as lowest bound. Now, observe that $Z(p_i) + \omega(p_i, \beta_i) - \omega(p^n, \beta_i) - \Delta(p_i - p^n)$ is worth 0 for $p_i = p^n$ for all β_i and has increasing differences since $\omega(p_i, \beta_i)$

²⁰We are a bit loose here in that we have not defined constrained-implementability for a direct mechanism. The definition is straightforward and we leave it to the reader.

itself satisfies this property. Hence, $\beta_i - d\beta_i \leq \beta_i$ implies the set monotonicity property

$$\mathcal{D}(\beta_i - d\beta_i) \subseteq \mathcal{D}(\beta_i). \quad (1.47)$$

In other words, $p(\beta_i - d\beta_i)$, which is optimal for the $\beta_i - d\beta_i$ -country is also feasible for the β_i -country.

Denote $\hat{p}(\beta_i) = \sup \{p \in \mathcal{D}(\beta_i)\}$ (with the *sup* being $+\infty$ in case $\mathcal{D}(\beta_i)$ is unbounded above). When $\hat{p}(\beta_i) < +\infty$, $\hat{p}(\beta_i)$ is the unique solution greater than p^n such that

$$Z(\hat{p}(\beta_i)) + \omega(\hat{p}(\beta_i), \beta_i) - \omega(p^n, \beta_i) = \Delta(\hat{p}(\beta_i) - p^n).$$

Because $Z(p_i)$ is continuous, $\hat{p}(\beta_i)$ is itself continuous. Moreover, $\hat{p}(\beta_i)$ is in fact non-decreasing since (1.47) holds. Because $Z(p_i)$ is differentiable, the *Implicit Theorem* holds and $\hat{p}(\beta_i)$ is differentiable (and thus Lipschitz-continuous since this derivative is uniformly bounded) with

$$\dot{\hat{p}}(\beta_i) = -\frac{\frac{\partial \omega}{\partial \beta_i}(\hat{p}(\beta_i), \beta_i) - \frac{\partial \omega}{\partial \beta_i}(p^n, \beta_i)}{Z'(\hat{p}(\beta_i)) + \frac{\partial \omega}{\partial p_i}(\hat{p}(\beta_i), \beta_i) - \Delta} > 0. \quad (1.48)$$

From the fact that $\omega(p_i, \beta_i)$ has increasing differences and $\hat{p}(\beta_i) > p^n$, the above numerator is positive. Since $\dot{\hat{p}}(\beta_i) > 0$, it also follows that

$$Z'(\hat{p}(\beta_i)) + \frac{\partial \omega}{\partial p_i}(\hat{p}(\beta_i), \beta_i) - \Delta < 0. \quad (1.49)$$

Consider now the following allocation $(\mathcal{V}^*(\beta_i), p_*(\alpha_i))$ defined as

$$\mathcal{V}^*(\beta_i) = \max_{p_i \in \mathcal{P}} Z(p_i) + \omega(p_i, \beta_i) \quad (1.50)$$

and

$$p_*(\beta_i) \in \arg \max_{p_i \in \mathcal{P}} Z(p_i) + \omega(p_i, \beta_i). \quad (1.51)$$

This allocation would implement the optimum of country i 's problem if it was unconstrained by the domestic domestic incentive-feasibility condition.

It is routine to show (Milgrom and Segal, 2002, Theorem 1) that:

1. $\mathcal{V}^*(\beta_i)$ is Lipschitz continuous and thus a.e. differentiable, with a derivative when it exists which is given by

$$\dot{\mathcal{V}}^*(\beta_i) = \frac{\partial \omega}{\partial \beta_i}(p_*(\beta_i), \beta_i) \text{ a.e.}; \quad (1.52)$$

2. $p_*(\beta_i)$ is non-decreasing and thus a.e. differentiable.
3. Moreover, because $Z(p_i)$ is differentiable, the following first-order condition characterizes $p_*(\beta_i)$:

$$Z'(p_*(\beta_i)) + \frac{\partial \omega}{\partial p_i}(p_*(\beta_i), \beta_i) = 0. \quad (1.53)$$

The solution to the constrained problem (1.25) is thus defined as

$$p(\beta_i) = \min \{p_*(\beta_i); \hat{p}(\beta_i)\}. \quad (1.54)$$

Both $p_*(\beta_i)$ and $\hat{p}_i(\beta_i)$ being non-decreasing, $p(\beta_i)$ is itself non-decreasing and thus a.e. differentiable.

The payoff function $\mathcal{V}(\beta_i)$ that solves (1.24) is thus defined as

$$\mathcal{V}(\beta_i) = \begin{cases} \mathcal{V}^*(\beta_i) & \text{on } I\Omega^c, \\ \omega(p^n, \beta_i) + \Delta(\hat{p}(\beta_i) - p^n) & \text{on } I\Omega. \end{cases} \quad (1.55)$$

From this, it follows that $\mathcal{V}(\beta_i)$ is a.e. differentiable and its derivative, when it exists, is

$$\dot{\mathcal{V}}(\beta_i) = \begin{cases} \frac{\partial \omega}{\partial \beta_i}(p_*(\beta_i), \beta_i) & \text{on } I\Omega^c, \\ \frac{\partial \omega}{\partial \beta_i}(p^n, \beta_i) + \Delta \dot{\hat{p}}(\beta_i) & \text{on } I\Omega. \end{cases} \quad (1.56)$$

The first case can be rewritten as (1.31). As far as (1.32) is concerned, observe that, using (1.48), we may rewrite

$$\frac{\partial \omega}{\partial \beta_i}(p^n, \beta_i) + \Delta \dot{\hat{p}}(\beta_i) = \frac{\partial \omega}{\partial \beta_i}(\hat{p}(\beta_i), \beta_i) + \dot{\hat{p}}(\beta_i) \left(Z'(\hat{p}(\beta_i)) + \frac{\partial \omega}{\partial p_i}(\hat{p}(\beta_i), \beta_i) \right).$$

Now observe that (1.49) implies, when $p(\beta_i) = p_*(\beta_i) \leq \hat{p}(\beta_i)$ that

$$Z'(\hat{p}(\beta_i)) + \frac{\partial \omega}{\partial p_i}(\hat{p}(\beta_i), \beta_i) \geq 0. \quad (1.57)$$

Taking into account (1.49), (1.57) and the definition (1.54), we may rewrite (1.56) as (1.32). \square

Proof of Lemma 6. First, using (1.22) yields

$$\mathbb{E}_{\beta_i}(\mathcal{V}(\beta_i) - \omega p(\beta_i), \beta_i) = \frac{n-1}{n} \mathbb{E}_{\beta_i}(E(p^n(\beta_i), \beta_i) - E(p(\beta_i), \beta_i)).$$

Using (1.26), we transform this condition as (1.34). □

Proof of Proposition 3. Observe that, thanks to the fact that $\omega(p, \beta_i)$ has increasing differences, the enforcement slack profile is increasing when $p(\beta_i) = p^g = 1$ for all $\beta_i \in \mathcal{B}$:

$$\dot{v}(\beta_i) = \frac{\partial \omega}{\partial \beta_i}(1, \beta_i) - \frac{\partial \omega}{\partial \beta_i}(p^n, \beta_i) > 0 \text{ a.e..} \quad (1.58)$$

This condition means that the enforcement slack has minimal value at $\underline{\beta}$. From (1.34), a simple integration by parts shows that

$$\mathbb{E}_{\beta_i} \left([\tilde{\omega}(p, \beta_i) - \Delta p]_{p^n}^1 \right) = v(\underline{\beta}) + \mathbb{E}_{\beta_i} \left(\frac{1 - G(\beta_i)}{g(\beta_i)} \left(\frac{\partial \omega}{\partial \beta_i}(1, \beta_i) - \frac{\partial \omega}{\partial \beta_i}(p^n, \beta_i) \right) \right). \quad (1.59)$$

Thus $v(\underline{\beta})$ is non-negative if and only if

$$\mathbb{E}_{\beta_i} \left(\tilde{\omega}(1, \beta_i) - \tilde{\omega}(p^n, \beta_i) - \frac{n-1}{n} \Delta \right) > \mathbb{E}_{\beta_i} \left(\frac{1 - G(\beta_i)}{g(\beta_i)} \left(\frac{\partial \omega}{\partial \beta_i}(1, \beta_i) - \frac{\partial \omega}{\partial \beta_i}(p^n, \beta_i) \right) \right).$$

From (1.59) and integrating by parts, it follows that

$$v(\underline{\beta}) = \omega(1, \underline{\beta}) - \omega(p^n, \underline{\beta}) - \frac{n-1}{n} \Delta - \frac{n-1}{n} \mathbb{E}_{\beta_i} \left([D(p + \beta_i) - p - \theta_e]_{p^n}^1 \right) \geq 0 \quad (1.60)$$

which means (1.35).

From (1.26), (1.58) and (1.59), it follows that

$$\mathcal{V}(\beta_i) = v(\underline{\beta}) + \omega(p^n, \beta_i) + \int_{\underline{\beta}}^{\beta_i} \left(\frac{\partial \omega}{\partial \beta_i}(1, \tilde{\beta}_i) - \frac{\partial \omega}{\partial \beta_i}(p^n, \tilde{\beta}_i) \right) d\tilde{\beta}_i + \frac{n-1}{n} \Delta,$$

or, using (1.60),

$$\mathcal{V}(\beta_i) = \omega(1, \beta_i) - \frac{n-1}{n} \mathbb{E}_{\beta_i} \left([D(p + \beta_i) - p - \theta_e]_{p^n}^1 \right). \quad (1.61)$$

Because (1.24) holds, a simple duality argument shows that we also have

$$Z(p) = \min_{\beta_i \in \mathcal{B}} \mathcal{V}(\beta_i) - \omega(p, \beta_i) \quad \forall p \in [p^n, 1].$$

Using (1.61), we obtain

$$Z(p) = \min_{\beta_i \in \mathcal{B}} \omega(1, \beta_i) - \omega(p, \beta_i) - \frac{n-1}{n} \mathbb{E}_{\beta_i} \left([D(p + \beta_i) - p - \theta_e]_{p^n}^1 \right)$$

which becomes (1.36) where the last equality follows from the fact that $\omega(p, \beta_i)$ has increasing differences. \square

Proof of Proposition 5. The optimization problem (\mathcal{P}) is to find an arc $v(\beta_i)$ of absolutely continuous functions and some controls $(u(\beta_i), p(\beta_i))$ that altogether maximize

$$(\mathcal{P}) : \max_{(\mathcal{V}(\beta_i), v(\beta_i), p(\beta_i), u(\beta_i))} \mathbb{E}_{\beta_i} (\tilde{\omega}(p(\beta_i), \beta_i))$$

subject to (1.28), (1.29), (1.33) and (1.34).

To prepare for the optimization, the first step is to observe that

$$\mathbb{E}_{\beta_i} \left(\tilde{\omega}(p(\beta_i), \beta_i) + \frac{n-1}{n} (D(p^n + \beta_i) - p^n - \theta_e) \right) = \mathbb{E}_{\beta_i} (\mathcal{V}(\beta_i)). \quad (1.62)$$

The second simplifying step is to replace (1.30) and (1.32) by the weaker requirement

$$\dot{\mathcal{V}}(\beta_i) = u(\beta_i) + \omega_{\beta_i}(p(\beta_i), \beta_i) \quad \forall \beta_i \in \mathcal{B} \quad (1.63)$$

where

$$u(\beta_i) \geq 0 \quad \forall \beta_i \in \mathcal{B}. \quad (1.64)$$

Lastly, the monotonicity requirement (1.29) is omitted and checked *ex post* on the solution of the so relaxed problem.

These different steps lead us to consider a relaxed optimization problem (\mathcal{P}') as

$$(\mathcal{P}') : \max_{(\mathcal{V}(\beta_i), p(\beta_i), u(\beta_i))} \mathbb{E}_{\beta_i} (\tilde{\omega}(p(\beta_i), \beta_i))$$

subject to (1.28), (1.62), (1.63) and (1.64).

Let denote by μ the non-negative Lagrange multiplier for (1.62). When Condition (1.35) fails, we necessarily have $\mu > 0$. Let also denote by ζ the non-negative Lagrange multiplier for the mixed constraint (1.28). To simplify notations, we will omit the Lagrange multiplier for (1.64) and directly proceed to constrained optimization over the domain $u(\beta_i) \geq 0$ on the simplified (pointwise) Lagrangean so obtained. This Lagrangean thus writes as

$$\mathcal{L}(\mathcal{V}, p, \zeta, \beta_i) = g(\beta_i) \left(\tilde{\omega}(p, \beta_i) + \mu \left(\tilde{\omega}(\tilde{p}, \beta_i) + \frac{n-1}{n} (D(p^n + \beta_i) - p^n - \theta_e) - \mathcal{V} \right) \right) \quad (1.65)$$

$$+\zeta(\mathcal{V} - \omega(p^n, \beta_i) - \Delta(p - p^n)).$$

We form the corresponding Hamiltonian as

$$\mathcal{H}(\mathcal{V}, p, u, \zeta, \beta_i, \lambda) = \mathcal{L}(\mathcal{V}, p, \zeta, \beta_i) + \lambda(u + \omega_{\beta_i}(p, \beta_i)). \quad (1.66)$$

Since (\mathcal{P}') has a mixed constraint (1.28), we apply *Pontryagin Principle* as stated in [Seierstad and Sydsaeter \(1986\)](#) (Chapter 4, Theorem 1). An absolutely continuous arc $\mathcal{V}^{sb}(\beta_i)$, together with some optimal controls $(p^{sb}(\beta_i), u^{sb}(\beta_i))$, which are optimal satisfy the following necessary conditions. There exists a piecewise continuously differentiable function $\lambda(\beta_i)$ (the costate variable for (1.63)), and a non-negative piecewise continuous function $\zeta(\beta_i)$ (the ‘‘Lagrange multiplier’’ for the mixed constraint (1.28)) which are all defined on \mathcal{B} and satisfy the following necessary conditions. From [Seierstad and Sydsaeter \(1986\)](#) (Chapter 4, Theorem 5), the sufficiency conditions of the Mangasarian type are satisfied in our context since $\mathcal{H}(\mathcal{V}, p, u, \zeta, \beta_i, \lambda)$ is concave in (\mathcal{V}, p, u) .

Costate variable:

$$-\dot{\lambda}(\beta_i) = \frac{\partial \mathcal{H}}{\partial \mathcal{V}}(\mathcal{V}^{sb}(\beta_i), p^{sb}(\beta_i), u^{sb}(\beta_i), \zeta(\beta_i), \beta_i, \lambda(\beta_i))$$

or

$$-\dot{\lambda}(\beta_i) = -\mu g(\beta_i) + \zeta(\beta_i). \quad (1.67)$$

Transversality conditions:

$$\lambda(\underline{\beta}) = \lambda(\bar{\beta}) = 0. \quad (1.68)$$

Control variables: $(p^{sb}(\beta_i), u^{sb}(\beta_i))$ maximizes $\mathcal{H}(\mathcal{V}^{sb}(\beta_i), p, u, \zeta(\beta_i), \beta_i, \lambda(\beta_i))$. It immediately follows from the linearity in $u(\beta_i)$ that we have

$$u^{sb}(\beta_i) = 0 \text{ if } \lambda(\beta_i) \leq 0. \quad (1.69)$$

Optimizing with respect to $p^{sb}(\beta_i)$, we obtain

$$g(\beta_i)(1 + \mu) \frac{\partial \tilde{\omega}}{\partial p}(p^{sb}(\beta_i), \beta_i) = \zeta(\beta_i)\Delta - \lambda(\beta_i) \frac{\partial^2 \omega}{\partial p \partial \beta_i}(p^{sb}(\beta_i), \beta_i). \quad (1.70)$$

From these optimality conditions, we immediately derive some facts.

Fact 1. Integrating (1.67) and using (1.68) yields

$$\lambda(\beta_i) = \mu G(\beta_i) - \int_{\underline{\beta}}^{\beta_i} \zeta(\tilde{\beta}) d\tilde{\beta} \quad (1.71)$$

with

$$\mu = \int_{\underline{\beta}}^{\bar{\beta}} \zeta(\tilde{\beta}) d\tilde{\beta}. \quad (1.72)$$

Because $\mu > 0$ when Condition (1.35) fails, $\zeta(\tilde{\beta})$ is necessarily positive on an interval Ω of positive measure.

Fact 2. Inserting (1.71), (1.72) into (1.70) yields

$$g(\beta_i)(1 + \mu) \frac{\partial \tilde{\omega}}{\partial p}(p^{sb}(\beta_i), \beta_i) = \zeta(\beta_i) \Delta + \mu \left(1 - G(\beta_i) - \int_{\beta_i}^{\bar{\beta}} \zeta(\tilde{\beta}) d\tilde{\beta} \right) \frac{\partial^2 \omega}{\partial p \partial \beta_i}(p^{sb}(\beta_i), \beta_i). \quad (1.73)$$

Simplifying further yields

$$p^{sb}(\beta_i) = 1 - \frac{\zeta(\beta_i)}{g(\beta_i)(1 + \mu)} \frac{\Delta}{1 - D'(p^{sb}(\beta_i) + \beta_i)} \quad (1.74)$$

$$- \frac{\mu}{1 + \mu} \left(\frac{1 - G(\beta_i)}{g(\beta_i)} - \frac{1}{g(\beta_i)} \int_{\beta_i}^{\bar{\beta}} \zeta(\tilde{\beta}) d\tilde{\beta} \right) (p^{sb}(\beta_i) - p^n) \frac{D''(p^{sb}(\beta_i) + \beta_i)}{1 - D'(p^{sb}(\beta_i) + \beta_i)}.$$

Fact 3. If (1.28) is slack in a left-neighborhood of $\bar{\beta}$ of the form $[\beta^*, \bar{\beta}]$, then $\zeta(\beta_i) = 0$ on that neighborhood and inserting into (1.74) yields (1.45). From (1.71) and (1.72), we then have

$$\lambda(\beta_i) = \mu(G(\beta_i) - 1) \leq 0 \quad (1.75)$$

so that (1.69) holds.

Fact 4. If (1.28) is slack in a left-neighborhood of $\bar{\beta}$, we have also $\dot{p}^{sb}(\bar{\beta}) > 0$. Indeed, first notice that

$$p^{sb}(\bar{\beta}) = 1. \quad (1.76)$$

Second, differentiating (1.45) at $\bar{\beta}$ yields

$$\dot{p}^{sb}(\bar{\beta}) = - \frac{\mu}{1 + \mu} \frac{n - 1}{n} \frac{d}{d\beta_i} \left(\frac{1 - G(\beta_i)}{g(\beta_i)} \right)_{\beta_i = \bar{\beta}} \frac{D''(p^{sb}(\beta_i) + \beta_i)}{1 - D'(p^{sb}(\beta_i) + \beta_i)} > 0 \quad (1.77)$$

when G satisfies the monotone hazard rate property $\frac{d}{d\beta_i} \left(\frac{1 - G(\beta_i)}{g(\beta_i)} \right) < 0$ and indeed $\frac{d}{d\beta_i} \left(\frac{1 - G(\beta_i)}{g(\beta_i)} \right)_{\beta_i = \bar{\beta}} = -1$.

Fact 5. Suppose that the enforcement constraint (1.28) is binding at β^* , thus

$$\mathcal{V}(\beta^*) = \Delta(p^{sb}(\beta^*) - p^n) + \omega(p^n, \beta^*) \quad (1.78)$$

Moreover, (1.79) implies

$$\dot{\mathcal{V}}(\beta_i) = \omega_{\beta_i}(p^{sb}(\beta_i), \beta_i) > \Delta p^{sb}(\beta_i) + \omega_{\beta_i}(p^n, \beta_i) \quad \forall \beta_i \in [\beta^*, \bar{\beta}]. \quad (1.79)$$

From this, it follows that

$$\mathcal{V}(\beta_i) > \Delta(p^{sb}(\beta_i) - p^n) + \omega(p^n, \beta_i) \quad \forall \beta_i \in [\beta^*, \bar{\beta}] \quad (1.80)$$

and thus the enforcement constraint (1.28) is slack on at $(\beta^*, \bar{\beta}]$. \square

Proof of Proposition 4. We first start with two preliminary remarks. First, with a pooling mechanism, the monotonicity requirement (1.29) trivially holds. Second, when Condition (1.35) fails, it must necessarily be that (1.28) is binding for some types.

We thus specialize the presentation made in the Proof of Proposition 5, especially the optimization of the relaxed problem (\mathcal{P}') , to the case $p(\beta_i) = p_0$ for all $\beta_i \in \mathcal{B}$. First, (1.62) becomes

$$\mathbb{E}_{\beta_i} \left(\tilde{\omega}(p_0, \beta_i) + \frac{n-1}{n} (D(p^n + \beta_i) - p^n - \theta_e) \right) = \mathbb{E}_{\beta_i} (\mathcal{V}(\beta_i)) \quad (1.81)$$

where (1.63) writes now as

$$\dot{\mathcal{V}}(\beta_i) = u(\beta_i) + \omega_{\beta_i}(p_0, \beta_i) \quad \forall \beta_i \in \mathcal{B} \quad (1.82)$$

together with the non-negativity condition (1.64).

Because of (1.64) and because $\omega(p, \beta_i)$ has increasing differences, we have the following string of inequalities when $p_0 \geq p^n$:

$$\dot{\mathcal{V}}(\beta_i) \geq \omega_{\beta_i}(p_0, \beta_i) \geq \omega_{\beta_i}(p^n, \beta_i) \quad \forall \beta_i \in \mathcal{B}. \quad (1.83)$$

Hence, (1.28), when binding, is binding at $\underline{\beta}$ only.

From this, we write

$$\mathcal{V}(\beta_i) = \mathcal{V}(\underline{\beta}) + \int_{\underline{\beta}}^{\beta_i} \omega_{\beta_i}(p_0, \tilde{\beta}_i) d\tilde{\beta}_i \quad \forall \beta_i \in \mathcal{B} \quad (1.84)$$

where

$$\mathcal{V}(\underline{\beta}) = \omega(p^n, \underline{\beta}) + \Delta(p_0 - p^n). \quad (1.85)$$

Using (1.84) and (1.85) and inserting into (1.81) yields a new expression of incentive-feasibility as

$$\mathbb{E}_{\beta_i} \left(\tilde{\omega}(p_0, \beta_i) + \frac{n-1}{n} (D(p^n + \beta_i) - p^n - \theta_e) \right) = \omega(p^n, \underline{\beta}) + \Delta(p_0 - p^n) + \mathbb{E}_{\beta_i} \left(\frac{1 - G(\beta_i)}{g(\beta_i)} \omega_{\beta_i}(p_0, \beta_i) \right). \quad (1.86)$$

Of course $p_0 = p^n$ satisfies this incentive-feasibility constraint. Moreover, the constraint defines a set of feasible prices $p_0 \geq p^n$ with non-empty interior when (1.39) holds.

These different steps lead us to consider the new optimization problem (\mathcal{P}'') as

$$(\mathcal{P}'') : \quad \max_{p_0} \mathbb{E}_{\beta_i} (\tilde{\omega}(p_0, \beta_i)) \quad \text{subject to (1.86)}.$$

Let again denote by μ the non-negative Lagrange multiplier for (1.81). When Condition (1.35) fails, we necessarily have $\mu > 0$. The Lagrangean thus writes as

$$\begin{aligned} \mathcal{L}(p_0) &= (1 + \mu) \mathbb{E}_{\beta_i} (\tilde{\omega}(p_0, \beta_i)) \\ &+ \mu \left(\frac{n-1}{n} \mathbb{E}_{\beta_i} (D(p^n + \beta_i) - p^n - \theta_e) - \omega(p^n, \underline{\beta}) - \Delta(p_0 - p^n) - \mathbb{E}_{\beta_i} \left(\frac{1 - G(\beta_i)}{g(\beta_i)} \omega_{\beta_i}(p_0, \beta_i) \right) \right). \end{aligned} \quad (1.87)$$

The first-order condition for optimality (which is also sufficient thanks to concavity of the objective) writes as

$$(1 + \mu) \mathbb{E}_{\beta_i} \left(\frac{\partial \tilde{\omega}}{\partial p}(p_0^*, \beta_i) \right) = \mu \left(\Delta + \mathbb{E}_{\beta_i} \left(\frac{1 - G(\beta_i)}{g(\beta_i)} \omega_{p\beta_i}(p_0^*, \beta_i) \right) \right). \quad (1.88)$$

Simplifying yields (1.40).

The right-hand side inequality of (1.41) follows immediately from (1.40) and the fact that $D'' > 0$. The left-hand side follows from the fact that $p_0 = p^n$ is of course feasible when (1.39) holds.

Turning now to the shape of the nonlinear schedule that would implement such fixed policy, we follow steps already found in the Proof of Proposition 3. We first derive from (1.84) and (1.85) the following expression of the payoffs profile

$$\mathcal{V}(\beta_i) = \omega(p^n, \underline{\beta}) + \Delta(p_0^* - p^n) + \int_{\underline{\beta}}^{\beta_i} \omega_{\beta_i}(p_0^*, \tilde{\beta}_i) d\tilde{\beta}_i \quad \forall \beta_i \in \mathcal{B}$$

or

$$\mathcal{V}(\beta_i) = \omega(p^n, \underline{\beta}) - \omega(p_0^*, \underline{\beta}) + \omega(p_0^*, \beta_i) + \Delta(p_0^* - p^n) \quad \forall \beta_i \in \mathcal{B}. \quad (1.89)$$

A simple duality argument then shows that

$$Z(p) = \min_{\beta_i \in \mathcal{B}} \mathcal{V}(\beta_i) - \omega(p, \beta_i) \quad \forall p \in [p^n, 1].$$

Using (1.89), we obtain

$$Z(p) = \min_{\beta_i \in \mathcal{B}} \omega(p^n, \underline{\beta}) - \omega(p_0^*, \underline{\beta}) + \omega(p_0^*, \beta_i) - \omega(p, \beta_i) + \Delta(p_0^* - p^n) \quad \forall p \in [p^n, 1]$$

or (1.42) where the last equalities follow from the fact that $\omega(p, \beta_i)$ has increasing differences, distinguishing two cases depending on whether p is greater or less than p_0^* . \square

Chapter 2. Third-Party Certification and Price Signaling ¹

Abstract

This paper studies the interplay between price signaling and third-party certification of product quality. A monopolist can either try to obtain a certification that reveals the exact quality of a good or signal quality to consumers through price. I first consider an exogenous certification that consists of a fee when there is a continuum of quality levels. I show that the structure of certification fee affects which types of monopolist choose certification. With constant fee, certification always occurs on an interval of high quality levels, while with per-unit fee or fee increasing with quality level it may occur on an interval of intermediate quality levels. Second, I examine an endogenous certification offered by a strategic certifier when there are two quality levels. This certification consists of a certification fee and a probability of audit. The certifier can either be self-interested and maximize their profit or be captured by the industry and maximize the monopolist's expected profit. I show that, when possible, the for-profit certifier does not audit and sets a high certification fee so as to capture all the monopolist's surplus. On the contrary, a certifier defending the industry always audits and sets a lower certification fee.

Keywords: *Asymmetric information, third-party certification, middleman, quality labels, price signaling.*

JEL Classification: D82, L12, L15.

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Introduction

MOTIVATION. Pesticide content of an apple, genetic modifications of cereals, use of child labor, animal welfare and geographical origin are all examples of *credence attributes*. These are attributes of products whose quality cannot be evaluated by the buyers, even after repeated purchases.¹ To bypass this asymmetry of information and inform buyers about the environmental impact, food safety and labor conditions along the supply chain, providers can try to obtain a certification for their products. Certification can be defined as a procedure, usually in the form of an audit, by which a third party gives a written assurance that a product, process or service is in conformity with certain standards. Standards are criteria concerning characteristics of products or the way they are made. They may concern environmental, organic, social or normative criteria (Liu (2003)).

Certification can be used for business-to-business (B2B) purposes, which is the case of the certification for standards SA800 for social performance, EUREPGAP for fruits and vegetables or IFS for food product safety and quality issues.² Recently, however, certification has been increasingly used for business-to-consumer purposes (Gruère (2013)). In this case, it generally leads to an on-product label that signals compliance to the specific standards. While certification can be seen as a form of communication between seller and buyer, a label is a form of communication with the end consumer (Jahn, Schramm, and Spiller (2004)). One example is the FSC label (Forest Stewardship Council) that shows the product has been certified against some sustainability standards. Producers can use certification on their own initiative to create a market advantage. They can also use it to respond to pressure from investors, demands from B2B buyers or even from insurers who view certification as a risk-reduction tool (Klintman (2016)).

The organization performing the certification is often a third-party certifier, an entity independent from the supplier and the buyer. The independence of the monitoring process gives credibility to the certification (Jahn, Schramm, and Spiller (2005)). Certifiers are generally private and for-profit entities but can also be related to the industry.³

¹The classical information economics typology is search, experience and credence attributes.

²For more details on the examples see SA800, EUREPGAP Fruit and Vegetables and IFS.

³A certifier related to the industry can either be an industry association, such as the European Retailers Produce Working Group (EUREP), or an entity that comprises of several stakeholders some of whom defend the industry interests such as the Certipaq created by professionals in the agriculture field. Notice that the certifier can also be public in some cases.

Most of the time, certifiers verify compliance with standards decided by standard setting organizations. These organizations may be governments, nonprofits or private entities. In order to increase the credibility of their standards, they delegate the certification to an independent third party. Though it is less common, some certifiers create their own standard but, in this paper, I mainly focus on those that do not.⁴

In that respect, it is interesting to see that different certifiers do not verify the same standards. For instance, in organic agriculture there are several labels and each of them corresponds to a different standard.⁵ Ordering them by stringency of the standard, from the lowest to the highest, one obtains: Agriculture Biologique, Biocoherence and Demeter. One can observe that, the certifier Certis only offers certification for Agriculture Biologique while Certipaq and Ecocert do it for all three. Furthermore, one can observe that, for the same standard, certifiers propose different fees.⁶ According to [Pacini and Assunção \(2011\)](#) “In order to stimulate smaller sellers to participate as members in certification schemes, most of them have adopted differentiated pricing levels”.⁷ These discrepancies in the services proposed by certifiers raise the following questions: What is the certifier’s strategy? Which standards do they certify and at which price? These questions motivate this work.

CONTRIBUTION. My goal is to model the certifier’s choice to better understand the diversity of the certification schemes and, in particular, two characteristics: the fees and the range of quality levels to be certified. To that end, I consider a monopolist that can either buy a certification or use price to signal the quality of their good. I explore two potential causes for the variety of certification schemes — the structure of audit costs and the certifier’s motivations — in two different settings.

⁴ For instance, the European Retailers Produce Working Group is an industry association composed of 22 large-scale retail chains in Europe has created their own standards for agricultural practices. Also some for-profit certifiers, such as EFSIS in the field of food safety or Greencircle in sustainability, developed standards of their own.

⁵On the multiplicity of labels see [Fischer and Lyon \(2014\)](#).

⁶Note that direct comparison between final prices are difficult. This comes from the fact that, different certifiers propose different fee systems and that, for many certifiers, quotations are only available on demand. For instance, for organic agriculture in Europe, the costs of certification with Ecocert include verification fees and additional fees based on the number of acres or animals (to give an idea, for wild crops below 20 acres, Ecocert certification costs around \$1000). Other certifiers, such as Certipaq Bio, Bureau veritas, Certisud, Certis, ask for a fixed membership fee or fees that vary with the complexity and/or the scope of the certification.

⁷See also [Vitalis \(2002\)](#) for examples of eco-label certification fees. Note that, in some rare cases, the certification may be free and audit costs are indirectly paid by the public through taxes.

In the first part of this paper, I consider a continuum of quality level and an exogenous certification. In that scenario, I investigate how the structure of audit costs affect the monopolist' decision to certify. Audit costs, usually represents the biggest costs for the certifier. They may be of different types depending on the scale and the complexity of the certification. In this paper I consider three of these types. In the first one, audit costs are *constant*. This happens when the main costs are independent of the audited quantity and quality level. In the second case, the certifier faces costs that *increase with quantity*, with per-unit costs for every unit of good audited. This occurs when auditing more products takes significantly more time, material or labor. In the third case, the certifier incurs audit costs that *increase with quality level*. This happens when evaluating higher quality levels is complex and requires higher and more expensive expertise.⁸ In my model, I therefore consider three different types of certification fee assuming that they reflect the three different audit cost structures previously mentioned. My *main prediction* in that part is that, the structure of audit costs determines which types of monopolist will signal and which types will get a certification. Indeed, the monopolist chooses certification only if its *net surplus*, namely the difference between its full information profit net of certification fee and its signaling profit is positive. With *constant* certification fee, this difference increases with quality. This implies that, for a well chosen fee, there is a threshold above which any quality level obtains a net positive surplus and will therefore certify rather than signal. I then consider certification fee that *increases with the quality level*. I show that, in this case, the types of monopolist that chooses certification is not necessarily an interval of high quality levels anymore. This comes from the fact that the *net surplus* does not necessarily increase with quality level. In particular, I show that when there are several quality thresholds for which the net surplus is worth zero, the types of monopolist that selects the certification may be on one or several intervals of *intermediate* quality levels. I lastly examine *per-unit* certification fees and show that it is a sub-case of the scenario in which certification fees increase with quality level.

In the second part of the paper, I examine two quality levels, low and high, and the certification is endogenous offered by a strategic certifier. In that scenario, I analyze how the objective of the certifier affects the certification fee and the probability of audit. I con-

⁸In reality, the certifier may incur at the same time constant, per-unit and increasing costs. In the present paper, I analyze each case separately. This allows us to compare how each cost structure affects the mechanism offered by the certifier.

siderer two types of certifier: a *private* one that is profit-driven and one *from the industry* that maximizes that industry expected profit. To my knowledge, I am the first to model endogenous certification in a context in which the firm chooses between two disclosure strategies: certification and price signaling. In my model, the certifier proposes a certification contract to the monopolist on a take-it-or-leave-it basis. That contract entails a certification fee and a probability of audit; the certifier pays a constant cost whenever they audit. When the monopolist refuses the contract, the monopolist reservation allocation takes place. I assume that this reservation allocation is the least costly separating outcome. I first characterize the existence of incentive-compatible allocations that weakly Pareto dominate this reservation allocation. I find that, when the gain to reveal information for the high quality level is higher than the gain to lie for the low quality level, an incentive-compatible certification always exists, no matter the size of the audit costs. Conversely, if this gain to lie is higher than the gain to reveal information, the existence of the certification depends on the size of the audit costs. When these are too high, auditing to prevent the monopolist from lying is too costly for the certifier and there is no certification that could honestly reveal quality level. I then derive the separating certification contract offered to a high quality level as a function of the certifier's objective. A *for-profit* certifier that maximizes their profit, sets the fee as high as possible while minimizing the probability of audit. I show that, in some cases, the for-profit certifier does *not audit* and captures *all* the monopolist surplus. This contract still respects the incentives because for a high enough fee, the low quality level has no interest in lying. Yet, in some other cases, the certifier is forced to audit with a positive probability and to let some surplus to the high quality level, otherwise the low quality level lies. They trade off the capture of the high quality level's surplus with the providing of a contract that respects incentives. Alternatively, a certifier that maximizes the expected *profit of the industry* tries to minimize the fee. They nevertheless need to cover their audit costs and make the high quality level pay enough so that low quality level does not lie. In this case, there is a tension between minimizing the cost for the industry and providing a credible and feasible certification. They select a *lower fee* and a *higher probability of audit* than a for-profit certifier.

Finally, as a extension with a continuum of quality levels, I study the strategy of the certifier that creates their *own* standard. I consider a particular environment in which there is a unique binary standard revealing that the quality level is above a certain threshold. I

further assume that the monopolist also uses price to signal quality within the interval of certified quality levels. I show that, in many cases, if the monopolist *simultaneously* uses certification and price signaling, there is no potential gain from certification because the sum of the certification and the signaling costs is too high. In these cases, the certifier cannot create their own standard.

For the sake of tractability, I make some simplifying assumptions. First, I assume that the quality level is exogenous. I thereby focus on the problem of asymmetry of information and overlook any moral-hazard issue.⁹ This corresponds to scenario in which it is difficult for a firm to modify the production technology because it is too costly, takes a long time or requires skills that are not available. For instance, in agriculture, replacing the use of pesticides by natural products may take several years. Second, I assume that the industry is composed of a monopoly. Despite the absence of competitors, a firm may still want to reveal information to consumers.¹⁰ This could either refer to one firm with significant market power or several firms in collusion. This assumption allows my model to support an important feature: when the monopolist does not use certification, they signal through price. If I were to assume perfect competition, firms could not use price signaling as an outside option. Alternatively, assuming imperfect competition would allow price signaling but at the cost of higher model complexity.¹¹ It follows that the effect of certification on competition is out of the scope of this paper.¹² The third assumption is that there is one certifier facing no competition. My primary goal is to focus on the strategy of one certifier as a function of their motivation and their cost. In reality, the nature of the competition between certifiers cannot be easily ascertained because, among other reasons, the number of certifiers varies between standards.¹³ In this paper, I actually show how audit costs could influence that number. Several other factors can potentially reduce competition between certifiers such as geographical barriers and the requirement for accreditation. This indicates that the degree of competition between certifiers may vary significantly. It is hence

⁹On the way certification modifies incentives for seller to provide high quality level goods see for instance [Albano and Lizzeri \(2001\)](#).

¹⁰See for instance [Crespi and Marette \(2001\)](#) and [Auriol, Schilizzi, et al. \(2003\)](#) for papers that study the interplay between certification and firms' competition.

¹¹See for instance [Daughety and Reinganum \(2007\)](#) and [Janssen and Roy \(2014\)](#) for environment with imperfect competition with signaling and disclosure.

¹²See [Auriol, Schilizzi, et al. \(2003\)](#) or [Crespi and Marette \(2001\)](#) on the impact of certification costs on market structure.

¹³The standards and labels widely used, such as the label FSC or MSC, have generally many [certifiers](#). The situation differs for labels, such as the organic label Bourgeon Suisse, that has only two or [three certifiers](#).

not at odds with reality to assume that a certifier has some market power and capacity to capture the disclosure surplus. I study an extreme case in which one certifier has all the market power. Finally, I gloss over the possibility of misleading certification by assuming that any information disclosed by the certifier is true and observed by consumers.¹⁴ I am aware that in reality the rapid growth of certification and the lack of structure render fraud likely to occur (Jahn, Schramm, and Spiller (2005)).¹⁵ Nevertheless and though this is a central concern, there are also reasons for considering that certification is to some extent reliable. First, certifiers are not let without any control. They have to be accredited before carrying out the certification.¹⁶ Also, some informational schemes include additional monitoring realized by the standard owner or by a control body involving private institutions or public authorities (Jahn, Schramm, and Spiller (2005)). Finally, the fear to lose reputation and to be condemned by the law for falsification may be strong enough to prevent certifiers from lying.¹⁷

RELATED LITERATURE. When sellers want to credibly reveal information about the quality of their product, they may try to obtain a third-party certification. Certification differs from pure voluntary disclosure in that sellers do not disclose information directly to consumers but through a *middleman*: the certifier.¹⁸ Following the seminal paper of Rubinstein and Wolinsky (1987), a literature focused on middleman as a *strategic* intermediary between sellers and uninformed consumers. In particular, Lizzeri (1999) studies the strategy of that middleman in a monopoly and in an environment of pure adverse selection. He shows that, due to their strategic position, for some consumers' beliefs, the monopolist

¹⁴A strand of that literature examines the incentives for a strategic certifier to lie about the information revealed. In particular, Mahenc (2017) investigates the possibility of fraudulent labeling. Assuming that the certifier maximizes a weighted sum of their revenue and the social welfare, he proves that, if this certifier is solely concerned by making profit and not enough by social welfare, certification cannot be honest. For an empirical analysis of the quality of third-party auditors see Duflo, Greenstone, Pande, and Ryan (2013).

¹⁵Cases of confirmed fraud are numerous, see examples in Auriol, Schilizzi, et al. (2003) and Crespi and Marette (2001)

¹⁶A governmental or a parastatal institute evaluates compliance with the guidelines set by the ISO (International Organization for Standardization), the European Union or some other inspection body (Liu (2003)). For instance, in the European Union, to be able to evaluate organic product, they must be controlled by institutes such as the COFRAC (organisme français d'accréditation) and INAO (institut national de l'origine et de la qualité) in France (see Européenne (2007)). However, for Jahn, Schramm, and Spiller (2005), accreditation is mostly a formal procedure that does not include any supervision of how certifications are made.

¹⁷For instance in France the delivery of false document is punished by the penal code.

¹⁸See Dranove and Jin (2010), Guerra (2001) and Prag, Lyon, and Russillo (2016) for a comprehensive theoretical and empirical review on certification and quality disclosure.

always goes to the middleman independently from the information they disclose to consumers. This implies that, the middleman can capture all the surplus without revealing any information. Competition between middlemen may however prevent the capture of surplus and the absence of information revelation.¹⁹ I contribute to this literature on the middleman by considering a strategic certifier that makes a take-it-or-leave-it offer to a monopolist. I however depart from the previously mentioned papers in one main feature: I consider that this monopolist has the *choice* between two forms of communication with consumers: either disclosure through certification offered by a middleman or signaling with price.²⁰ In this, my approach is closely related to [Daughety and Reinganum \(2008a\)](#). They study a monopolist that can either use price to signal quality or disclose by paying a fixed fee. Disclosure perfectly reveals quality and is truthful. In this context, they show that the certifier reveals information and, for a well chosen fee, any type of monopolist whose quality level is above a certain threshold will disclose. As a first pass, I study the same setting as [Daughety and Reinganum \(2008a\)](#) but I differ in assuming that disclosure requires a fee that may increase with quality level. I show how this affects the types of monopolist that disclose and thereby qualify their result by showing that, in some cases, an interval of intermediate – not high — quality levels disclose. In the second part of the paper, I consider a different setting. The monopolist first decides whether to disclose or not then sets price. This means that, contrary to [Daughety and Reinganum \(2008a\)](#), the price signal is chosen after the contract is signed. That raises the question of how consumers react when they simultaneously observe price and certification signals. That framework allows us to go one step further by endogenizing the disclosure strategy.

Also, in one of the scenario I examine, the certifier defends the interest of the monopolist. In that, the certification I derived seems linked to the one that would emerge if there was a collusion between the monopolist and the certifier. My model however differ in that, the certifier is a middleman that does not observe the information about the quality level of the monopolist before auditing and that cannot decide for the output price. They thereby embody an entity — independent from the monopolist — but that is either under its influenced or that has aligned interest. In the contracting literature related to quality

¹⁹See [Biglaiser and Li \(2018\)](#) and [Albano and Lizzeri \(2001\)](#) that study how the presence of a middleman affects seller's moral hazard problem.

²⁰For price signaling I rely on [Mailath \(1987\)](#) for a continuum and [Bagwell and Riordan \(1991\)](#) for two quality levels. Other works analyze price signaling in a monopoly in richer environments, among which: [Milgrom and Roberts \(1986\)](#), [Daughety and Reinganum \(1995\)](#) and [Mahenc \(2008\)](#).

verification, DeMarzo, Fishman, and Hagerty (2005) study the role of a self-regulatory organization (SRO) in enforcing anti-fraud rules. My paper presents some resemblance since their SRO is similar to my certifier from the industry. Both maximize the industry expected profit, face audit costs and offer enforcement policy. However there are some noticeable differences. First, in their model, the SRO chooses an enforcement policy, then customer and agent negotiate a contract. In the present model, I consider a more basic setting in which there is only a contract between the certifier and the monopolist. Second, they consider several agents in competition to offer contracts to customers while I consider a monopolist. Third, in their model, when the enforcement or contract fails, the reservation pay-off of the agent is zero while in the present model, the monopolist gets a type-dependent reservation outcome that is the least-costly separating outcome.

ORGANIZATION OF THE PAPER. Section 2.1 presents the model as well as two relevant benchmarks: full information equilibrium and separating equilibrium with price signaling. Section 2.2 investigates the decision of a monopolist that chooses between price signaling and an exogenous costly certification with a continuum of quality levels. Section 2.3 analyzes, with two quality levels, the endogenous certification mechanism offered by a strategic certifier. Finally, in Section 2.4, as an extension, I discuss the feasibility of a certification when the certifier creates their own standard. Proofs are relegated to an Appendix.

2.1. Model and Benchmarks

MONOPOLY. There is a single firm selling in this market. The firm produces one unit of a good of quality level θ at a linear cost that increases with quality $C(\theta) = \theta$ and sells this unit on the market at price p . I assume that for each quality level θ there is a corresponding standard.²¹

BUYERS. There is a continuum of heterogeneous consumers of mass one in this economy. Each consumer buys one unit of good. Goods are vertically differentiated. All consumers prefer higher quality level and lower prices. A consumer has the following indirect utility

²¹As explained in the introduction, certification verifies compliance to a standard. I do not model the choice of these standards, so I can use the concepts of standard and quality level interchangeably in the rest of the paper.

from purchasing a good of quality level θ :

$$v(\theta) - p + \varepsilon.$$

The quality θ is independently drawn from the common knowledge cumulative distribution $G(\cdot)$ with compact support $\Theta = [\underline{\theta}, \bar{\theta}]$, $v(\theta)$ is the common valuation for a good of quality level θ with a derivative $\dot{v}(\theta) > 0$ and ε is a consumer's specific parameter. Consumers' taste parameters ε are independently drawn from the same common knowledge cumulative distribution $F(\cdot)$ with compact support $[\underline{\varepsilon}, \bar{\varepsilon}]$. Consumers' aggregate demand is:

$$1 - F(p - v(\theta)).$$

Finally, I make assumptions that will be maintained throughout the paper.

Assumption 2. $\frac{d}{d\varepsilon} \left(\frac{1-F(\varepsilon)}{f(\varepsilon)} \right) \leq 0, \forall \varepsilon \in [\underline{\varepsilon}, \bar{\varepsilon}]$.

Assumption 3. $v(\theta) \geq \theta, \forall \theta \in \Theta$.

Assumption 1 is a monotonicity condition that should hold for technical reasons. Assumption 2 implies that for each quality level θ consumers' common valuation is larger than its production cost.

2.1.1. Full information equilibrium

When consumers can observe the quality level, the monopolist sets the price so as to maximize their profit, i.e., such as:

$$p^m(\theta) = \arg \max_p (p - \theta) (1 - F(p - v(\theta))).$$

The full information monopoly price is:

$$p^m(\theta) = \theta + \frac{1 - F}{f} (p^m(\theta) - v(\theta)). \quad (2.1)$$

Taking the derivative of (2.1) with respect to quality level, I obtain that the full information price increases with the quality level θ :

$$\dot{p}^m(\theta) = \frac{1 - \dot{v}(\theta) \left(\frac{1-F}{f}\right)' (p^m(\theta) - v(\theta))}{1 - \left(\frac{1-F}{f}\right)' (p^m(\theta) - v(\theta))} \geq 0. \quad (2.2)$$

2.1.2. Signaling equilibrium

Assume now that consumers can no longer observe the quality level θ . I make an assumption that will hold throughout the paper.

Assumption 4. $\frac{F^{-1}(1)}{v(\underline{\theta})} > \bar{\theta}$.

Assumption 3 implies that there is a price in the interval $[\underline{\theta}, \frac{F^{-1}(1)}{v(\underline{\theta})}]$ at which any type of quality level will have a positive demand and a positive price-cost margin.²² This guarantees that any quality level, even when it is misperceived by consumers as the lowest quality level, can make positive profits.

I look for perfect Bayesian-Nash equilibrium in which the monopolist sets their price so as to signal quality level to uninformed consumers. After learning their quality level θ , the seller posts a price p , consumers observe the price, update their beliefs about the quality level, decide whether to buy or not and exchange takes place. Several kinds of perfect Bayesian-Nash equilibrium can occur in signaling games: separating, pooling, or semi-separating. I am interested in the separating equilibrium in which the price chosen by the monopolist differs for every quality level. Consumers observe the signaling price $p^s(\theta)$ and can infer the quality level θ . At the separating equilibrium, a monopolist whose quality level is θ has no incentive to deviate from $p^s(\theta)$ and choose another price $p^s(\hat{\theta})$, $\hat{\theta} \neq \theta$. This implies that the following incentive-compatibility condition must be respected:

$$p^s(\theta) = \arg \max_{\hat{\theta} \in [\underline{\theta}, \bar{\theta}]} \left(p(\hat{\theta}) - \theta \right) \left(1 - F \left(p(\hat{\theta}) - v(\hat{\theta}) \right) \right) \quad (2.3)$$

where θ the monopolist's true quality level and $\hat{\theta}$ the consumers' inference about quality level.

²²Notice that to obtain that expression I must have $F(\cdot)$ strictly monotonic on $[\underline{\varepsilon}, \bar{\varepsilon}]$ and $\bar{\varepsilon} \geq 1 \geq \underline{\varepsilon}$.

Proposition 6. *In the separating equilibrium, incentive compatibility implies a signaling price $p^s(\theta)$ such that:*

$$\dot{p}^s(\theta) = \frac{\dot{v}(\theta)}{1 - \frac{1}{p^s(\theta) - \theta} \frac{1-F}{f} (p^s(\theta) - v(\theta))} \quad (2.4)$$

and

$$\dot{p}^s(\theta) \geq \dot{v}(\theta). \quad (2.5)$$

Incentive compatibility defines the signaling price through a differential equation and tells us that it increases faster than consumers' valuation with the quality level.

Necessary and sufficient conditions required for the existence of a separating equilibrium, as defined by Mailath (1987) are respected.²³ In addition, Mailath (1987) shows that if the price respects both the differential equation from incentive compatibility (as defined in Proposition 6) and the following initial value condition:

$$p^s(\underline{\theta}) = p^m(\underline{\theta}). \quad (2.6)$$

there is a unique separating perfect Bayesian equilibrium.²⁴ At the equilibrium, this initial value condition (2.6) tells us that the lowest quality level charges a signaling price that is equal to the full information price.²⁵ In addition, at the equilibrium, for higher levels of quality, the signaling price is higher than the full information price, i.e. $\dot{p}^s(\theta) > \dot{p}^m(\theta)$, $\forall \theta \in]\underline{\theta}, \bar{\theta}]$. The monopolist distorts their price upward to signal higher quality level. This distortion reduces their profit with respect to the full information equilibrium. This profit reduction is what is called *signaling costs*.

2.2. Signaling versus exogenous costly disclosure

We first consider a similar setting as Daughety and Reinganum (2008a). A monopolist simultaneously chooses between two options: either paying for a certification or signaling its quality level with price. The certification consists in a fee $K(\theta)$ and reveals the exact

²³See these conditions in Appendix.

²⁴See Mailath (1987) Corollary of Theorem 2. See also Daughety and Reinganum (2008a) and Mahenc (2008).

²⁵The idea of this equilibrium condition is that both when $p^m(\underline{\theta})$ is on the equilibrium path (i.e. $p^m(\underline{\theta}) \in p^s([\underline{\theta}, \bar{\theta}])$) and when $p^m(\underline{\theta})$ is off the equilibrium path, it is optimal for $\underline{\theta}$ to select $p^m(\underline{\theta})$. This comes from the fact that, the worst beliefs consumers could hold, both in the equilibrium path and off the equilibrium path, is $\underline{\theta}$.

quality level to consumers. Of importance, I assume that this fee reflects the verification cost incurred by the third-party performing the certification. We consider several structure of fee, reflecting different types of verification cost, and study how this affects the monopolist's choice.

With the certification, the monopolist gets the full information profit minus the fee:

$$\pi^m(\theta) - K(\theta) = (p^m(\theta) - \theta) (1 - F(p^m(\theta) - v(\theta))) - K(\theta), \forall \theta \in [\underline{\theta}, \bar{\theta}]. \quad (2.7)$$

Using the envelop theorem, (2.1), and noting $\dot{K}(\theta)$ the derivative of the certification fee, the derivative of (2.7) with respect to quality level writes:

$$\dot{\pi}^m(\theta) - \dot{K}(\theta) = (1 - F(p^m(\theta) - v(\theta))) (v(\theta) - 1) - \dot{K}(\theta). \quad (2.8)$$

Notice that the monopolist' profit under full information $\dot{\pi}^m(\theta)$ increases with the quality level. Alternatively, if the monopolist does not go to the certifier, they do not pay a fee and get the signaling equilibrium profit. That profit writes:

$$\pi^s(\theta) = \max_{\hat{\theta}} (p^s(\hat{\theta}) - \theta) (1 - F(p^s(\hat{\theta}) - v(\hat{\theta}))), \forall \theta \in [\underline{\theta}, \bar{\theta}].$$

Using the envelop theorem to differentiate with respect to θ , I obtain:

$$\dot{\pi}^s(\theta) = -(1 - F(p^s(\theta) - v(\theta))) < 0. \quad (2.9)$$

This signaling profit strictly decreases with the quality level. Indeed, from Assumption 3, there always exist a price at which the demand is positive, it is therefore the case with the equilibrium price. This means that, as quality level increases, it becomes more costly to signal quality level through price.

Now, I define the profit difference between full information profit and signaling as:

$$\Delta\Pi(\theta) = \pi^m(\theta) - \pi^s(\theta).$$

From (2.8) and (2.9) I know that the full information and the signaling profits are both monotonic with quality level and their derivative have opposite signs. This means that the quality level adversely affects profits under full information and signaling: for the former,

it increases profits and for the latter, it reduces profits. As a result, the profit difference increases with the quality level, i.e. $\Delta\dot{\Pi}(\theta) > 0$. If the disclosure was free, the lowest quality level $\underline{\theta}$ would be indifferent between signaling and certification while all the other quality levels such as $\theta > \underline{\theta}$ would certify. When disclosure costs $K(\theta)$, the monopolist of type θ goes to the certifier only if the profit difference between full information and signaling is big enough to offset the certification fee, i.e. only if $\Delta\Pi(\theta) \geq K(\theta)$.

Constant certification fee

We first consider the case in which the certification fee is the same for every quality level, as in [Daughety and Reinganum \(2008a\)](#). This reflects cases in which the verification cost is the same independently from the quality level and the quantity verified. When the certification fee is fixed, i.e. $K(\theta) = K, \forall \theta \in [\underline{\theta}, \bar{\theta}]$, the monopolist chooses the certification only if $\Delta\Pi(\theta) \geq K$. Because $\Delta\dot{\Pi}(\theta) \geq 0$, for a well chosen fee, there is a quality threshold above which the monopolist always goes to the certifier. Indeed, if the certification fee is such that: $\Delta\Pi(\bar{\theta}) \geq K \geq \Delta\Pi(\underline{\theta})$, there is a unique $\theta^* \in [\underline{\theta}, \bar{\theta}]$ such that: $\Delta\Pi(\theta^*) = K$. Depending on the quality level, the monopolist has different strategies: for low quality levels, the monopolist signals their quality level through a costly price distortion and for high quality levels, the monopolist pays for the certification. This is the main result from [Daughety and Reinganum \(2008a\)](#). We will now study how this result is affected by assuming that the certification fee may vary with the quality level.

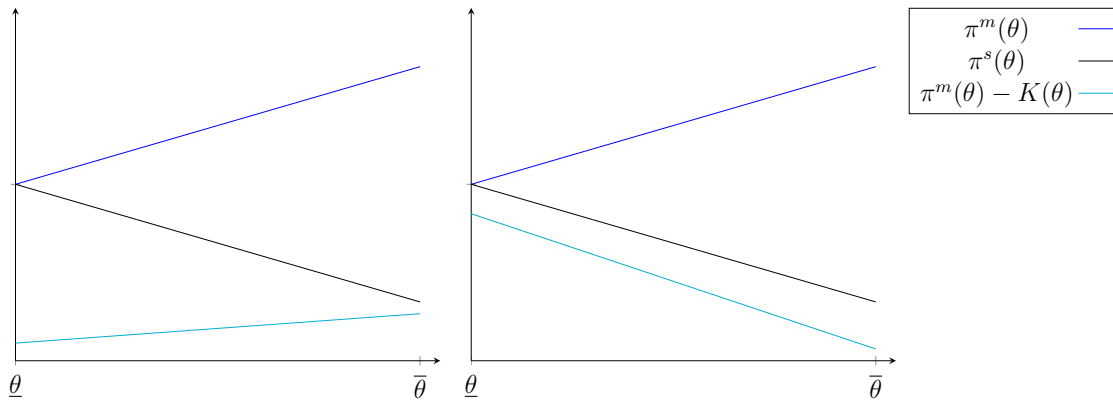
Certification fee increasing with quality level

We now consider a more general case in which the certification fee increases with the quality level, i.e. $\dot{K}(\theta) \geq 0$. Implicit is the idea that a better quality requires a more costly expertise to be verified by a third-party and that this reflects in the certification fee.

When the certification fee increases with the quality level, the net surplus the monopolist gets from certification $\pi^m(\theta) - K(\theta) - \pi^s(\theta)$ is not necessarily increasing with quality level anymore; it may be a decreasing or a non-monotonic function of quality level. If the certification fee is too high and/or increases too fast with the quality level, the monopolist will always prefer to signal. The next graphs illustrate two different scenario in which this is the case, i.e. $\pi^m(\theta) - K(\theta) < \pi^s(\theta), \forall \theta \in [\underline{\theta}, \bar{\theta}]$. In case a., the profit from certification

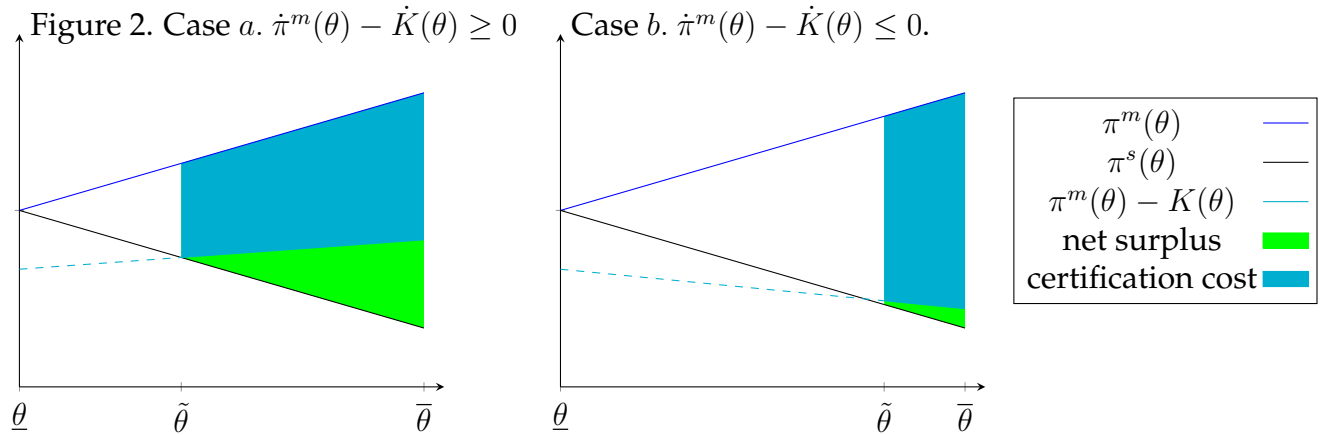
net of certification fee is increasing with quality level but the monopolist whatever their type still obtain a better profit with signaling. In case b., the profit from certification net of certification fee decreases with the quality level because the marginal increase of the certification fee is higher than the marginal increase of the full information profit.

Figure 1. Case a. $\dot{\pi}^m(\theta) - \dot{K}(\theta) \geq 0$. Case b. $\dot{\pi}^m(\theta) - \dot{K}(\theta) \leq 0$.



In both scenario, there is no intersection between the full information profit net of certification fee and the signaling profit function. For at least some types of monopolist to choose disclosure, there must be at least one crossing between the full information profit net of certification fee and the signaling profit. In what follows, I examine different cases according to the number of crossings between the full information profit net of certification fee and the signaling profit or, in other words, the number of times the net surplus is worth zero.

SINGLE CROSSING. First, there can be a single crossing between the full information profit net of certification fees and the signaling profit. This can happen when the full information profit net of certification fee increases with quality level (case a. in the graph above), but it may also happen when the full information profit net of certification fee decreases with quality (case b. in the graph above). In the latter case, the full information profit net of certification fee decreases less fast with quality level than the signaling profit making. As explained in the next Proposition, in both cases, after a certain threshold of quality level, the monopolist chooses the certification as they get a net surplus.



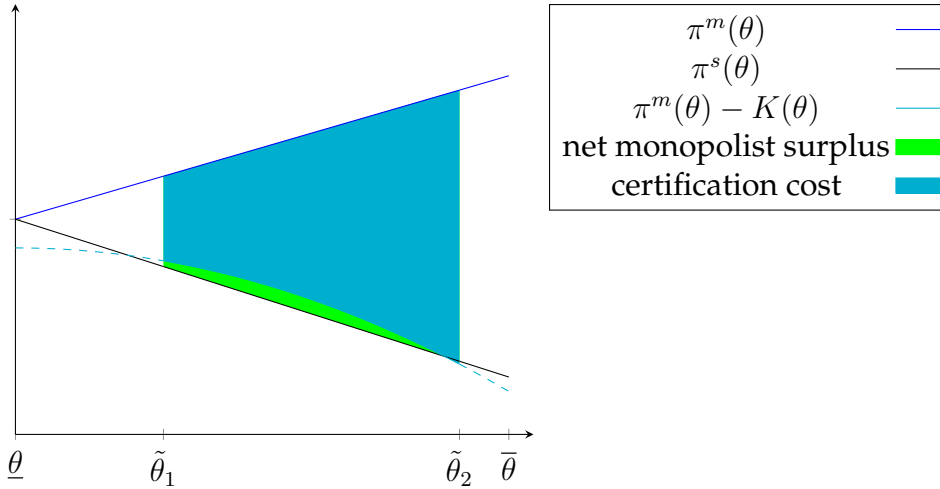
Proposition 7. *If there is a unique $\tilde{\theta} \in]\underline{\theta}, \bar{\theta}[$ such that: $\pi^m(\tilde{\theta}) - \pi^s(\tilde{\theta}) = K(\tilde{\theta})$, any monopolist whose quality level is under the threshold $\tilde{\theta}$ uses price to signal while any monopolist whose level is above this threshold discloses with certification.*

This scenario is very similar to the case in which the certification fee is fixed and the intuition are the same. In both cases, monopolist with a high-quality type will disclose with certification while a low-quality type will signal.²⁶

MULTIPLE CROSSINGS. Alternatively, there can be multiple crossings between the full information profit net of certification fee and the signaling profit. For clarity of exposition, I examine a scenario in which there are two crossings but the reasoning could be extended to multiple crossings. For instance, this scenario may happen when the full information profit net of certification fee, i.e. $\pi^m(\theta) - K(\theta)$, is increasing then decreasing or when it is decreasing and concave (see the graph above for an illustration).

²⁶In the present graphs, case a. (respectively case b.) the function $\pi^m(\theta) - c(\theta)$ is represented as linear increasing (resp. linear decreasing). The intuition is exactly the same for an increasing and convex function (resp. decreasing and concave function).

Figure 3. Double crossing.



Proposition 8. *If there are two quality levels $\tilde{\theta}_1 \in]\underline{\theta}, \bar{\theta}[$ and $\tilde{\theta}_2 \in]\underline{\theta}, \bar{\theta}[$ with $\tilde{\theta}_1 < \tilde{\theta}_2$ such that: $\pi^m(\theta) - \pi^s(\theta) = K(\theta)$ is true for both $\theta = \tilde{\theta}_1$ and $\theta = \tilde{\theta}_2$, a monopolist whose quality level is in the interval $[\tilde{\theta}_1, \tilde{\theta}_2]$ will pay for the certification, a monopolist whose quality level is either in the low interval $[\underline{\theta}, \tilde{\theta}_1[$ or the high interval $]\tilde{\theta}_2, \bar{\theta}[$ will signal with price.*

This proposition directly results from the fact that the monopolist gets a net surplus with certification only when its quality level is in the interval $[\tilde{\theta}_1, \tilde{\theta}_2]$.²⁷ This result differs with [Daughety and Reinganum \(2008a\)](#) in the interval of quality levels choosing a costly disclosure over price signaling. With a certification fee that increases with quality level, the monopolist that chooses the certification may not have its quality level in the high interval. In particular, this might happen when the certification fee reflects the cost of verification that is increasing with the quality level.

REMARK. Alternatively, the monopolist may have to pay fixed per-unit certification fee K . This may reflect the case in which the third-party certifier incurs verification cost that depends on the quantity of good verified. In this scenario, the monopolist pays an amount that corresponds to the demand multiplied by the fixed per-unit cost K , namely:

$$K(1 - F(p^m(\theta) - v(\theta))).$$

²⁷This is assuming that when the monopolist is indifferent between the certification and signaling they will certify.

The derivative of this cost with respect to the quality level

$$-K (\dot{p}^m(\theta) - \dot{v}(\theta)) f(p^m(\theta) - v(\theta))$$

is positive.²⁸ This implies that the cost of certification increases with the quality level. This comes from the fact that demand increases with the quality level. We can therefore conclude that, in the present model the case of per-unit certification fee is in fact a special case of certification fee that increases with the quality level. The choice of the monopolist has therefore the same characteristics as the one described above. \square

2.3. Signaling versus endogenous certification with two quality levels

In the previous section, the certification was exogenous and the monopolist was simultaneously choosing between certification and signaling. We now turn to a different setting in which the certification is endogenous decided by a strategic middleman and the monopolist first chooses whether to accept this certification before deciding which price to set. To that end, I consider a non-cooperative game between a strategic certifier (the principal) and the monopolist (the agent).

CERTIFIER. The certifier is assumed to have the power to propose a contract to the monopolist on a take-it-or-leave-it basis. The contract consists in a fixed certification fee and a probability of being audited. The certifier does not observe the true quality level of the monopolist unless it audits. When the certifier audits, they incur a fixed verification cost of c .

CONSUMERS. In my model, consumers do not observe whether the monopolist try to obtain a certification nor the contract between the certifier and the monopolist. Consumers however observe the certification outcome, if any, and the price. We make a particular assumption about consumers' beliefs: when they observe a certification outcome, they trust it and ignore any information coming from price. However, when there do not observe a certification outcome, they infer quality level from price.

²⁸Using the fact that $\dot{v}(\theta) \geq \dot{p}^m(\theta)$.

REMARK. There is not a consensus in the literature about how consumers update their beliefs when they face multi-signal. In my case, several options could have been considered for how consumers use information coming from the price and the outcome of the certification. First, consumers may take into account both signals and consider that there are dependent. This corresponds to cases in which consumers are receptive to the two signals and understand the link between the two. In this case, the beliefs update after observing first the certification signal and second the price signal would follow a two-stages process as it has been explored by Daley and Green (2014). This would however raise the issue of some redundancy of information because both signals convey similar information. Daley and Green (2014) show that for this reason it most likely to obtain a pooling equilibrium. Alternatively, consumers may take into account both signals but consider that there are independent. This corresponds to cases in which consumers are receptive to the two signals but do not see the link between certification outcome and the price (maybe because they have limited comprehension). In this case, the information released through price does not influence that released by the certification. The two events “the firm’s quality is low or high conditional on observing prices” and “the firm’s quality is low or high conditional on the certification outcome” are both independent and mutually non-exclusive. At the separating equilibrium, the two signals should coincide with the true quality level. The more complex issue would be to define the beliefs out of the equilibrium when the two signals do not coincide. Finally, consumers may take into account only one signal. We choose that last option that corresponds to cases in which consumers either have a strong preference for one type of signal or are not able to treat more than one signal due to limited attention or information processing capacity. In my model, when consumers observe two signals, certification outcome and price, the use only the former. One can justify this approach because in reality the certification outcome could be simpler to interpret than prices that may reflect more than just the quality level.²⁹ □

TIMING. First, nature independently draws the quality level (or type) θ of the monopolist from a commonly known distribution that assigns probability λ and $1 - \lambda$ to high quality level $\bar{\theta}$ and low quality level $\underline{\theta}$ respectively. This quality level is observed only by the monopolist and not by the certifier nor the consumers. Next, the certifier proposes a menu of contracts to the monopolist that specify a fixed certification fee and a probability of being

²⁹Even though I do not model it, prices may vary with time following seasons, sales, . . .

audited. The monopolist accepts or rejects the contract in accordance with their type. The contract is executed if accepted; otherwise, the monopolist's reservation allocation takes effect. It follows that the monopolist accepts the contract if and only if its expected utility exceeds the reservation outcome. When the contract is accepted, the certifier audits according to the probability in the contract. If a lie is detected, the certifier does not reveal information to consumers and the monopolist gets its reservation allocation. If no lie is detected, the certifier communicates perfectly to all consumers the quality level associated with the contract chosen by the monopolist. In the third stage, the monopolist sets their price. In the last stage, consumers observe the outcome from certification, if any, and the price; they revise their beliefs and make their purchasing decisions.

MONOPOLIST' RESERVATION ALLOCATION. We assume that the reservation outcome corresponds to the the least costly separating equilibrium outcome, also called the Riley separating equilibrium outcome (Riley (1979)). We note $\pi^r(\underline{\theta})$ and $\pi^r(\bar{\theta})$ the reservation outcome obtained by the the low and high quality levels respectively. As explained above, I assume that when consumers do not observe any certification outcome, they infer quality level from price. This justifies that when the monopolist refuses the contract, they obtain the least costly separating equilibrium outcome. The idea is that when the monopolist does not use certification, they play a signaling game similar to that investigated by Bagwell and Riordan (1991).³⁰ We further assume that the outcome of this game is the separating equilibrium satisfying the intuitive criterion (Cho and Kreps (1987)). At this equilibrium, the high quality distorts its price upward in a way that this distortion causes the minimum loss in profit needed to fully reveal that quality is high. The low quality level does not distort its price with respect to full information and therefore gets the same profit as they would get in a full information. The reservation allocation therefore entail $\pi^m(\bar{\theta}) > \pi^r(\underline{\theta}) = \pi^m(\underline{\theta}) > \pi^r(\bar{\theta})$.³¹

This reservation allocation has important implications in my model. First, the monopolist with a low quality level gets the same profit under price signaling and full information.

³⁰My model is a sub-case of the model of Bagwell and Riordan (1991) in which all consumers are uninformed.

³¹The reservation outcome presents very similar features with the separating outcome with a continuum of types derived in the previous section. With a continuum of types and under the assumptions I made, the separating outcome of the signaling game was unique (Mailath (1987)). With two quality levels, to rule out the presence of multiple equilibria, I follow the common method of employing the intuitive criterion from Cho and Kreps (1987) that imposes additional restrictions on the beliefs held by consumers out of equilibrium.

It follows that, a low quality level would never choose certification unless it is free. Such a certification would be costly for the certifier if it entails a verification and would not reveal more information to consumers than what the reservation outcome already does. For this reason I will focus on the case in which a certifier proposes a certification targeting only the high quality levels.³² Furthermore, the high quality level has no interest in mimicking a low quality level. Indeed, either they accept a certification that provides them with higher profit than the reservation outcome or they refuse the certification and get the reservation outcome from which, by definition of a separating equilibrium that respects the intuitive criterion, they have no interest to deviate. The certifier therefore looks for the certification contract $\{K(\bar{\theta}), q(\bar{\theta})\}$ to offer to the monopolist. If the monopolist accepts it, it is inspected with probability $q(\bar{\theta})$. If no lie is detected or there is no inspection, the certifier announce to consumers that the quality level is $\bar{\theta}$.³³ If a lie is detected, the monopolist gets its reservation utility. In what follows, I use the following notations: $\bar{K} = K(\bar{\theta})$ and $\bar{q} = q(\bar{\theta})$.

EQUILIBRIUM CONCEPT. We look for a perfect Bayesian separating equilibrium in which a high quality level accepts the certification contract and a low quality level refuses it. Consumers trust the certification and believe that the quality level is high as soon as they observe the outcome from certification. In separating equilibria, these beliefs are correct as the fact of having the certification truthfully reveals when the good is of high quality level. For this, the contract $\{\bar{K}, \bar{q}\}$ offered by the certifier and targeted to high quality level must respect incentive and participation constraints. The perfect Bayesian equilibrium consists of strategies — for the certifier and for the monopolist — and beliefs for the consumers. At the equilibrium: the certifier maximizes their objective taking into account consumers' beliefs and anticipating the monopolist strategy, the monopolist chooses first whether to accept or not the contract and second which price to set in a way to maximize their profit taking into account consumers' beliefs and consumers chooses whether to buy or not the good after updating their beliefs. Remark that, when the monopolist refuses the contract, they get the reservation allocation. This implies that the high quality level only accepts the contract if they get a profit higher than their reservation allocation. The equilibrium set of

³²Notice that this often corresponds to the reality in which there is rarely a certification for the lowest quality level. An alternative would have been to consider that the certifier offers a free certification for the low quality level without doing any verification.

³³Notice that with two quality levels, it would be equivalent for the certifier to reveal a quality threshold to consumers.

the certification contract therefore consists in the incentive-feasible allocation that weakly Pareto dominate the reservation allocation. It follows that the least costly separating equilibrium is the lower bound for the Pareto criterion of the set of equilibrium allocations when the certifier proposes a contract.

REMARK. Notice that in my model, the values of the price p is chosen after contracting. This contrasts with the traditional signaling literature (in particular [Spence \(1978\)](#)). My approach follows more the screening literature since a certifier offers a contract targeted to a certain quality level that they do not observe. The price p is nevertheless is not contractually set in the certification mechanism but the monopolist sets it after deciding whether to accept or not the contract proposed by the certifier. \square

INCENTIVE AND PARTICIPATION CONSTRAINTS. First, the contract must respect the participation constraint of the high quality level. At the equilibrium, the monopolist maximizes profit with respect to price, given the beliefs held by consumers after observing the outcome of the certification. A high quality level whose quality level is revealed by the certification sets the full information price $p^m(\bar{\theta})$ and gets the full information profit $\pi^m(\bar{\theta})$. Thus, they choose the certification only if their profit under full information net of certification fee is higher than their reservation outcome, namely:

$$\pi^m(\bar{\theta}) - \bar{K} \geq \pi^r(\bar{\theta}) \quad (2.10)$$

Second, the contract must respect the incentive constraint of the low quality level. If this low quality level accepts the certification contract addressed to the high quality level and is not audited, they can choose any price since consumers do not take into account the price after observing the certification outcome. The low quality level that successfully lies therefore chooses the price that maximizes its profit taking into account that consumers believe they are of high quality level, namely p such as:

$$p^*(\underline{\theta}, \bar{\theta}) = \arg \max_p (p - \underline{\theta}) (1 - F(p - v(\bar{\theta}))) .$$

That gives the price $p^*(\underline{\theta}, \bar{\theta}) = \underline{\theta} + \frac{1-F}{f} (p^*(\underline{\theta}, \bar{\theta}) - v(\bar{\theta}))$ and the associated profit $\pi(p^*(\underline{\theta}, \bar{\theta}), \underline{\theta}, \bar{\theta})$. Then, the monopolist does not try to obtain the certification if their expected profit with it

is lower than their reservation outcome, namely:

$$\pi^r(\underline{\theta}) \geq (1 - \bar{q}) \pi(p^*(\underline{\theta}, \bar{\theta}), \underline{\theta}, \bar{\theta}) + \bar{q} \pi^r(\underline{\theta}) - \bar{K}. \quad (2.11)$$

This constraint says that the payoff a monopolist of type $\underline{\theta}$ gets with their reservation outcome should be higher than the expected payoff they get by pretending to be of the high quality level. When the monopolist try to obtain the certification $\bar{\theta}$, they are not audited with probability $1 - \bar{q}$ and consumers believe it is of quality level $\bar{\theta}$. With probability \bar{q} , the monopolist is audited, their lie is detected, they do not get the certification and obtain the reservation outcome minus the certification fee. Notice that, if there were no fee nor audit, the low quality level would always pretend to be a high quality level. Indeed, because $\pi^r(\underline{\theta}) = \pi^m(\underline{\theta})$ and $\dot{\pi}^m(\theta) \geq 0$, the following inequality holds $\pi(p^*(\underline{\theta}, \bar{\theta}), \underline{\theta}, \bar{\theta}) \geq \pi^m(\bar{\theta}) \geq \pi^m(\underline{\theta})$.

Finally, the certifier proposes a certification only if the audit cost is covered by the certification fee. This implies that the following constraint must be respect:

$$\bar{K} \geq \bar{q}c. \quad (2.12)$$

2.3.1. Set of incentive-feasible contracts

The certification contract $\{\bar{K}, \bar{q}\}$ must respect (2.10), (2.11) and (2.12), respectively the high quality participation constraint, the low quality incentive constraint and the certifier's budget constraint. Notice that the participation constraints of high quality level (2.10) puts a higher bound on the fee \bar{K} and that both the low quality incentive constraint (2.11) and the certifier's budget constraint (2.12) put a lower bound on the fee \bar{K} . The next Lemma gives the set of incentive-feasible certification contract obtained by taking together these three constraints.

Lemma 7. *The set of incentive-feasible certification contract for the high quality level entails a certification fee and a probability of control such that:*

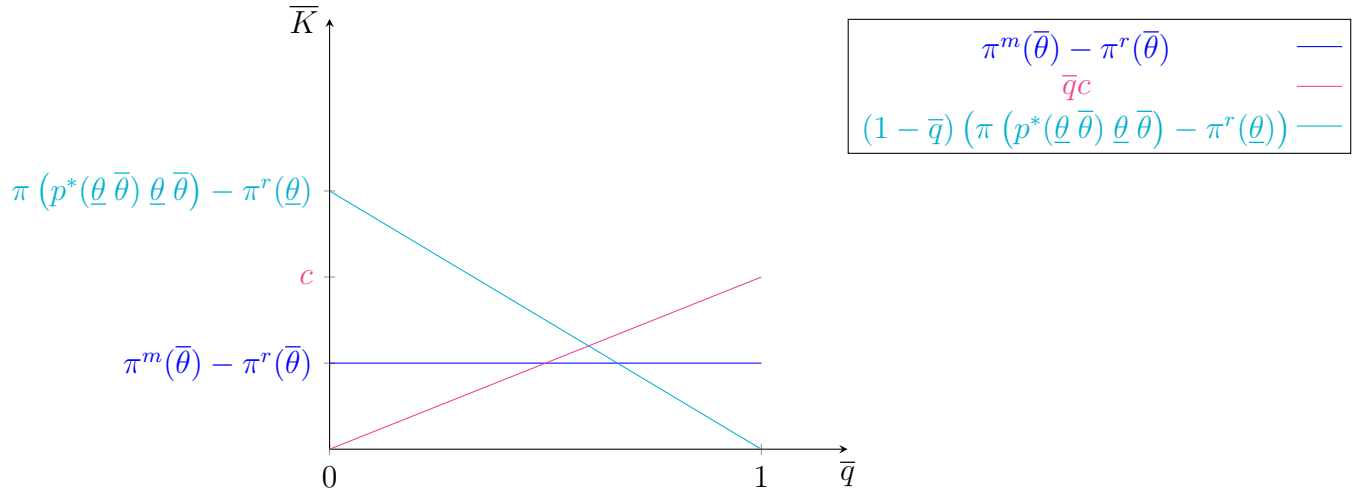
$$\begin{cases} \bar{K} \in [\max\{\bar{q}c; (1 - \bar{q}) (\pi(p^*(\underline{\theta}, \bar{\theta}), \underline{\theta}, \bar{\theta}) - \pi^r(\underline{\theta}))\}; \pi^m(\bar{\theta}) - \pi^r(\bar{\theta})] \\ \bar{q} \in [0, 1]. \end{cases} \quad (2.13)$$

The certifier faces trade-off in how to use the two instruments: the fee and the probability of auditing to respects these constraints. They can deter lying from the low quality level by setting a high enough fee and/or a high enough audit probability. However, a too high fee may discourage the high quality level from choosing certification and too many audits may be too costly for the certifier’s budget constraint.

2.3.2. Existence of an incentive-feasible contract and audit costs

When the set described in (2.13) is empty, there is no incentive-feasible certification contract. This happens when the smallest fee \bar{K} , required to respect both the low quality level incentive constraint and the high quality level participation constraint, is too high. Figure 4. illustrates this case.³⁴

Figure 4. No solution



The next Lemma describes two different cases in which an incentive-feasible contract exists.

Lemma 8. • *An incentive-feasible certification contract exists for any value of audit costs c whenever the gross gain to reveal information for the high quality level is higher than the gross gain to lie for the low quality level, i.e. when*

$$\pi^m(\bar{\theta}) - \pi^r(\bar{\theta}) \geq \pi(p^*(\underline{\theta}, \bar{\theta}), \underline{\theta}, \bar{\theta}) - \pi^r(\underline{\theta}). \tag{2.14}$$

³⁴In this graph and in the followings, for ease of presentation, profit functions are drawn as linear functions. In reality they can be represented by any monotonic function satisfying the properties described before.

- When (2.14) is not respected, an incentive-feasible certification contract exists only if audit costs c are not too high and verify:

$$\frac{(\pi^m(\bar{\theta}) - \pi^r(\bar{\theta})) (\pi(p^m(\bar{\theta}), \underline{\theta}, \bar{\theta}) - \pi^r(\underline{\theta}))}{(\pi(p^m(\bar{\theta}), \underline{\theta}, \bar{\theta}) - \pi^r(\underline{\theta})) - (\pi^m(\bar{\theta}) - \pi^r(\bar{\theta}))} \geq c. \quad (2.15)$$

This Lemma tells us that first, when the gain to reveal information for the high quality level is higher than the gross gain to lie for the low quality level, there is always an incentive-feasible mechanism.³⁵ In this particular case, high audit costs do not preclude the existence of an incentive-feasible mechanism. The intuition is that, in this case, an incentive-feasible mechanism with zero audit probability exists (see the next subsection). If on the contrary, the gross gain to lie for the low quality level exceeds the gross certification gain for high quality level, there is no incentive-feasible mechanism with a zero probability of audit. Since the probability of audit must be strictly positive, audit costs matter. The constraint (2.15) defines a threshold cost above which the certification mechanism cannot exist because audit costs are too high. In what follows, I always assume that (2.15) is respected. This emphasizes the fact that, in some cases, the existence of a solution depends on the size of unit cost of audit c .

REMARK. We can compare this Lemma with the Proposition 2 of [Daughety and Reinganum \(2008a\)](#). The latter states that there exists a range of disclosure costs such that some quality levels will signal and others will disclose. In my model, because disclosure is endogenous, the certifier chooses the certification fee and the probability of audit. Lemma 2 tells us that, whether the monopolist chooses disclosure or signaling does not always depend on audit costs. This differs from [Daughety and Reinganum \(2008a\)](#). In fact, their model could be interpreted as the limit case in my model when the probability of audit approaches one. \square

CERTIFIER'S OBJECTIVE. The objective of the certifier is intended to reflect the goal of the certification body. We will consider two different types of certifier with different goal: a self-interested certifier that maximizes its profit and a certifier that maximizes the expected profit from the industry (here a monopoly). The latter is a distinct entity than the monopolist but may have been captured by that monopolist or has stakeholders defending them. This certifier is nevertheless not in collusion with the monopolist as they do

³⁵By gross gain I mean that it does not include the certification fee.

not know the true quality level before auditing and they cannot recommend a price to the monopolist.

2.3.3. For-profit certifier

We first study a for-profit certifier that looks for a certification contract, namely a fee \bar{K} and an audit probability \bar{q} in the set of incentive-feasible allocations that maximizes its expected revenue, namely:

$$\begin{aligned} \max_{\{(\bar{K}, \bar{q})\}} \lambda (\bar{K} - c\bar{q}) \\ \text{s.t. (2.13).} \end{aligned}$$

The next proposition characterizes the separating PBE contract when the certifier is for-profit.

Proposition 9. *The separating contract proposed by a for-profit certifier to high quality level entails:*

- if (2.14) is respected, the certification fee is maximal and there is no verification:

$$\{\bar{K} = \pi^m(\bar{\theta}) - \pi^r(\bar{\theta}); \bar{q} = 0\}.$$

- if (2.14) is not respected, the certification fee is maximal and the probability of audit is positive:

$$\{\bar{K} = \pi^m(\bar{\theta}) - \pi^r(\bar{\theta}); \bar{q} = 1 - \frac{\pi^m(\bar{\theta}) - \pi^r(\bar{\theta})}{\pi(p^*(\underline{\theta}, \bar{\theta}), \underline{\theta}, \bar{\theta}) - \pi^r(\underline{\theta})}\}.$$

To better understand the two different cases and the associated optimal mechanisms, Figure 5. and Figure 6. below represent the incentive-feasible set (2.13) in both cases. The certifier can choose any fee and probability that are in the set. They certifier chooses a fee as high as possible and a probability of audit as low as possible so as to maximize their revenue and minimize audit costs. Figure 5. represents a case when (2.14) is respected. In this case, a high fee is enough to discourage the low quality level to mimic the high quality level. The certifier is able to set the maximal fee and no verification. This optimum, represented by the red dot in the figure, is the best from the certifier's point of view.

Figure 5. Optimal Solution

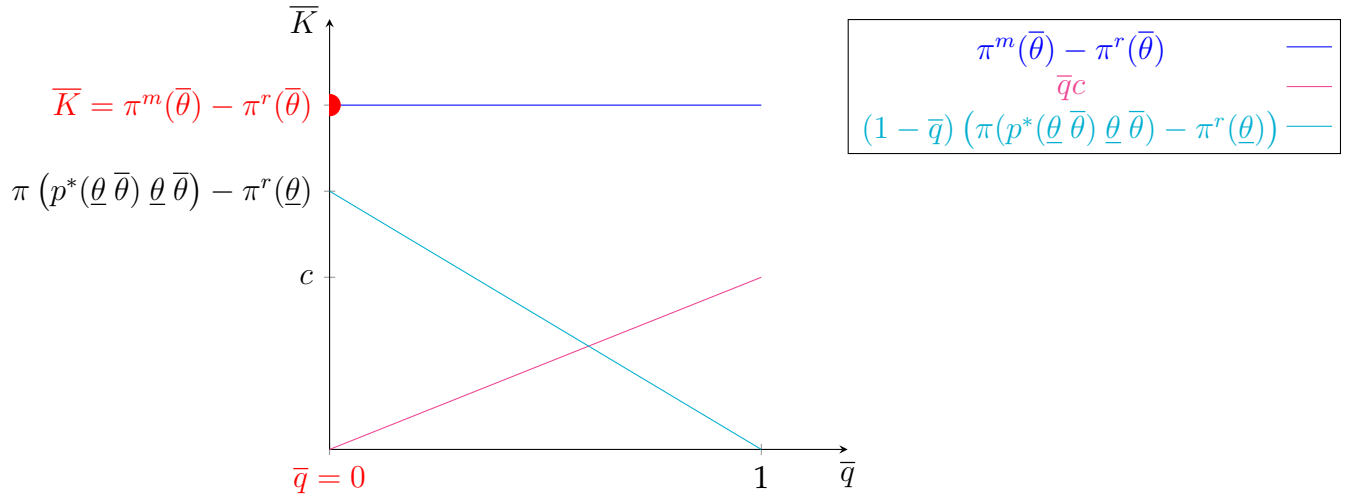
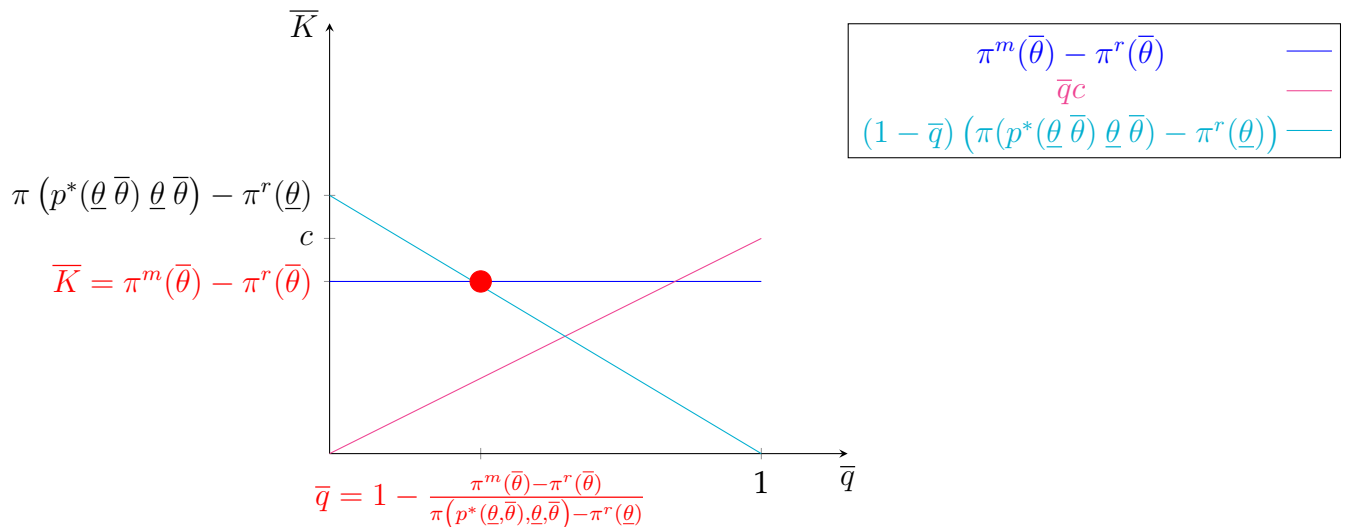


Figure 6. represents the case when (2.14) is not respected. A high fee alone is not enough anymore to satisfy the incentive constraint of low quality level. The certifier must offer a contract with positive probability of audit for high quality level. They choose the combination of lowest probability and the highest fee that satisfy both the participation constraint of the high quality level and the incentive constraint of the low quality level. This optimal point (red dot in the figure) is found at the intersection of these two constraints.

Figure 6. Optimal Solution



Notice that, the high quality level receives the same profit as with its reservation outcome, i.e. $\pi^m(\bar{\theta}) - K(\bar{\theta}) = \pi^r(\bar{\theta})$. Their surplus is entirely captured by the certifier.³⁶

³⁶This effect is the same as the one described by Lizzeri (1999).

2.3.4. Industry certifier

We now examine the case of a certifier from the industry. This certifier embodies an independent entity created by the members of the industry — composed here of one monopoly.³⁷ The certifier maximizes the expected profit of the industry, namely:

$$\begin{aligned} \max_{\{\bar{K}, \bar{q}\}} \lambda (\pi^m(\bar{\theta}) - \bar{K}) + (1 - \lambda)\pi^r(\underline{\theta}) \\ \text{s.t. (2.13).} \end{aligned}$$

This type of certifier instead of selecting the high quality level fee \bar{K} as high as possible, will select a combination of a fee \bar{K} and a probability of audit \bar{q} in the incentive-feasible set that limits the cost for the monopolist. The next Proposition characterizes the separating PBE contract when the certifier maximizes the expected profit of the monopolist.

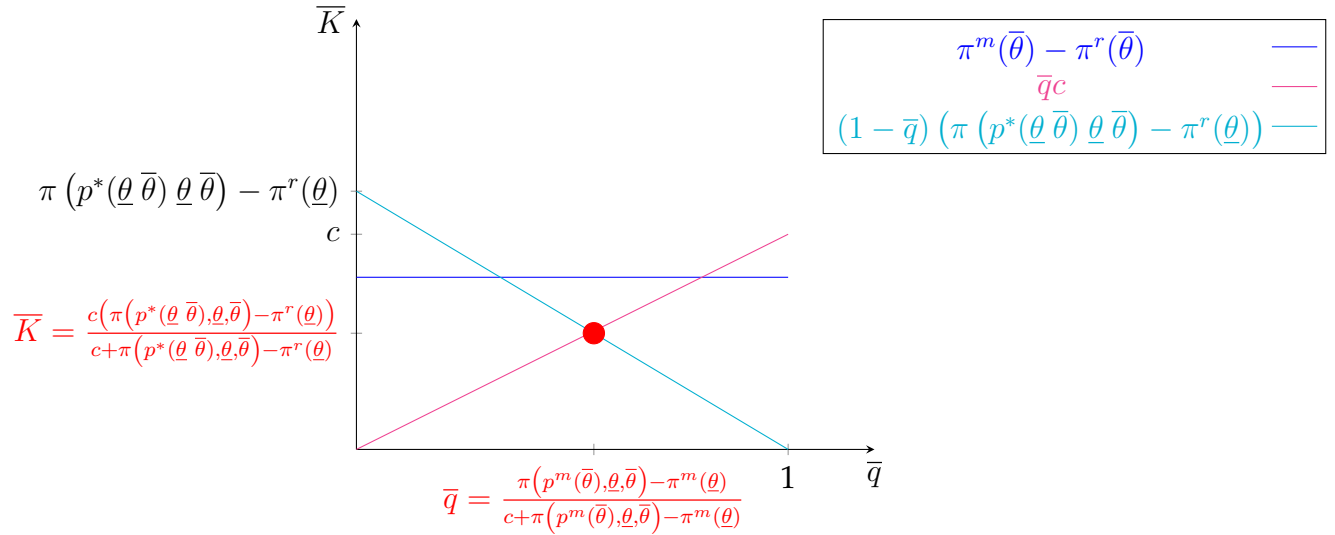
Proposition 10. *When the certifier maximizes the industry's expected profit, the optimal certification mechanism entails a lower fee and a higher probability of verification than a for-profit certifier would set for the high quality level, namely*

$$\{\bar{K} = \frac{c (\pi (p^*(\underline{\theta}, \bar{\theta}), \underline{\theta}, \bar{\theta}) - \pi^r(\underline{\theta}))}{c + \pi (p^*(\underline{\theta}, \bar{\theta}), \underline{\theta}, \bar{\theta}) - \pi^r(\underline{\theta})}; \bar{q} = \frac{\pi (p^*(\underline{\theta}, \bar{\theta}), \underline{\theta}, \bar{\theta}) - \pi^r(\underline{\theta})}{c + \pi (p^*(\underline{\theta}, \bar{\theta}), \underline{\theta}, \bar{\theta}) - \pi^r(\underline{\theta})}\}.$$

To understand the intuition of this proposition, Figure 7. illustrates the set of contract that respect the constraints and the optimal solution. The certifier chooses the red point in the incentive-feasible set because it is the lowest fee for high quality level \bar{K} that respects both the incentives for low quality level (2.11) and their budget constraint (2.12). Both (2.11) and (2.12) are binding and \bar{q} and \bar{K} are such that: $\bar{q}c = (1 - \bar{q}) (\pi(\bar{\theta}, p^m(\bar{\theta})) - \pi^m(\bar{\theta}))$ and $\bar{K} = \bar{q}c$. Taking these equations together, I obtain the optimal fee and probability of audit. Notice that, in this case, even if a high fee would be enough to dissuade low quality level from mimicking the high quality level, the certifier rather offers a lower fee and a higher probability of audit in order to maximize the monopoly profit.

³⁷Note that, the industry could be composed of several identical monopolists operating in separate markets. These monopolists then gather as an association to create a certification mechanism for their products.

Figure 7. Optimal Contract



2.4. Extension: certifier as a standard setter

In the previous sections, I considered the problem of a certifier choosing which standards to certify and at which price. For that, I made two assumptions about standards and certification. First, I assumed that standards were *exogenous*. This feature fits with the reality of certifiers as, in many cases, standard setting organizations create standards and certifiers decide which standards to verify. Second, I assumed that there were as many standards as quality levels. As a consequence, certification was revealing to consumers the *exact* quality level (corresponding to the standard). In reality, there are often more than two quality levels and there are less standards than quality levels. Firms generally certify for the standard the closest to their true quality level. This implies that, when there are many standards along the quality line, it is not a bad approximation to assume that certification reveals the true quality level. However, when there are few standards along the quality line, one should assume that certification reveals a less precise information.

As a extension, I consider a scenario with a continuum of quality levels that investigates two alternative assumptions. First, I consider that, a *strategic certifier creates their own standard*. As explained in the introduction, in the reality, some certifiers create their own standards. Second, I consider that there is a *unique standard and the certification for this standard reveals to consumers whether quality level is above the standard*. Certification brings a less precise information. The information provided by the certification is “binary”, namely, it

indicates to consumers that the quality level of a product is above a given standard.

CERTIFIER. There is a now again a continuum of quality levels $\theta \in [\underline{\theta}, \bar{\theta}]$. The certifier looks for one quality level to create a standard and decides the price of the certification for this standard.³⁸ We denote θ^* the quality level corresponding to the standard and $K(\theta^*)$ the price of the corresponding certification.³⁹ This time, audit happens with certainty and the monopolist cannot lie. However, since there is a unique standard and not a continuum, even with the certification, the monopolist does not reveal their exact quality level to consumers. Certification only reveals to consumers that the quality level is above the standard θ^* .

CONSUMERS' BELIEFS. Consumers observe both the certificate and the price of the product. As before, when there is no certificate, consumers infer quality level from price. When consumers observe a certificate, they know that quality level is in the restricted interval $[\theta^*, \bar{\theta}]$ and their expected valuation for quality level is:

$$v^E(\theta^*) = \mathbb{E}_\theta (v(\theta) | \theta \in [\theta^*, \bar{\theta}]) = \frac{\int_{\theta^*}^{\bar{\theta}} v(\theta) k(\theta) d\theta}{G(\bar{\theta}) - G(\theta^*)}$$

where $k(\theta) = g(\theta)$, $\forall \theta \in [\theta^*, \bar{\theta}]$ and $k(\theta) = 0$ everywhere else.⁴⁰ Without further information, their demand for a certified good would be: $1 - F(p - v^E(\theta^*))$. However, consumers have access to a second piece of information: the price. Since consumers infer quality from the price when there is no certification, one can consider that, when there is certification, consumers not only take into account certificate but also the price to update their beliefs about quality level. We consider the update of the beliefs as a two-stages process. First, consumers observe the certificate, and update their beliefs about the interval of quality levels for the good. Second, they observe the price as a signal of quality within the interval $[\theta^*, \bar{\theta}]$.

³⁸Note that it is common in the literature to limit each standard's owner/labeling organization to offer one standard/label. See for instance [Fischer and Lyon \(2014\)](#).

³⁹Notice that the fees only depend on the standard. They are independent of the true quality level of the certified firm for two reasons. First, the audit, instead of controlling the exact quality level, controls whether the quality level is above the threshold. This implies that the certifier most probably cannot use the audit to observe the exact quality level and differentiate between quality levels. Second, because consumers do not observe the certification scheme but only the outcome, namely the certificate, the monopolist cannot try to signal within the interval of certified quality levels by paying a high fee.

⁴⁰Their expected valuation is the expected valuation on the truncated distribution of the quality variable. The worst belief consumers can hold when they observe the certificate is now that the good is of quality level θ^* and not anymore $\underline{\theta}$.

MONOPOLY'S PRICING STRATEGY WITHOUT CERTIFICATION. For quality levels lower than the threshold $\theta < \theta^*$, the monopolist does not go to the certifier and obtains its reservation outcome. With a continuum of quality levels, the reservation outcome corresponds to the profit the firms gets in the unique separating perfect Bayesian equilibrium of signaling as described in Section 2.1. In this equilibrium, the monopolist of type θ sets the signaling price $p^s(\theta)$ (with the boundary condition $p^s(\underline{\theta}) = p^m(\underline{\theta})$) and gets the signaling profit $\pi^s(\theta)$.

MONOPOLY'S PRICING STRATEGY WITH CERTIFICATION. In Section 2.1, I defined the separating perfect Bayesian equilibrium of signaling where quality level was on the interval $[\underline{\theta}, \bar{\theta}]$. When consumers observe a certificate, they know that quality level is in the interval $[\theta^*, \bar{\theta}]$. I am now interested in the separating Bayesian-Nash equilibrium of signaling on this interval. Consumers observe the signaling price in the high quality level interval $\tilde{p}^s(\theta)$ and can infer the quality level θ . At the separating equilibrium, a monopolist whose quality level is $\theta \in [\theta^*, \bar{\theta}]$ has no incentive to deviate from $\tilde{p}^s(\theta)$ and choose another price $\tilde{p}^s(\hat{\theta})$, $\hat{\theta} \neq \theta$, $(\hat{\theta}, \theta) \in [\theta^*, \bar{\theta}]^2$. This implies that the following incentive-compatibility condition must be respected:

$$\tilde{p}^s(\theta) = \arg \max_{\hat{\theta} \in [\theta^*, \bar{\theta}]} \left(p(\hat{\theta}) - \theta \right) \left(1 - F \left(p(\hat{\theta}) - v(\hat{\theta}) \right) \right) \quad (2.16)$$

where θ the monopoly's true quality level and $\hat{\theta}$ the consumers' inference about the quality level.

Lemma 9. *The signaling price $\tilde{p}^s(\theta)$ that respects incentive-compatibility in the interval $[\theta^*, \bar{\theta}]$ is such that:*

$$\dot{\tilde{p}}^s(\theta) = \frac{\dot{v}(\theta)}{1 - \frac{1}{p^s(\theta) - \theta} \frac{1-F}{f}(p^s(\theta) - v(\theta))}. \quad (2.17)$$

and

$$\dot{\tilde{p}}^s(\theta) \geq \dot{v}(\theta). \quad (2.18)$$

This lemma defines the signaling price in the interval $[\theta^*, \bar{\theta}]$ with a differential equation and second-order condition. In addition, the unique signaling price is defined by an initial value condition.

Lemma 10. *On the interval $[\theta^*, \bar{\theta}]$, the initial condition for the signaling price is such that:*

$$\tilde{p}^s(\theta^*) = p^m(\theta^*). \quad (2.19)$$

This initial value condition (2.6) tells us that signaling price for the lowest quality level on the interval $[\theta^*, \bar{\theta}]$ is the same at full information equilibrium. Notice that, because of this initial value condition, $\tilde{\pi}^s(\theta^*) = \pi^m(\theta^*)$.

MONOPOLY'S PROFIT. Using the expression of the price, I write the profit of the monopolist that goes to the certifier:

$$\tilde{\pi}^s(\theta) - K(\theta^*) = (\tilde{p}^s(\theta) - \theta) (1 - F(\tilde{p}^s(\theta) - v(\theta))) - K(\theta^*).$$

If instead, the monopolist does not go to the certifier, it gets:

$$\pi^s(\theta) = (p^s(\theta) - \theta) (1 - F(p^s(\theta) - v(\theta))).$$

Set of incentive-feasible certification mechanisms.

MONOPOLY'S PARTICIPATION CONSTRAINT. The cutoff type θ^* must be indifferent between going to the certifier or not, namely:

$$\pi^s(\theta^*) = \tilde{\pi}^s(\theta^*) - K(\theta^*). \quad (2.20)$$

This equation defines the fee that is equal to the difference between the signaling profit with and without certificate. In addition, all quality levels above the threshold θ^* go to the certifier only if their participation constraint is respected, it requires that:

$$\tilde{\pi}^s(\theta) - K(\theta^*) \geq \pi^s(\theta), \quad \forall \theta \geq \theta^*.$$

Using the expression of the fee in (2.20), their participation constraints write:

$$\tilde{\pi}^s(\theta) - \pi^s(\theta) \geq \tilde{\pi}^s(\theta^*) - \pi^s(\theta^*), \quad \forall \theta \geq \theta^*. \quad (2.21)$$

Quality levels above the threshold participate only if the difference between their signaling profit with certificate and their signaling profit without certificate is higher than the fee $K(\theta^*)$. This exactly equals the difference between the signaling profit with and without certificate for the threshold quality θ^* .

CERTIFIER'S BUDGET CONSTRAINT. As before, the certifier implements the mechanism

only if audit costs are at least covered by the fees, namely:

$$(1 - G(\theta^*)) K(\theta^*) \geq (1 - G(\theta^*)) c. \quad (2.22)$$

Using the expression of the fee (2.20) into (2.22) and simplifying, I obtain:

$$\tilde{\pi}^s(\theta^*) - \pi^s(\theta^*) \geq c. \quad (2.23)$$

Remembering that $\tilde{\pi}^s(\theta^*) = \pi^m(\theta^*)$, this condition tells us that for the threshold quality, the gain between the full information and the signaling profit should be higher than audit costs. Taking (2.21) and (2.23) together, the next Lemma summarizes conditions for a certification mechanism to exist.

Lemma 11. *An feasible certification mechanism with a binary certificate revealing a high quality levels' interval exists when there is a quality threshold $\theta^* \in [\underline{\theta}, \bar{\theta}]$ such that*

$$\tilde{\pi}^s(\theta) - \pi^s(\theta) \geq \tilde{\pi}^s(\theta^*) - \pi^s(\theta^*) \geq c, \quad \forall \theta \geq \theta^*. \quad (2.24)$$

For every quality level in the high interval, the difference of signaling profits with and without the certificate must be higher than the the difference of signaling profits at the threshold quality θ^* . From the feasibility condition, it follows that for every quality level above the threshold, the difference of signaling profits must cover audit costs.

Cases of non-existence of a mechanism

The monopolist trades-off different costs. If the monopolist does not go to the certifier, they bear strong costs of signaling. If they go to the certifier, signaling costs are lower but they come along with certification costs. Whenever the costs with a certifier are higher than the signaling costs alone, the monopolist refuses to participate in the certification.

First, as before, a mechanism does not exist when there is no θ^* satisfying the feasibility constraint (2.23). This happens when audit costs are too high. Assuming that I am not in this case, there is an additional requirement on θ^* . Every quality level above that threshold θ^* must be able to pay the certification fee. Finding a threshold that respects both constraints may not be possible. We describe in the next proposition some condi-

tions under which the certifier cannot use any high quality levels' interval to sell a binary certificate.

Proposition 11. *Even if there is a quality threshold θ^* respecting (2.23), the certifier cannot propose a binary certificate to high quality levels' interval when*

$$1 - F(\tilde{p}^s(\theta^*) - v(\theta^*)) \neq 1 - F(p^s(\theta^*) - v(\theta^*)). \quad (2.25)$$

This proposition tells us that participation constraints are violated if the demand for the threshold quality is not the same for the two different signaling prices. The intuition of this result lies in the participation constraint. Participation constraints (2.21) impose that the difference in signaling profit with and without certificate should be higher for quality levels above the threshold than the difference at the threshold. At the extreme, if you consider quality levels very close to the threshold, such as $\theta^* + \varepsilon$, their participation relies on the fact that at the threshold quality θ^* , the derivative of the signaling profit with certificate is higher than the derivative of the signaling profit without. This condition reformulated gives (2.25).

To illustrate the previous proposition, consider the case when consumers' taste parameter ε is uniformly distributed on $[\underline{\varepsilon}, \bar{\varepsilon}]$. In this scenario, there is only two extreme cases in which the certifier is able to use a binary certificate in a high quality levels' interval. The next corollary describes these cases.

Corollary 1. *Assuming that consumers' taste parameter is uniformly distributed, an incentive-feasible certification exists only if there is a θ^* such that (2.23) and*

$$\tilde{p}^s(\theta^*) - v(\theta^*) \geq \bar{\varepsilon} \text{ or } p^s(\theta^*) - v(\theta^*) \leq \underline{\varepsilon}.$$

are respected.

In the first case, for the threshold quality θ^* , every consumers demand the good. In the second case, the demand for the threshold quality θ^* is nil. In these two particular cases, the demand for the threshold quality θ^* is the same whether the monopolist goes to the certifier or not. It appears that, these cases are restrictive. Most likely, the sum of the cost of signaling in the high interval and the certification fee are in fact too high for the

monopolist to choose the certification. In this context, a strategic certifier cannot propose their own standard.

In this extension, I considered an alternative role for the certifier. My goal was to take a glance at how I could think about this alternative role of the certifier while staying in the scope of the article. To that end, I made some assumptions that can be debated. We first assumed that, within the interval of certified quality, the monopolist was still using their price to signal the exact quality level to consumers. As a result, I found that, in many cases, the certification plus the signaling costs are too high and the monopolist rather uses pure signaling. One can therefore wonder whether it is a good assumption that the monopolist uses signaling and certification simultaneously. One could argue that, in presence of two types of signals, certification and prices, consumers only consider the information about the certification even when it does not reveal perfectly the quality level. Secondly, I assumed that there was a unique standard on the market. In reality, if one would be interested in further investigations about the choice of standard, it would be necessary to introduce some competition between different standard setters.

2.5. Conclusion

This paper analyzed the strategic interaction between two forms of communication for a monopolist: price signaling and third-party certification of product quality. We started from the observation that the certification schemes vary along several axes: the range of quality levels to be certified and the certification characteristics (such as fee and probability of audit). We then explored two potential causes to explain that diversity: the structure of audit costs and the certifier's motivation. My model provided several predictions about how they can affect the choice of certification. First, with a continuum of quality levels, I assumed that certification is exogenous and certification fee reflects audit costs. The monopolist chooses certification only when they get a better profit with certification than with signaling. We showed that, when audit costs are constant, an interval of high quality levels certify, while when audit costs are per-unit or increase with quality, in some cases, an interval of intermediate quality levels certify. According to this, a regulator considering to delegate quality revelation to third-parties should dedicated a special attention to audit costs. Second, with two quality levels, I considered a endogenous certification offered by

a strategic certifier. The certifier must propose a contract that is incentive-feasible taking into account the reservation allocation. We showed that a for-profit certifier, whenever it is possible, will not audit and put the highest feasible fee while a certifier defending the industry will audit with a certain probability and select the lowest possible fee. These results may contribute to explain the discrepancies observed in certification.

For future research, it would be interesting to relax some hypothesis in this paper. First, one could introduce competition between strategic certifiers. If certifiers are identical, under perfect competition, the certification fee is equal to the audit costs and they cannot capture any surplus. A more interesting situation would be to consider heterogeneous certifiers with different audit costs. The structure of audit costs would have an effect on the nature of the competition as it will affect the number of potential certifiers competing for each standard.⁴¹ Second, one could consider a similar model but with oligopolistic firms. More generally, there are many alleys for future research on the subject of certification. One could investigate the differences between two types of certification: product and process certification (Auriol, Schilizzi, et al. (2003)).⁴² Also, it would be valuable to integrate a time dimension to take into account that, in reality, the certification is valid only for a certain period of time. Finally, in this paper, I focused on certification, which is only one of the steps of the full disclosure process.⁴³ In particular, in the main part of this paper, I assumed the existence of standards for each quality level. In practice, an entity other than the certifier creates these standards. This implies that a disclosure process involves not only one, but two intermediaries: the certifier and the standard setter. In the next chapter of the thesis I therefore study a disclosure process that takes into account this aspect.

⁴¹For instance, one could consider the competition between a certifier defending the industry and a for-profit certifier. In this paper, I assumed that a for-profit certifier and a certifier defending the industry face the same audit costs. Alternatively, one could assume that, due to their proximity with the industry, a certifier defending the industry faces lower audit costs than a for-profit certifier.

⁴²Product certification is mostly linked to consumption and process certification is mostly linked to production. The former generally refers to certification for food and industry (such as *Appellation d'Origine Contrôlée* for French wine) and the latter refers more to the life-cycle impact of the product (such as the environmental impact of the production).

⁴³See Delmas, Lyon, and Jackson (2019) for a detailed description of the different steps of the disclosure process.

2.6. Appendix

Proof of Proposition 6. In a separating equilibrium, incentive compatibility requires:

$$p^s(\theta) = \arg \max_{\hat{\theta} \in [\underline{\theta}, \bar{\theta}]} \left(p(\hat{\theta}) - \theta \right) \left(1 - F \left(p(\hat{\theta}) - v(\hat{\theta}) \right) \right)$$

It implies:

$$\dot{p}(\hat{\theta}) \left(1 - F \left(p(\hat{\theta}) - v(\hat{\theta}) \right) \right) - \left(p(\hat{\theta}) - \theta \right) \left(\dot{p}(\hat{\theta}) - \dot{v}(\hat{\theta}) \right) f \left(p(\hat{\theta}) - v(\hat{\theta}) \right) = 0, \quad (2.26)$$

or equivalently:

$$\dot{p}(\hat{\theta}) \left(1 - F \left(p(\hat{\theta}) - v(\hat{\theta}) \right) - \left(p(\hat{\theta}) - \theta \right) f \left(p(\hat{\theta}) - v(\hat{\theta}) \right) \right) + \dot{v}(\hat{\theta}) \left(p(\hat{\theta}) - \theta \right) f \left(p(\hat{\theta}) - v(\hat{\theta}) \right) = 0.$$

Rearranging terms, we obtain:

$$\dot{p}(\hat{\theta}) = \frac{-\dot{v}(\hat{\theta}) \left(p(\hat{\theta}) - \theta \right) f \left(p(\hat{\theta}) - v(\hat{\theta}) \right)}{\left(1 - F \left(p(\hat{\theta}) - v(\hat{\theta}) \right) - \left(p(\hat{\theta}) - \theta \right) f \left(p(\hat{\theta}) - v(\hat{\theta}) \right) \right)}.$$

This being also true at $\hat{\theta} = \theta$, we have (2.4).

Incentive compatibility also requires the following local second-order condition to be respected:

$$\frac{d^2}{d\hat{\theta}^2} \left(\left(p(\hat{\theta}) - \theta \right) \left(1 - F \left(p(\hat{\theta}) - v(\hat{\theta}) \right) \right) \right) \Big|_{\hat{\theta}=\theta} \leq 0. \quad (2.27)$$

Differentiating (2.26) at $\hat{\theta} = \theta$ with respect to θ , I obtain:

$$\frac{d^2}{d\hat{\theta}^2} \left(\left(p(\hat{\theta}) - \theta \right) \left(1 - F \left(p(\hat{\theta}) - v(\hat{\theta}) \right) \right) \right) \Big|_{\hat{\theta}=\theta} + f \left(p(\theta) - v(\theta) \right) \left(\dot{p}(\theta) - \dot{v}(\theta) \right) = 0. \quad (2.28)$$

Taking together (2.28) and (2.27), the local second-order condition writes more simply as (2.5). \square

EXISTENCE OF A SEPARATING EQUILIBRIUM: The existence of a separating equilibrium relies on conditions over the profit function (see Mailath (1987)). If I define $\pi \left(p, \theta, \hat{\theta} \right) = \left(p - \theta \right) \left(1 - F \left(p - v(\hat{\theta}) \right) \right)$, I can verify that several conditions are respected:

1. $\pi(p, \theta, \hat{\theta})$ is twice continuously differentiable on $\mathbb{R} \times [\underline{\theta}, \bar{\theta}]^2$.
2. $\forall p > \theta$ and $p > v(\hat{\theta})$, $\pi_{\hat{\theta}}(p, \theta, \hat{\theta}) > 0$. Indeed, $\pi_{\hat{\theta}}(p, \theta, \hat{\theta}) = (p - \theta)\dot{v}(\hat{\theta})f(p - v(\hat{\theta}))$ which is strictly positive for $p > \theta$.
3. $\forall p > v(\hat{\theta})$, $\pi_{p\theta}(p, \theta, \hat{\theta}) > 0$. Indeed, $\pi_{p\theta}(p, \theta, \hat{\theta}) = f(p - v(\hat{\theta}))$ is strictly positive for $p > v(\hat{\theta})$.
4. $\pi_p(p, \theta, \theta) = 0$ has a unique solution in p , $\tilde{p}(\theta)$ which maximizes $\pi(p, \theta, \theta)$ and such that $\pi_{pp}(\theta, \theta, \tilde{p}(\theta)) < 0$. Indeed, the unique solution is the monopoly price $\tilde{p}(\theta) = p^m(\theta) = \frac{1-F}{f}(p(\theta) - v(\theta)) + \theta$.
5. $\forall p > \theta$ and $p > v(\hat{\theta})$, $\frac{\pi_p(p, \theta, \hat{\theta})}{\pi_{\hat{\theta}}(p, \theta, \hat{\theta})}$ is a strictly monotonic function of θ . Differentiating $\frac{\pi_p(p, \theta, \hat{\theta})}{\pi_{\hat{\theta}}(p, \theta, \hat{\theta})}$ with respect to θ yields:

$$\frac{(p - \theta)\dot{v}(\hat{\theta})f^2(p - v(\hat{\theta})) + \dot{v}(\hat{\theta})f(p - v(\hat{\theta})) \left((1 - F(p - v(\hat{\theta}))) - (p - \theta)f(p - v(\hat{\theta})) \right)}{\left((p - \theta)\dot{v}(\hat{\theta})f(p - v(\hat{\theta})) \right)^2} \\ = \frac{1}{\dot{v}(\hat{\theta})(p - \theta)^2} \frac{1 - F}{f}(p - v(\hat{\theta})).$$

The latter expression is strictly positive.

These five conditions are necessary and sufficient for the existence of a separating equilibrium (see [Mailath \(1987\)](#) Theorem 3). [Mahenc \(2008\)](#) gives a detailed interpretation of these condition in the context of a monopolist signaling environmental cleanness of their product. In my case, the interpretation is similar. Of interest, condition 2 states that when the monopolist prices above marginal cost and above the perceived valuation of quality level, the monopolist prefers to be perceived as higher quality level. It follows that the worst belief that can be hold by consumers is that the good is of low quality level $\underline{\theta}$. Condition 5 is the single crossing property requiring the monotonicity of the marginal rate of substitution between price and perceived quality level.

Proof of Lemma 9. Proof of Lemma 9 is similar as the proof of Proposition 6 to the difference that the interval instead of being $[\underline{\theta}, \bar{\theta}]$ is now the interval $[\theta^*, \bar{\theta}]$. \square

Proof of Lemma 10. The following proof is based upon a similar proof in Mahenc (2008). I define $\pi(p, \theta, \hat{\theta}) = (p - \theta) \left(1 - F(p - v(\hat{\theta}))\right)$ where θ is the true quality level and $\hat{\theta}$ is the quality level perceived by consumers. If the type θ^* set an equilibrium price $\tilde{p}^s(\theta^*) \neq p^m(\theta^*)$, then the deviation to $p^m(\theta^*)$ would be profitable, no matter whether $p^m(\theta^*)$ is on or off the equilibrium path. First, if $p^m(\theta^*)$ is on the equilibrium path, it means that for some $\theta \in [\theta^*, \bar{\theta}]$ $p^m(\theta^*) = \tilde{p}^s(\theta)$ and by observing $\tilde{p}^s(\theta)$ consumers believe the quality level is θ . Then, $\pi(\tilde{p}^s(\theta), \theta^*, \theta) > \pi(p^m(\theta^*), \theta^*, \theta^*)$ since θ^* is the worst belief. Second, if $p^m(\theta^*)$ is off the equilibrium path, then consumers' beliefs after observing $p^m(\theta^*)$ are arbitrarily set at θ^* , and $\pi(p^m(\theta^*), \theta^*, \theta) \geq \pi(\tilde{p}^s(\theta^*), \theta^*, \theta^*)$. \square

Proof of Proposition 11. For $\theta > \theta^*$ I can write the participation constraints (2.21) such as:

$$\frac{\tilde{\pi}^s(\theta) - \tilde{\pi}^s(\theta^*)}{\theta - \theta^*} \geq \frac{\pi^s(\theta) - \pi^s(\theta^*)}{\theta - \theta^*}, \quad \forall \theta > \theta^*. \quad (2.29)$$

Using the Limit Inequality Theorem (see above the Theorem), as $\lim_{\theta \rightarrow \theta^{*+}} \frac{\tilde{\pi}^s(\theta) - \tilde{\pi}^s(\theta^*)}{\theta - \theta^*} = \dot{\tilde{\pi}}^s(\theta^*)$ and $\lim_{\theta \rightarrow \theta^{*+}} \frac{\pi^s(\theta) - \pi^s(\theta^*)}{\theta - \theta^*} = \dot{\pi}^s(\theta^*)$, (2.29) implies that:

$$\dot{\tilde{\pi}}^s(\theta^*) \geq \dot{\pi}^s(\theta^*).$$

Using the expressions of profit' derivatives and simplifying, I obtain a necessary condition:⁴⁴

$$F(\tilde{p}^s(\theta^*) - v(\theta^*)) \geq F(p^s(\theta^*) - v(\theta^*)).$$

Since $F'(\cdot) \geq 0$ and $\tilde{p}^s(\theta^*) = p^m(\theta^*) < p^s(\theta^*)$ -(initial value condition), it implies that this condition is respected only if: $F(\tilde{p}^s(\theta^*) - v(\theta^*)) = F(p^s(\theta^*) - v(\theta^*))$ or equivalently (2.25). \square

Theorem 1 (Limit Inequality Theorem (with one-sided limit)). *If $f(\theta) \leq g(\theta)$ for all θ on the set $] \theta^*, \bar{\theta}]$, and $\lim_{\theta \rightarrow \theta^{*+}} f(\theta) = L$ and $\lim_{\theta \rightarrow \theta^{*+}} g(\theta) = M$, then $L \leq M$.*

Proof of Theorem 1. I will assume that $L > M$, and show that this produces a contradiction. Choose $\epsilon = L - M$. Since $\lim_{\theta \rightarrow \theta^{*+}} g(\theta) - f(\theta) = M - L$, then there is a $\delta > 0$ such that for every θ , the expression $0 < \theta - \theta^* < \delta$ implies $|g(\theta) - f(\theta) - (M - L)| < \epsilon$. Thus,

⁴⁴Recall that we have: $\dot{\pi}^s(\theta) = -(1 - F(p^s(\theta) - v(\theta))) \leq 0$ and $\dot{\tilde{\pi}}^s(\theta) = -(1 - F(\tilde{p}^s(\theta) - v(\theta))) \leq 0$

$-\epsilon < g(\theta) - f(\theta) - M + L < \epsilon$, $g(\theta) - f(\theta) - M + L < L - M$, which gives $g(\theta) < f(\theta)$. This result contradicts the original hypothesis that $f(\theta) \leq g(\theta)$, so the assumption must be false. Therefore, $L \leq M$. \square

Chapter 3. The Two Middlemen¹

Abstract

This paper studies a disclosure that reveals the quality of a good to consumers and consists of two steps: certification and labeling. That disclosure involves two middlemen — the certifier and the owner of the label — and it includes a certification fee and a price for the label. A monopolist has the choice between paying for that disclosure or signaling quality through price. I derive the disclosure when the certifier is a for-profit private entity and the label owner is private either a for-profit entity or an entity that defends the industry's interest. I show that, when the label owner defends the industry, the price of that label and the sharing of the surplus depend on whether there is competition between the certifiers. If that is the case, their label is free and the monopolist gets all the disclosure surplus. However, without competition between certifiers, if a label owner defending the industry wants to prevent the certifier from capturing the surplus, the price of their label has to be equal or higher than what it would be if they were a for-profit entity. This means that a label owner defending the industry should favor competition between certifiers or, when that is not possible, monetize the label.

Keywords: *Asymmetric information, middlemen, third-party certification, labeling, price signaling.*

JEL Classification: D82, L12, L15.

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Introduction

MOTIVATION. Governments were traditionally the main organizations to provide informational schemes (Delmas, Lyon, and Jackson (2019)) but a recent study from the OCDE (Prag, Lyon, and Russillo (2016)) found that schemes owned or operated by governments are now a minority, with nonprofits and private entities forming the bulk of schemes introduced over the past 20 years.¹ Though nonprofits dominate the landscape, that study shows a shift towards privately-owned schemes. Both Bourgeon, the main organic food label in Switzerland, that belongs to the federation of swiss organic farmers BioSuisse and Coffee and Farmer Equity Practices, a standard for producers of high-quality sustainably grown coffee, that is owned by the private firm Starbucks, are examples of private informational schemes.² One is from the industry, the other is a for-profit entity.

What are the disclosure strategies associated with these informational schemes? Delmas, Lyon, and Jackson (2019) decompose information disclosure strategies into four elements: codification, standardization, certification and labeling. Codification consists of converting tacit knowledge into explicit knowledge. Standardization defines the specific type of rule approved by a recognized body. Certification attests that a product or organization meets certain standards. Labeling communicates information through a label or a symbol that indicates compliance with the standards. Disclosure strategies often include these four elements but I will focus on just the last three.³

In this paper I look at a typical case in which standardization and labeling are made by

¹The main suppliers of the information schemes are nonprofits, governments, trade and industry associations, and for-profit entities. Notice that some suppliers be defined as multi-stakeholders organizations such as the 4C Association, the FSC (Forest Stewardship Council), or the MSC (Marine Stewardship Council) (Wijen and Chiroleu-Assouline (2019)).

The OCDE study from Prag, Lyon, and Russillo (2016) identifies the main trends of the recent evolution of the Environmental Labeling and Informational Schemes (ELIS). To analyze the growth of ELIS, they compiled a dataset covering 544 schemes worldwide between 1970 and 2012, combining the EcoLabel index with a review of the literature and consultations with experts. They measured that ELIS multiplied by a factor of five between 1998 and 2009.

²There are many other examples of private owners that are for-profit entities (such as the CarbonNeutral Company, Carrefour or Living Direct) and industry associations (such as the Association for Soaps, Detergents and Maintenance Products, AvoGreen).

³It is however not always the case that they include these four elements. For instance the CDP (formerly the Carbon Disclosure Project) includes only codification and certification (Delmas, Lyon, and Jackson (2019)), EUREPGAP or COLEACP (issued by industry associations) do not include labeling (Liu (2003)) or Recyclable content (issued by the US Federal trade commission) and the Flybe Aircraft Eco-label (issued by an industry association) do not comprise certification. For the references see <http://www.ecolabelindex.com>.

the same entity.⁴ They can either certify for themselves or delegate to a third party. In the former case, they can be suspected of a conflict of interest (Liu (2003)).⁵ In the latter case, which is more common, the credibility of the standard and associated label is enhanced (Gruère (2013)). So, to obtain a label verified by a certifier, firms often have to pay both labeling and certification fees. For instance, to obtain the label Bourgeon, a swiss producer pays both a fee to a certifier and royalties of 0.9% of the profit made from labeled products to BioSuisse, the label owner.⁶

What are the characteristics of a disclosure composed of labeling and certification offered by two private middlemen? What are its effects on market pricing and how is the surplus shared between firms and middlemen? These are the questions that motivate the present work.

CONTRIBUTION. In the literature, certification and labeling are often either studied separately or bundled together and handled by one single middleman. This paper innovates by describing a disclosure that comprises two steps — certification and labeling — and involves two middlemen: the certifier and the label owner. To that end, I consider a model in which a monopolist can either buy a label or use price to signal the quality of their good. I study how the presence of these two middlemen impacts market pricing, the cost of disclosure and the sharing of the disclosure surplus. My main result is that a label owner defending the monopolist's interest can prevent the certifier from capturing the disclosure surplus, either by encouraging competition between certifiers or by monetizing the label. However, in the latter case, the price of the label has to be equal or higher than what it would be if the label owner was a for-profit entity.

A central feature of this work is in how my model deals with the structure and timing of the disclosure. It is composed of two types of cost: a certification fee, decided by the certifier, and the price of the label, decided by the label owner.⁷ In other words, it comprises two contracts offered by two distinct parties. These are *complementary*, meaning

⁴Alternatively, some entities use pre-existing standards to create their label.

⁵Indeed, standard setters may be tempted to promote their standards or to have bias, for or against, certain type of producers.

⁶This rule holds if the profit realized is above CHF100000, otherwise the producer pays a fixed contribution of CHF300)

⁷Though in practice the structure of the disclosure cost can differ, I focus on a common situation in which I assume that the two costs of disclosure are of different types: the certification fee is a fixed cost while the price of the label is a per-unit cost.

that firms accept either both or none of them. Also, the timing of the disclosure goes as follows. The label owner offers firms a price for the label.⁸ To use it, firms must first obtain a certification from a third-party certifier, who will then communicate the result back to the label owner.⁹ Though labeling occurs after certification, I assume that the labeling contract *predates* the certification contract. This is because I look at the common case in which the label owner is the one setting the standard and thereby initiating the disclosure process.

A second important feature of my model concerns the motivation of the middlemen. First, I study a label owner that is private and that can be of two types: a for-profit entity that maximizes their profit or an entity defending the industry — here composed of one monopoly.¹⁰ Of importance, in both cases, they are not in collusion with the monopolist which translate by the fact that they do not know at the moment of offering their contract the quality level of the monopolist. Because of that independence, my study departs from the literature on self-labeling.¹¹ Also, though this independence is necessary to maintain the credibility of the label this does not preclude the fact that the label owner defends the interest of the monopolist. In this case, they embody an entity that either is under the influence of the monopolist or share a common interest. This can for instance correspond to an industry association that creates their own label such as BioSuisse or the Association for Soaps, Detergents and Maintenance Products. Second, in my model, certifiers are private and for-profit, which it is mostly the case in reality.¹² I consider two cases: either the certifier is in a monopolistic position or in perfect competition. In reality, I observe a significant variability in the number of certifiers from one label to the other.¹³

For the sake of tractability I make some *simplifying assumptions*. First, I only consider two quality levels: high and low. This could cover cases in which either there are only

⁸In the model sections, the price of the label will be referred to as royalties.

⁹For the sake of simplicity I assumed the most basic certification contract in which audit happens with certainty. See the previous chapter of the thesis for a study of the certifier's strategy in which audit happens only with a certain probability.

¹⁰According to (Liu (2003)), when informational schemes are set by the industry or by another private actor, their interests are likely to be reflected in the standard.

¹¹Notice that there exists a literature that compares self-labeling and third-party labeling (see for instance Baksi and Bose (2007))

¹²They can alternatively be public or linked to the industry.

¹³For instance for the label MSC fisheries has fourteen approved certifiers while the organic food label Bourgeon has only two. For a more detailed discussion on the certifiers' competition see the previous chapter of the thesis.

two quality levels or consumers are only able to perceive two different levels of quality. Second, there is only one label owner. This is a reasonable assumption because, in reality, labels correspond to different levels of quality and so, in a scenario with two levels of quality, most often there is a label only for the high level.¹⁴

The *main results* of the paper are as follows. In the main part of this chapter, I consider a *monopoly* that has the choice between price signaling and disclosure. I model an endogenous disclosure mechanism with two strategic middlemen: the certifier and the label owner. In a first scenario, I consider that both middlemen are *for-profit* entities. The label owner chooses the price of the label that maximizes its revenue while respecting the feasibility constraints of the mechanism, namely the participation constraint of the monopolist and the budget constraint of the certifier. There are two cases, either the label owner can implement the optimal price or they must implement a second-best price that is lower. I show that, when the for-profit label owner can implement the optimal price, they *share* the surplus with either the certifier or, when there is competition between certifiers, the monopolist. However, when the label owner has to implement a lower price, they capture *all* the disclosure surplus. Since the label owner is the first to offer their contract as a take-it-or-leave-it offer, they are able to capture all the surplus. Nevertheless, their optimal strategy is not necessarily to capture all that surplus because the price that allows them to do so may not be the optimal price. This is because the price of the label creates a market price distortion. In a second scenario, the label owner *defends the industry* and the certifier is a for-profit entity. In this case, the price of their label and the sharing of the surplus depends on the competition between certifiers. I show that, when there is competition, the label is *free* and the monopolist gets *all* the disclosure surplus. Indeed, when certifiers are competing, they cannot capture any surplus. Alternatively, in the absence of competition, the certifier will try to capture the surplus but the label owner is able to do it first. For that, they need the price of their label to be *equal or higher* than what it would be if they were a for-profit entity. In this case, the monopolist does not get any disclosure surplus. This may suggest that the label owner may reinvest the revenue from labeling

¹⁴Note that the literature with competing labels remains relatively small but starts developing. In particular, [Fischer and Lyon \(2014\)](#) study the competition between two types of label owners: NGO and private. Of interest, in my model, the label owner and the certifier, because they provide complementary and not substitutable contracts, are not direct competing but they have conflicting objectives. This shows that in the disclosure process, on the top of the competition between label owners, there is a tension between the label owner and the certifier.

so that the monopolist could ultimately benefit from it later. I conclude that, for a label owner defending the industry to prevent a certifier from capturing the disclosure surplus, they should either encourage competition between certifiers or, when that is not possible, monetize the label.

Finally, as an extension, I consider a *duopoly*. I first examine the full information equilibrium in which two competing firms pay to disclose information. I show that an exogenous disclosure composed of a certification fee and labeling royalties *relaxes* price competition between the two firms. I then consider the separating perfect Bayesian equilibrium of price signaling in a duopoly. Lastly, I compare the realized profits of firms in these two equilibria. I show that, contrary to [Daughety and Reinganum \(2007\)](#), in some cases a firm facing a rival of higher quality level can get higher profit with disclosure than price signaling.

RELATED LITERATURE. As in the precedent chapter of the thesis, this work is related to the literature on the middleman and price signaling.¹⁵ In particular, in [Daughety and Reinganum \(2008a\)](#) a monopolist has the choice between using their price to signal quality or disclose quality by paying an exogenous certification fee. My work is directly related to their paper but it differs in two angles. First, there are two middlemen: the label owner and the certifier, instead of one. Second, because the middlemen are strategic, the disclosure process I describe is endogenous. Also, [Daughety and Reinganum \(2007\)](#) compare price signaling to free disclosure in a duopoly assuming that firms can commit to disclose before learning their type.¹⁶ My extension with a duopoly is directly inspired from their paper. I nevertheless consider an alternative disclosure that, instead of being free, is composed of a fixed cost and a per-unit fee.

My work is also related to the literature that study how disclosure costs affect market pricing and competition.¹⁷ In particular, [Crespi and Marette \(2001\)](#) consider a public third-party certifier providing food safety information to imperfectly informed buyers facing firms in Bertrand competition. They show that, different way of funding the certification

¹⁵See in particular [Lizzeri \(1999\)](#) and [Bagwell and Riordan \(1991\)](#).

¹⁶For papers that compare price signaling and a costly disclosure under imperfect competition see, for a duopoly [Daughety and Reinganum \(2008b\)](#) and, for different settings [Janssen and Roy \(2014\)](#) and [Caldieraro, Shin, and Stivers \(2011\)](#). More broadly for the literature on quality disclosure and imperfect competition see [Stivers \(2004\)](#), [Board \(2003\)](#), [Hotz and Xiao \(2005\)](#), [Cheong and Kim \(2004\)](#) and in particular [Levin, Peck, and Ye \(2009\)](#)

¹⁷On that topic see for instance [Auriol, Schilizzi, et al. \(2003\)](#) and [Yenipazarli \(2015\)](#)

have different impact on pricing and competition: a per-unit fee distorts the price but does not change the nature of competition while a fixed fee modifies the nature of the competition. In my model, disclosure simultaneously involves both types of disclosure costs: per-unit and fixed fee. I find that both in a monopoly and a duopoly, a per-unit fee distorts market pricing while a fixed fee does not. In addition, in the duopoly, per-unit cost relaxes price competition between two vertically differentiated firms while the fixed fee only affects the ordering of the profits.

Finally my paper is part of the literature that investigates and disentangles the different steps of disclosure process. As previously mentioned, [Delmas, Lyon, and Jackson \(2019\)](#) describe disclosure as a multi-step process: codification, standardization, certification and labeling. In particular, they show that certification and labeling are two different processes that are often complementary, but not always. For instance, [Delmas and Grant \(2014\)](#) show that in some industries, such as wine, eco-labeling and eco-certification strategies should be considered separately.¹⁸ In the current paper, contrary to [Delmas and Grant \(2014\)](#), I do consider that certification and labeling have complementary, but not separate benefits. I therefore restrict my analysis to products for which the certification does not bring benefits alone. In general this concerns final consumption goods for which the label is a form of communication with the end consumer.

ORGANIZATION OF THE PAPER. Section 3.1 presents the basic model as well as two relevant benchmarks: full information equilibrium and separating equilibrium with price signaling. Section 3.2 presents the disclosure mechanism with one strategic middleman. In section 3.3, I derive the disclosure mechanism with two strategic middleman. Finally in section 3.4 I examine an extension with a duopoly. Proofs are relegated to an Appendix.

¹⁸In case of wine, some benefits are associated with the certification process, such as improved reputation in the industry or increased product quality, that are independent the benefits associated with the actual label. Some wine are certified but does not have any labels. I observe a similar behaviors in other industries such as for instance in fishery. Some fisheries are certified against the MSC standard. Some retailers buy from these certified fisheries but do use the label to sell their fishes. It may reflect the fact, even though consumers are sensible to the quality associated to the MSC standard, the sealers are not always able to extract a margin from the label.

3.1. Model and benchmarks.

Both this and the previous chapter of the thesis share a common framework. I will therefore sometimes refer the reader to the previous chapter to avoid repetitions.

MONOPOLY. There is a single firm selling in this market. The firm produces one unit of a good of quality level θ at a linear cost increasing with the quality level $C(\theta) = \theta$ and sells this unit on the market at price p . A quality level θ represents the quality of the product, it may cover one or a set of multi-attribute criteria.¹⁹

BUYERS. There is a continuum of heterogeneous consumers of mass one in this economy. Each consumer buys one unit of good. Goods are vertically differentiated. All consumers prefer higher quality level and lower price. A consumer has the following indirect utility from purchasing a good of quality level θ :

$$v(\theta) - p + \varepsilon.$$

The quality θ is independently drawn from the common knowledge cumulative distribution $G(\cdot)$ with compact support $\Theta = [\theta_L, \theta_H]$, $v(\theta)$ is the common valuation for a good of quality level θ with the derivative $\dot{v}(\theta) > 0$ and ε is a consumer's specific parameter. Consumers' taste parameters ε are independently drawn from the same common knowledge cumulative distribution $F(\cdot)$ with compact support $[\underline{\varepsilon}, \bar{\varepsilon}]$. Consumers' aggregate demand is:

$$1 - F(p - v(\theta)).$$

Finally, I make assumptions that will be maintained throughout the paper.

Assumption 5. $\frac{d}{d\varepsilon} \left(\frac{1-F(\varepsilon)}{f(\varepsilon)} \right) \leq 0, \forall \varepsilon \in [\underline{\varepsilon}, \bar{\varepsilon}]$.

Assumption 6. $v(\theta) \geq \theta, \forall \theta \in \Theta$.

¹⁹This last interpretation of the quality as a multi-attribute criteria is supported by [Delmas and Colgan \(2018\)](#). They argue that consumers look for "green bundle" meaning that consumers look for a bunch of attributes and not only environmental attribute alone.

3.1.1. Full information equilibrium.

When consumers can observe the quality level θ , the monopolist sets the price so as to maximize their profit, i.e., such as:

$$p^m(\theta) = \arg \max_p (p - \theta) (1 - F(p - v(\theta))).$$

The full information monopoly price is:

$$p^m(\theta) = \theta + \frac{1 - F}{f} (p^m(\theta) - v(\theta)). \quad (3.1)$$

3.1.2. Separating signaling equilibrium.

Assume now that consumers can no longer observe the quality level θ . I note $p^s(\theta)$ and $\pi^s(\theta)$ the price and associated profit of the monopolist at the unique separating perfect Bayesian equilibrium in which the monopolist sets their price so as to signal quality level to uninformed consumers.²⁰

3.1.3. Exogenous disclosure.

Assume now that the monopolist can pay for a disclosure that consists in being audited to obtain a label that reveals perfectly their quality level θ to consumers. That disclosure entails a fee K and a price for the label k . Henceforth, I will refer to the price of the label as royalties. In this case, the profit of the monopolist writes:

$$\pi^d(\theta, k) - K = \max_p (p - \theta - k) (1 - F(p - v(\theta))) - K.$$

The monopolist chooses the disclosure price that maximizes their profit, namely:

$$p^d(\theta, k) = \theta + k + \frac{1 - F}{f} (p^d(\theta, k) - v(\theta)). \quad (3.2)$$

²⁰Since this equilibrium has been derived in the previous chapter of the thesis, I refer the reader to the Chapter 2 Section 2 for the more details.

This price is distorted with respect to the full information monopoly price $p^m(\theta)$. Indeed, if the fee K does not affect the pricing choice of the monopolist, the royalties k do. Taking the derivative of the price with respect to royalties:

$$p_k^d(\theta, k) = \frac{1}{1 - \left(\frac{1-F}{f}\right)' (p^d(\theta, k) - v(\theta))} \geq 0,$$

I see that the disclosure price increases with the royalties. If royalties tend to zero, the disclosure and full information prices are the same.

REMARK. In the previous chapter of the thesis I considered a [Daughety and Reinganum \(2008a\)](#) setting in which a monopolist simultaneously chooses between two options: either signaling quality with price or paying for the disclosure. Contrary to [Daughety and Reinganum \(2008a\)](#) and to what I did in the previous chapter of the thesis, the disclosure in the current chapter consists not only in a fixed fee but also in a per-unit cost. As a comparison I can briefly see how this additional disclosure cost would affect the choice of the monopolist previously studied.

When the monopolist pays for the disclosure, the royalties distort their price with respect to the full information price. This distortion is costly but this cost decreases with the quality level. Indeed, using the expression of the disclosure price (3.2), I see that the disclosure profit is increasing with the quality level, i.e.

$$\pi_\theta^d(\theta, k) = (1 - F(p^d(\theta, k) - v(\theta))) (\dot{v}(\theta) - 1) > 0. \quad (3.3)$$

This implies that, as quality level increases, it becomes more and more valuable for the monopolist to go through the disclosure process. With price signaling, the monopolist also distorts their price upward to signal higher quality level. However, this distortion increases with the quality level. This implies that the signaling profit decreases with the quality level, i.e.

$$\dot{\pi}^s(\theta) = -(1 - F(p^s(\theta) - v(\theta))) \leq 0. \quad (3.4)$$

The choice of the monopolist to go through the disclosure process or not depends on the respective profit they can get under each option. They choose disclosure whenever the profit difference $\pi^d(\theta, k) - \pi^s(\theta)$ is positive. Using (3.3) and (3.4), it is immediate that this difference is increasing with the quality level, i.e. $\pi_\theta^d(\theta, k) - \dot{\pi}^s(\theta) \geq 0$; from this follows

the next proposition.

Proposition 12. *For a well chosen couple of certification fee and royalties (K, k) , such as: $\pi^d(\theta_H, k) - \pi^s(\theta_H) \geq K \geq \pi^d(\theta_L, k) - \pi^s(\theta_L)$, there is a unique quality threshold θ^* such that $\pi^d(\theta^*, k) - \pi^s(\theta^*) = K$.*

This result tells us that, for well chosen values of certification fee and royalties, there is a quality threshold above which disclosure costs are lower than signaling costs. This implies that, any quality level above the threshold θ^* will disclose while the other levels will signal with price. I thereby extend the result of [Daughety and Reinganum \(2008a\)](#) to the case in which the exogenous disclosure is composed of both a fee and per-unit costs. \square

3.2. Endogenous disclosure with one middleman

In the previous section, I derived as a benchmark an exogenous disclosure. I will now examine an endogenous disclosure. To that end, I consider a non-cooperative game between strategic middlemen and a monopolist. As a first step, I study a disclosure in which there is only one strategic middleman in charge of both certification and labeling.²¹ In this scenario there are three players: the middleman, the monopolist and consumers.

MIDDLEMAN. The middleman is assumed to have the power to propose a contract to the monopolist on a take-it-or-leave-it basis. That contract consists in a certification fee and the royalties. When the monopolist accepts the contract, the middleman audits with certainty, incurs a cost c and discovers the quality. They then distribute a label that perfectly reveals the quality level to consumers.

CONSUMERS. They do not observe the contract between the middleman and the monopolist. They however observe the label, if any, and the price. I assume that when they observe a label, they trust it and ignore any information coming from price. When there is no label, they infer quality level from price.²²

²¹Notice that, in reality, there are cases in which only one entity does all the steps of the disclosure process. Common examples of standards setters that realize their own certification are entities that initially were doing certification and later developed their own standards. It is the case of EFSIS or the German Technical Inspection agency ([Jahn, Schramm, and Spiller \(2005\)](#)).

²²For a more detailed discussion on these beliefs see the previous chapter of the thesis in which the same assumption is made. The label is equivalent there to the outcome from certification.

TIMING. First, nature independently draws the quality level (or type) θ of the monopolist from a commonly known distribution that assigns probability λ and $1 - \lambda$ to high quality level θ_H and low quality level θ_L respectively. This quality level is private information of the monopolist. Next, the middleman proposes a menu of contracts to the monopolist that specify a fixed certification fee and royalties. The monopolist accepts or rejects the contract in accordance with their type. The contract is executed if accepted; otherwise, the monopolist's reservation allocation takes effect. When the contract is accepted, the middleman audits and gives a label to the monopolist that perfectly reveals quality level. In the third stage, the monopolist sets their price. In the last stage, consumers observe the label, if any, and the price; they accordingly update their beliefs and make their purchasing decisions.

MONOPOLIST' RESERVATION ALLOCATION. I assume that the reservation allocation corresponds to the the least costly separating equilibrium outcome. I note $\pi^r(\theta_L)$ and $\pi^r(\theta_H)$ the reservation outcome obtained by the the low and high quality levels respectively. At this equilibrium, the high quality distorts its price upward in a way that this distortion causes the minimum loss in profit needed to fully reveal that quality is high. The low quality level does not distort its price with respect to full information and therefore gets the same profit as they would get in a full information. The reservation allocation therefore entails $\pi^m(\theta_H) > \pi^r(\theta_L) = \pi^m(\theta_L) > \pi^r(\theta_H)$.²³ This reservation allocation has an important implication in my model. Indeed, the monopolist with a low quality level gets the same profit under the reservation allocation and full information. It follows that, a low quality level would never choose disclosure unless it is free. Such a disclosure would however be costly for the middleman that audits and would not reveal more information to consumers than what the reservation outcome already does. For this reason I will focus on the case in which a middleman proposes *a disclosure targeting only the high quality levels*. That middleman therefore looks for the disclosure contract $\{K(\theta_H), k(\theta_H)\}$ to offer to the monopolist where $K(\theta_H)$ is the certification fee and $k(\theta_H)$ is the royalties. In what follows, I use the following notations: $K_H = K(\theta_H)$ and $k_H = k(\theta_H)$.

EQUILIBRIUM CONCEPT. I look for a perfect Bayesian separating equilibrium in which a high quality level accepts the disclosure contract and a low quality level refuses it. For this, the contract $\{K_H, k_H\}$ offered by the middleman and targeted to high quality level

²³I refer to the previous chapter for a more detailed explanation of the reservation allocation.

must respect participation constraints. When consumers observe the label, they know that the good is of high quality level. At the equilibrium: the middleman maximizes their objective taking into account consumers' beliefs and anticipating the monopolist strategy, the monopolist chooses first whether to accept or not the contract and second which price to set in a way to maximize their profit taking into account consumers' beliefs and consumers choose whether to buy or not the good after updating their beliefs. Remark that, when the monopolist refuses the contract, they get the reservation allocation. The equilibrium set of the disclosure contract therefore consists in the feasible allocation that weakly Pareto dominate the reservation allocation. The least costly separating equilibrium is the lower bound for the Pareto criterion of the set of equilibrium allocations when the middleman proposes a contract.

PARTICIPATION CONSTRAINTS. Under disclosure the monopolist of high quality level sets the disclosure price $p^d(\theta_H, k_H)$ and receives the associated disclosure profit $\pi^d(\theta_H, k_H)$ minus the certification fee K_H . They accept the middleman's disclosure contract $\{K_H, k_H\}$ only if their expected utility exceeds the reservation outcome. This implies that, the following participation constraints must be respected:

$$\pi^d(\theta_H, k_H) - K_H \geq \pi^r(\theta_H). \quad (3.5)$$

Also, the strategic middleman only proposes a contract $\{K_H, k_H\}$ if they expect audit costs to be covered by the revenue from disclosure. This constraint writes:

$$K_H + k_H (1 - F(p^d(\theta_H, k_H) - v(\theta_H))) \geq c. \quad (3.6)$$

Set of feasible contracts

Taking together the monopolist participation and middleman's budget constraints, namely (3.5) and (3.6), I obtain the set feasible disclosure mechanisms for the high quality level as stated in the next lemma.

Lemma 12. *The disclosure contract offered to a high quality level is feasible only if:*

$$\begin{aligned} & (p^d(\theta_H, k_H) - \theta_H) (1 - F(p^d(\theta_H, k_H) - v(\theta_H))) - \pi^r(\theta_H) \\ & \geq K_H + k_H (1 - F(p^d(\theta_H, k_H) - v(\theta_H))) \geq c. \end{aligned} \quad (3.7)$$

This constraint says that gross gain from disclosure should be higher than the disclosure costs paid by the monopolist, which should be higher than the audit costs incurred by the middleman.²⁴ Of importance, the left-hand side of the inequality, i.e. the gross gain from disclosure, is by definition maximal at the full information price $p^m(\theta)$. This puts a higher bound on the certification fee and royalties the middleman can ask for. Also, there is a solution to the disclosure problem only if the feasible set described in (3.7) is not empty. This requires the following assumption insuring that the maximal surplus created by disclosure covers audit costs.

Assumption 7.

$$\pi^m(\theta_H) - \pi^r(\theta_H) \geq c.$$

3.2.1. For-profit middleman

I will successively consider two kinds of middleman: a for-profit entity and an entity defending the industry. I first consider a for-profit middleman that searches a certification fee K_H and the royalties k_H maximizing their expected revenue while being in the set of feasible allocations, namely:

$$\begin{aligned} \max_{\{K_H, k_H\}} & K_H + k_H (1 - F(p^d(\theta_H, k_H) - v(\theta_H))) - c \\ \text{s.t.} & (3.7). \end{aligned}$$

The middleman has two tools to capture the surplus: the certification fee and the royalties. The certification fee does not distort monopoly price contrary to royalties. The middleman anticipates the pricing strategy of the monopolist and takes into account the effect of the royalties on the disclosure price. In the description of the feasible mechanism, I saw that the gross gain from disclosure is maximal at the full information price $p^m(\theta)$. The middleman wants this surplus to be maximal in order to capture it. The monopolist only sets the full information price if royalties are nil. The next proposition exposes the separating PBE disclosure contract offered by a for-profit middleman.

Proposition 13. *When a for-profit middleman offers a disclosure contract only to the high quality*

²⁴By gross disclosure gain I mean the profit difference between signaling and disclosure without taking into account disclosure costs, the royalties and certification fees.

level, it consists of the maximal certification fee, i.e. $K_H = \pi^m(\theta_H) - \pi^s(\theta_H)$ and nil royalties, i.e. $k_H = 0$. They capture all the surplus.

3.2.2. Industry middleman

I now consider a middleman that defends the industry. That middleman looks for the certification fee K_H and the royalties k_H that maximize the industry expected profit (here composed of one monopoly). Their program is the following:

$$\begin{aligned} \max_{\{K_H, k_H\}} \quad & \lambda (\pi^d(\theta_H, k_H) - K_H) + (1 - \lambda)\pi^s(\theta_L) \\ \text{s.t.} \quad & (3.7). \end{aligned}$$

Since the certification fee and the royalties only affect the disclosure profit, the middleman objective in fact comes down to maximize the profit of a high quality level. By definition the profit of this type of monopolist is maximal at the full information price $p^m(\theta_H)$. By asking zero royalties, the monopolist does not distort their price, which means that they set the full information price. The middleman therefore chooses zero royalties and a certification fee as small as possible but that covers the audit costs. The following proposition summarizes the disclosure mechanism offered by the middleman defending the industry.

Proposition 14. *When a middleman defending the industry offers a disclosure contract only to the high quality level, it consists of a certification fee covering certification costs, i.e. $K_H = c$ and nil royalties, i.e. $k_H = 0$. The monopolist gets all the surplus.*

When the middleman, either for-profit or defending the industry, has the choice, they do not use royalties because they distort the monopolist's price. This distortion reduces the surplus that any type of middleman wants to maximize.²⁵ In what follows, I will consider two middlemen and assume that one uses a fixed fee and the other royalties.

In terms of sharing of the surplus, a for-profit middleman captures all the monopolist's surplus while a middleman defending industry sets a disclosure in which the monopolist gets all the surplus. A certification realized by the owner of the label may however lack

²⁵Of importance, in reality, other elements, that are out of the scope of that paper, affect which instrument the middleman may use. For instance, when the middleman and the firm decide a one or several years contract, the future amount of sells is uncertain. In this case, the middleman may prefer royalties, as their revenue will adapt to the realized profit.

of credibility for consumers. To solve this issue, the disclosure process may involve two middlemen. I will examine this scenario in the next section.

3.3. Endogenous disclosure with two middlemen

In the previous section, I investigated a strategic middleman undertaking both certification and labeling. I now consider the case in which the disclosure involves two strategic middlemen: a certifier and a label owner. There then are four players: the certifier, the label owner, the monopolist and the consumers. The certifier and the label owner offer separate but complementary contracts to the monopolist that accepts either both or none of them.

CERTIFIER. The certifier proposes a contract on a take-it-or-leave-it basis to the monopolist that consists in a fixed certification fee. If the monopolist accepts the contract, the certifier audits, incurs a fixed cost c and observes the quality level of the monopolist.

LABEL OWNER. The label owner sells labels that perfectly reveal quality level to consumers. The label owner does not directly observe the quality level but the certifier tells them the result of the certification. They offer a take-it-or-leave-it contract to the monopolist that is represented by the royalties paid by the monopolist to use the label as a function of the quality level revealed by the certification. I assume that the label owner bears negligible costs to issue the labels.²⁶

TIMING. First, nature independently draws the quality level θ of the monopolist from a commonly known distribution that assigns probability λ and $1 - \lambda$ to $\bar{\theta}$ and $\underline{\theta}$ respectively. This quality level is observed only by the monopolist and not by the middlemen nor the consumers. Next, the label owner offers a labeling contract to the monopolist that specifies royalties. After that, the certifier proposes a contract to the monopolist that specifies a fixed certification fee. The monopolist accepts or rejects both contracts in accordance with their type. The contract is executed if accepted; otherwise, the monopolist's reservation allocation takes effect. The reservation allocation is, as before, the least-costly separating allocation. When the contract is accepted, the certifier audits and communicates the result back to the label owner that distributes a label. In the third stage, the monopolist sets their

²⁶In particular these costs are negligible compared to audit costs. I discuss in the last section the case in which the label owner incurs some labeling costs.

price. In the last stage, consumers observe the label, if any, and the price; they revise their beliefs and make their purchasing decisions.

As it was the case with one middleman, a low quality level would only accept both contracts if they entail zero certification fee and zero royalties. Such disclosure mechanism would be costly for the certifier without bringing more information than what the reservation allocation does. For this reason, I focus on disclosure mechanism in which the middlemen only proposes a disclosure mechanism composed of two contracts targeting only the high quality level. The certifier therefore looks for the contract K_H and the label owner the contract k_H .

CONSTRAINTS. First, the decision of the monopolist to accept the disclosure mechanism is the same in the previous section. This means that the high quality level accepts the disclosure whenever (3.5) is respected. Second, the certifier faces a budget constraint and only offers a contract if their audit costs are covered by the certification fees. Knowing that only the high quality level goes through the disclosure process, this constraint writes:

$$K_H \geq c. \quad (3.8)$$

Set of feasible contracts

Taking together monopolist's participation and certifier's budget constraints, namely (3.5) and (3.8), I obtain the set feasible disclosure mechanism for high quality level as stated in the next lemma.

Lemma 13. *The disclosure mechanism offered to a high quality level is feasible only if:*

$$\pi^d(\theta_H, k_H) - \pi^s(\theta_H) \geq K_H \geq c. \quad (3.9)$$

The certification fee paid by the monopolist must cover audit costs but be lower than the difference between the disclosure profit and the signaling profit. As before, Assumption 7 should hold for a disclosure mechanism to exist.

Certifier contract

The for-profit certifier takes as given the labeling contract k_H and anticipates monopolist's and consumers' behaviors when they choose the fee K_H . I consider two scenarios. First, when there is a single certifier, they choose the fee K_H that maximizes their revenue and respects the feasibility constraint (3.9). The certifier selects the highest fee that respects the feasibility constraint, namely $K_H(k_H) = \pi^d(\theta_H, k_H) - \pi^s(\theta_H)$. In the second scenario, the certifier is in perfect competition with several identical certifiers. Due to perfect competition, they set certification fee that is equal to audit costs, i.e. $K_H = c$.

3.3.1. For-profit label owner

I will successively consider two types of label owner: a for-profit label owner and a label owner defending the industry. For each type I derive the disclosure mechanism and the sharing of the surplus. I first consider a for-profit label owner that maximizes their revenue.

LABEL OWNER. The label owner anticipates certifier's, monopolist's and consumers' behaviors. They know that the certifier chooses K_H taking k_H as given and so as to respect their maximization program. The for-profit label owner selects the level of royalties k_H that maximizes their expected revenue taking into account the feasibility constraint, namely:

$$\begin{aligned} \max_{k_H} \quad & \lambda (1 - F(p^d(\theta_H, k_H) - v(\theta_H))) k_H \\ \text{s.t.} \quad & (3.9). \end{aligned}$$

The label owner's revenue is quasi concave with respect to royalties. First, higher royalties mechanically increase their revenue. However, higher royalties also affect the monopolist price. Indeed, to a higher k_H , the monopolist answers by increasing the disclosure price $p^d(\theta_H, k_H)$. This triggers a decrease of the demand which reduces the label owner's revenue. The label owner trades off these two opposite effects. The value of royalties that maximizes their revenue is noted k^* and is worth

$$k^* = \frac{1}{p_k^d(\theta_H, k^*)} \frac{1 - F(p_k^d(\theta_H, k^*) - v(\theta_H))}{f}.$$

This optimal value is feasible only if it satisfies the feasibility constraint (3.9), i.e. if $\pi^d(\theta_H, k^*) - \pi^s(\theta_H) \geq c$. Because the disclosure profit decreases with royalties, i.e. $\pi_k^d(\theta, k) = -(1 - F(p^d(\theta, k) - v(\theta))) \leq 0$, the higher the royalties the harder it is to satisfy this feasibility constraint. I call \tilde{k} the threshold level of royalties such that the feasibility constraint (3.9) is binding, namely:

$$\pi^d(\theta_H, \tilde{k}) = \pi^s(\theta_H) + c.$$

Above this threshold, royalties are too high and the mechanism is not feasible because the certifier and/or the monopolist would not accept it. This means that the label owner can only choose royalties lower than this threshold. There are then two possible cases. Either the optimal level of royalties is lower than the threshold, i.e. $k^* \leq \tilde{k}$, and the feasibility constraint (3.9) is slack at k^* or the optimal level of royalties is higher than the threshold, i.e. $k^* > \tilde{k}$, and the feasibility constraint (3.9) is not respected for k^* . In the former case, the label owner implements the optimal level of royalties k^* . In the latter case, they choose a second-best level of royalties that is no other than the highest level of royalties that satisfies (3.9), namely the threshold \tilde{k} . The next proposition summarizes this separating disclosure mechanism.

Proposition 15. *When the label owner is a for-profit entity, the optimal disclosure mechanism addressed to a high quality level is such that:*

- *The label owner sets royalties such as:*

$$k_H = \min\{k^*, \tilde{k}\}$$

- *When there is only one certifier, they set the highest feasible fee, i.e. $K_H(k_H) = \pi^d(\theta_H, k_H) - \pi^s(\theta_H)$.*
- *When certifiers are in perfect competition, they select a certification fee that is equal to the audit costs, i.e. $K_H = c$.*

The label owner and the certifier have conflicting objectives, they both want to capture the surplus. The next corollary discusses the sharing of the surplus.

Corollary 2. • *When the label owner is for-profit, if the optimal level of royalties is feasible, i.e. if k^* satisfies (3.9), the surplus is shared among the label owner and the certifier or the*

label owner and the monopolist when there are competition between certifiers.

- *When the label owner is for-profit, if the optimal level of royalties is not feasible, i.e. if k^* does not satisfies (3.9), the label owner captures all the surplus.*

When the label owner is able to implement the optimal royalties k^* , the feasibility constraint (3.9) is not binding. This implies that, the label owner does not capture all surplus from disclosure. The remaining surplus is captured by the certifier when there is no competition or goes to the monopolist if there is competition between certifiers. When the label owner cannot implement k^* , they implement the second-best level that is \tilde{k} . With \tilde{k} , the feasibility constraint (3.9) is, by definition, binding. This implies that the label owner captures all the monopolist's surplus. It is interesting to see that the optimal strategy for the for-profit label owner is not necessarily to capture all the surplus. Indeed, the level of royalties \tilde{k} that may allow the label owner to capture all the surplus differs from the level of royalties k^* that maximizes their revenue. This is because royalties create a price distortion.

It appears that, because the label owner chooses first their contract, they can capture the surplus before the certifier and the monopolist. The monopolist might get some surplus only if there is competition between certifiers.

3.3.2. Industry label owner

I now consider a label owner defending the industry that is here composed of one monopoly. They may embody an industry association whose goal is to create a standard and associated label to reveal information to consumers or a labeling entity that has been captured by the monopoly.²⁷ In both case, they do not observe the quality level at the moment of deciding the royalties and they cannot recommend a price to the monopolist. In this they cannot be considered in collusion with the monopolist.

The label owner defending the industry maximizes the expected profit of the monop-

²⁷Note that, they may represent the interest of one or several identical monopolists operating on separate markets. These monopolists may gather to defend their interests even if they are not operating in the same markets.

olist subject to the same feasibility constraint as before. Their program is the following:

$$\begin{aligned} \max_{k_H} \quad & \lambda (\pi^d(\theta_H, k_H) - K_H) + (1 - \lambda)\pi^s(\theta_L) \\ \text{s.t.} \quad & (3.9). \end{aligned}$$

The next proposition describes the disclosure mechanism when the label owner defends the industry. I later explain the intuition and discuss the share of the surplus in this scenario.

Proposition 16. *When the label owner defends the industry, the optimal disclosure mechanism addressed to a high quality level is such that:*

- *When the certifier is not in competition, they choose the highest feasible fee, i.e. $K_H(k_H) = \pi^d(\theta_H, k_H) - \pi^s(\theta_H)$, and the label owner is indifferent between any level of royalties k_H in the set $k_H \in [0, \tilde{k}]$.*
- *When the certifiers are in competition, the fee is equal to audit costs, i.e. $K_H = c$ and the label owner offers the label for free, i.e. $k_H = 0$.*

The label owner has aligned interests with the monopolist and therefore chooses the level of royalties that maximizes the expected profit of the monopoly. Since royalties only affect the disclosure profit, it comes down to maximize only the profit of the high quality level. As royalties decrease disclosure profit, if royalties are worth zero the profit of the monopolist should be maximum. This happens when there is competition between certifiers that charge the smallest certification fee and the label owner gives the label for free. However, when there is no competition, the certifier selects the highest certification fee that saturates the feasibility constraint (3.9), namely the fee that is equal to the difference between the disclosure and the signaling profit. In this case, the monopolist can only obtain their signaling profit. The label owner cannot prevent the certifier from choosing this certification fee. It follows that they are indifferent between any royalties in the feasible set, namely any royalties between zero and \tilde{k} that saturate the feasibility constraint. In this scenario, the sharing of the surplus depends on the competition or not between certifiers as explained in the next corollary.

Corollary 3. • *When there are several certifiers and the label owner defends the industry, the monopolist gets all the surplus from disclosure.*

- *When there is only one certifier and the label owner defends the industry, the monopolist does not get any surplus from disclosure. The surplus is shared between the two middlemen depending on the level of royalties chosen by the label owner. If the label owner chooses \tilde{k} , they get all the surplus and the certifier none.*

For-profit certifiers and label owner defending the industry have conflicting interests. As showed by [Lizzeri \(1999\)](#), perfect competition between certifiers prevents certifiers from capturing the disclosure surplus. As explained in the introduction, in reality, the label owner is involved in the decision about which certifiers are entitled to certify their label. In practice, I see that label owners allow for several certifiers to perform certification. My model supports this fact as it is in the label owner's interest to allow for as many certifiers as possible to increase competition.²⁸ Nevertheless, the number of qualified certifiers may not be enough for competition to be perfect. In these cases, certifiers may have the capacity to capture some of the disclosure surplus. In my model, in the extreme case in which there is only one certifier, the monopolist cannot get any of the disclosure surplus. The label owner defending the industry cannot prevent a for-profit certifier from capturing the surplus, but by capturing it themselves. Indeed, if the label owner wants to capture all the surplus, they must select royalties as high (if $k^* \geq \tilde{k}$) or higher (if $\tilde{k} \geq k^*$) than a for-profit label owner. Though it is not in the objective of the label owner as I modeled it, one would suggest that, the label owner defending the industry should capture the surplus instead of letting the certifier capturing it. The label owner may ultimately use that money to promote the label or reinvest later in favor of the industry.²⁹

3.3.3. Potential extensions with a monopoly

LABEL OWNER'S COSTS. I assumed that the label owner issues labels at no or negligible costs. If the label owner faces labeling costs, it would add a label owner's budget constraint to the disclosure mechanism thereby reducing the interval of feasible royalties and

²⁸Under the condition that it does not affect the credibility of the label, which implies that certifiers should be well qualified.

²⁹In this case, one could argue that, I should take the return of investment into the participation constraint of the monopolist. I decided not to do that. First, to give credibility to the industry association there must be a true separation between the revenue of association and the monopolist. Second, due to this separation, it may be unclear how much and how long it would take for the monopolist to benefit from any re-investment of that money. It seems nevertheless coherent to assume that the monopolist prefers the industry association to get the disclosure surplus.

certification fees. It would however not affect the main results.

LABEL OWNER DEFENDING CONSUMERS. I could also derive the disclosure mechanism offered when the label owner defends consumers and aims at maximizing consumers' surplus.³⁰ I know that the higher the royalties, the higher the disclosure price selected by the monopolist and the lower the consumers' surplus. That label owner would then choose zero royalties so that the monopolist would set a disclosure price equal to their full-information price. The certifier's choice would remain the same as previously. Without competition, the certifier would choose the maximal certification fee, i.e. $K_H = \pi^m(\theta_H) - \pi^s(\theta_H)$, and capture all the disclosure surplus. With competition, the certification fee would be equal to the audit costs, i.e. $K_H = c$, and the monopolist would get all the disclosure surplus. In fact, whether the certifier chooses a small or high certification fee would not affect consumers' welfare, it would only affect the sharing of the surplus between the monopolist and the certifier. Of interest, this could fit with some cases observed in reality in which labels offered by non-profit entities are for free.

3.4. Extension Duopoly.

In this paper, I examined the interplay between an endogenous disclosure mechanism composed of certification fee and labeling royalties and price signaling. In a duopoly, a natural further work first consists in considering an exogenous disclosure composed of certification fee and labeling royalties and price signaling as two separate scenarios.³¹ In this extension, I will therefore examine the full information equilibrium in which two competing firms disclose information through disclosure. Disclosure, as before, will perfectly reveal quality level, is costly and composed of a certification fee and labeling royalties. I will then consider the separating perfect Bayesian equilibrium of price signaling

³⁰The middleman whose objective is to maximizing consumers' surplus may be understood as a non-profit entity (such as NGO or governmental agencies). In practice, non-profit entities are generally concerned about the environment or the provision of quality/safety. However, in my model, I do not model environmental externality and quality is exogenous. I therefore cannot investigate a non-profit entity minimizing externality or maximizing quality provision. For want of anything better, I would consider a non-profit entity maximizing consumers' surplus. That objective may be considered as a secondary objective for a non-profit entity that is also concerned about consumers' purchasing power (alternatively it could be part of the objective of a governmental entity).

³¹The study of the interplay between an endogenous disclosure mechanism composed of certification fee and labeling royalties and price signaling in a duopoly constitutes a further step and is left for future research.

in a duopoly following [Daughety and Reinganum \(2007\)](#). Lastly, I will have a discussion about the comparison between these two equilibrium.

Model

I consider an industry composed of two firms, named A and B . Each firm produces one unit of good of quality level i , $i = A, B$, denoted θ_i at a linear cost increasing with the quality level $C(\theta_i) = \theta_i$.

Products are *vertically differentiated* with respect to quality. The quality level of a product θ_i is either high θ_H with probability λ or low θ_L with probability $1 - \lambda$. As before, consumers cannot directly observe the quality level but know the ex-ante expected quality level for a firm denoted μ and that is equal to $\mu = \lambda\theta_H + (1 - \lambda)\theta_L$. All else equal, consumers prefer higher quality and lower prices.

Products are also *horizontally differentiated*. There is a continuum of heterogeneous consumers of mass one in this economy. Horizontal differentiation is captured by a Hotelling model. Consumers are uniformly located within an interval $[0, 1]$. I assume that, consumers location is common knowledge. Firm A is located at $x = 0$ and firm B is located at $x = 1$. Each consumer is characterized by their distance x from firm A (or equivalently their distance $1 - x$ from firm B). x can be interpreted literally as consumer's location or alternatively as the consumer's ideal consumption. Consumers face transportation cost (or alternatively deception cost) t per distance unit.

Given prices p_A and p_B charged by firms A and B , respectively, a type- x consumer purchasing one unit of product from firm A and B , has the indirect utility $v(\theta_A) - p_A - tx$ and $v(\theta_B) - p_B - (1 - x)t$, respectively. For sake of tractability I assume that, the valuation function is linear in the quality level, namely:

Assumption 8. $v(\theta) = \alpha\theta$ with $\alpha > 1$.

I will consider two different scenarios and derive the associated equilibrium. In the first scenario, firms use disclosure to reveal information to consumers (I will denote "disclosure" with the subscript d). In the second scenario, firms use their own price to reveal information to consumers (I will denote "signaling" with the subscript s).

3.4.1. Exogenous disclosure

I now study disclosure composed of certification and labeling. I examine an equilibrium in which low and high quality levels pay for a disclosure. The cost of disclosure consists of a certification fee $K(\theta)$ and labeling royalties $k(\theta)$ that depend on quality level.³² The timing of the game is as follows. First, nature selects quality levels θ_A and θ_B . Each firm observes its quality level. Disclosure happens revealing each firm quality level to firms and consumers. Next, firms simultaneously and non-cooperatively choose prices for their products. Finally, consumers decide from which firm to buy.

Disclosure happens before pricing and purchasing decisions. This implies that a firm knows both its quality level and its rival's quality level at the moment of setting its price.³³ Similarly consumers observe quality levels of both firms at the moment of deciding from which firm to buy. Given the prices p_A and p_B , a consumer located at x buys one unit of product A if:

$$\alpha\theta_A - p_A - xt \geq \alpha\theta_B - p_B - (1 - x)t$$

and otherwise buys one unit of product B . The consumer indifferent between consuming product A and B is $\tilde{x} = \frac{1}{2} + \frac{\alpha(\theta_A - \theta_B) - (p_A - p_B)}{2t}$. It follows that, the aggregate demand addressed to firm A is \tilde{x} and the aggregate demand addressed to firm B is $1 - \tilde{x}$. The aggregate demand for each product is increasing with vertical differentiation, decreasing with its own price, increasing with rival's price and decreasing with transportation costs. To ensure that any type of producer whatever the cost advantage has a positive market share, i.e. $\tilde{x} \in [0, 1]$, when selling at marginal cost, i.e. $p_i = \theta_i$, I make the following assumption.

Assumption 9. $t > (\alpha - 1)\Delta$,

where I define $\Delta = (\theta_H - \theta_L)$.

³²This disclosure is exogenous in the sense that I do not model how the middlemen choose $K(\cdot)$ and $k(\cdot)$, but I keep the assumptions that, there are two kinds of disclosure costs and that these costs depend on quality level.

³³The same hypothesis is made by [Daughety and Reinganum \(2007\)](#) and [Levin, Peck, and Ye \(2009\)](#). This assumption is not at odd with the reality. In fact, labels are granted for a minimum period of one year during which it is likely that several rounds pricing competition happen.

Since firms' demands functions are symmetric, I can write firm's i profit:

$$(p_i - \theta_i - k(\theta_i)) \left(\frac{1}{2} + \frac{\alpha(\theta_i - \theta_j) - (p_i - p_j)}{2t} \right) - K(\theta_i), \quad i = A, B; i \neq j. \quad (3.10)$$

The next proposition gives the equilibrium of disclosure.

Proposition 17. *The full disclosure ex post equilibrium price, quantity and profit for a firm whose quality level is m ($m = L, H$) facing a rival of quality level r ($r = L, H$) are as follows:*

$$\begin{aligned} P_{mr}^d &= t + \frac{\alpha(\theta_m - \theta_r)}{3} + \frac{2\theta_m + \theta_r}{3} + \frac{2k(\theta_m) + k(\theta_r)}{3}, \\ D_{mr}^d &= \frac{1}{2} + \frac{(\alpha - 1)(\theta_m - \theta_r) - k(\theta_m) + k(\theta_r)}{6t}, \\ \Pi_{mr}^d &= \frac{(3t + (\alpha - 1)(\theta_m - \theta_r) - k(\theta_m) + k(\theta_r))^2}{18t} - K(\theta_m). \end{aligned}$$

I see that both horizontal and vertical differentiation affect the equilibrium price, demand and profit. Price is increasing with the first, second and third terms, respectively transportation costs (horizontal differentiation), quality valuation difference (vertical differentiation) and its own and its rival's production costs. Further, the last term tells us that the equilibrium price is increasing with its own royalties and rival's royalties. It first reflects that royalties paid by a firm imply an upward distortion of its price. Second, it shows that the higher the royalties paid by that firm's rival, the more it increases its own price. Indeed, because its rival that pays higher royalties sets a higher price, the firm can set a higher price for itself without losing consumers. It shows that royalties *relax* price competition such as vertical and horizontal differentiation. The certification fee, however, plays the role of a fixed setup cost. This does not affect market pricing but affect firm's profit and therefore the decision to enter the market.

ENTRY CONDITIONS. A the equilibrium, profits must be positive. For that, I derive restrictions on the certification fee and the level of royalties using values of prices, demands and profits at the equilibrium. First, the price-cost margins should be positive. When both firms have the same quality level, it is immediate to obtain that they get the same positive demand, i.e. $D_{HH}^d = D_{LL}^d = \frac{1}{2} > 0$. In this case, profits are positive, i.e. $\Pi_{LL}^d \geq 0$ and $\Pi_{HH}^d \geq 0$ only if

$$\frac{1}{2}t \geq K_L \text{ and } \frac{1}{2}t \geq K_H. \quad (3.11)$$

These restrictions tell us that certification fee should not be prohibitively high compared to transportation costs, namely compared to the size of horizontal differentiation. Second, when firms have different quality levels, the demands $D_{LH}^d \geq 0$ and $D_{HL}^d \geq 0$ are positive only if:

$$(\alpha - 1)\Delta + 3t \geq k_H - k_L \geq (\alpha - 1)\Delta - 3t. \quad (3.12)$$

That means that the gap between royalties paid by the high and low quality levels should not be too low otherwise the demand addressed to a low quality level is negative but it should not be too high neither otherwise the demand addressed to the high quality level is negative. In addition, the profits are positive, i.e. $\Pi_{LH}^d \geq 0$ and $\Pi_{HL}^d \geq 0$, only if:

$$\frac{(3t - (\alpha - 1)\Delta - k_L + k_H)^2}{18t} \geq K_L. \quad (3.13)$$

$$\frac{(3t + (\alpha - 1)\Delta - k_H + k_L)^2}{18t} \geq K_H. \quad (3.14)$$

COMPARATIVE STATICS. I now examine comparative statics to understand better the effect of royalties on firms in a duopoly. The next corollary describes the signs of the derivatives of a firm's price, demand and profit with respect to its own and its rival's quality level.

Corollary 4. *The derivatives of a firm's price, demand and profit with respect to its own quality level ($m = L, H$) and its rival's quality level ($r = L, H$) are such that:*

a. *If royalties slightly increase or decrease with the quality level, i.e. $\alpha - 1 \geq \dot{k}(\theta) \geq -\left(\frac{\alpha+2}{2}\right)$:*

i *the price of the firms increases with its own quality level and decreases with its rival's quality*

level, i.e. $\frac{\partial P_{mr}^d}{\partial \theta_m} \geq 0$ and $\frac{\partial P_{mr}^d}{\partial \theta_r} \leq 0$,

ii *the firm's demand increases with its own quality level and decreases with its rival's quality*

level, i.e. $\frac{\partial D_{mr}^d}{\partial \theta_m} \geq 0$ and $\frac{\partial D_{mr}^d}{\partial \theta_r} \leq 0$

iii *the profit of the firm decreases with its rival's quality level, i.e. $\frac{\partial \Pi_{mr}^d}{\partial \theta_r} \leq 0$, and $\frac{\partial \Pi_{mr}^d}{\partial \theta_m} = \frac{\alpha-1-\dot{k}(\theta_m)}{3} D_{mr}^d + (P_{mr}^d - k(\theta_m) - \theta_m) \frac{\partial D_{mr}^d}{\partial \theta_m} - \dot{K}(\theta_m)$.*

b. *If royalties strongly decrease with the quality level, i.e. $\dot{k}(\theta) \leq -\left(\frac{\alpha+2}{2}\right)$:*

i *the price of the firm price decreases with both its own and its rival quality level, i.e. $\frac{\partial P_{mr}^d}{\partial \theta_m} < 0$*

and $\frac{\partial P_{mr}^d}{\partial \theta_r} \leq 0$,

ii the derivatives of demand and profit are the same as in the previous case a.

c. If royalties strongly increase with the quality level, i.e. $\dot{k}(\theta) \geq \alpha - 1$:

i the price of the firm price increases with both its own and its rival's quality level, i.e. $\frac{\partial P_{mr}^d}{\partial \theta_m} \geq 0$ and $\frac{\partial P_{mr}^d}{\partial \theta_r} \geq 0$,

ii the demand of the firm decreases with its own quality level and increases with its rival's quality level, i.e. $\frac{\partial D_{mr}^d}{\partial \theta_m} \leq 0$ and $\frac{\partial D_{mr}^d}{\partial \theta_r} \geq 0$,

iii the profit of the firm increases with its rival's quality level, i.e. $\frac{\partial \Pi_{mr}^d}{\partial \theta_r} \geq 0$, and $\frac{\partial \Pi_{mr}^d}{\partial \theta_m} = \frac{\alpha-1-\dot{k}(\theta_m)}{3} D_{mr}^d + (P_{mr}^d - k(\theta_m) - \theta_m) \frac{\partial D_{mr}^d}{\partial \theta_m} - \dot{K}(\theta_m)$.

Three main effects determine the signs of these derivatives. The first is *vertical differentiation*: a higher quality level increases the price and demand of a firm, while a higher rival's quality level decreases them. The second results from *royalties*. For instance, when royalties increase with quality level, a firm with a higher quality level will set a higher price, which then decreases its demand. Also, a firm facing a rival with a higher quality level will increase its own price because price competition is relaxed. In fact, because a firm with low quality level pays lower royalties than its rival, disclosure gives that firm a competitive advantage. With two quality levels, the magnitude of that effect depends on relative the gap between k_L and k_H . The third effect concerns the *certification fee*. When the fee decreases with quality, having a higher quality level affects negatively the profit.

Vertical differentiation, the royalties and the fee may affect prices, quantities and profits in the same or opposite directions. Which effects dominate depends on the preferences' parameter α as well as the royalties and certification fee's functions $k(\cdot)$ and $K(\cdot)$. Corollary 4 describes *three* possible cases. In case a, the royalties either slightly increase or decrease with the quality level, which means that the difference of royalties paid by low and high quality level is limited. In this case, the effect of vertical differentiation is stronger than the royalties. This implies that, the price and quantity of the firm increase with its own quality level and, its price, quantity and profit decrease with its rival's quality level. These effects the same as in a duopoly model of *free* disclosure in presence of vertical differentiation (see [Daughety and Reinganum \(2007\)](#)). In case b, the royalties significantly decrease with the quality level. The royalties' effect is strong which gives an advantage to the high quality levels that pay less royalties than the low quality levels. The price of the

firm now decreases with its own quality level. This results from the fact that, the royalties' effect overcomes the vertical differentiation. The other derivatives remain the same as the royalties and the vertical differentiation effects go in the same direction. Finally in case c , the royalties significantly increase with the quality level. As in the previous case, the royalties' effect is stronger than the vertical differentiation. However, now, the royalties' effect gives an advantage to the low quality levels. As a result, the price of the firm increases both with its own quality level and its rival's quality level. Also, the demand increases with its own quality level and both the demand and the profit are increasing with its rival's quality level. In the three cases, the sign of the derivative of prices and demands is determined by the joint effect of vertical and royalties. The sign of the derivative of firm's profit with respect to its own quality level however additionally depends on the certification fee. This renders the interpretation of its sign undetermined without additional assumptions about the model's parameters.

The equilibrium, in which disclosure is costly and composed of a certification fee and royalties that vary with the quality level, allows us to identify effects that are not visible if the disclosure was free. First, the royalties *soften price competition*. Second, depending on the relative strength of vertical differentiation and royalties, the disclosure *affects differently* the price, demand and profit of a firm as a function of its quality level.

3.4.2. Separating signaling equilibrium

I look for perfect Bayesian equilibrium in which firms use their price to signal their quality level to uninformed consumers. The timing of the game is the following: First, nature selects the nature of the goods θ_A and θ_B . Each firm observes its quality level but not its rival's quality level. Next, firms simultaneously and non-cooperatively choose prices for their products. Finally, consumers observe prices, update their beliefs and decide from which firm to buy.

I am interested in separating perfect Bayesian equilibrium in which the price chosen by a firm perfectly reveals its quality level to consumers. In this equilibrium, the price chosen differs for every quality level; both firms post the same price only if they have the same quality level. This implies that consumers observe the signaling price, update their beliefs and can infer the quality level. At the equilibrium, consumers' beliefs should be

correct. In addition, firms A and B have symmetric cost and demand functions and the prior distribution over quality level μ is also the same for both firms. I can thus focus on symmetric equilibrium in which both firms use the same price strategy and consumers' beliefs about quality level does not depend on the firm being A or B but solely on the observed price p . I denoted $\phi(p) \in [0, 1]$ a representative consumer's posterior belief that a product is of high quality level, after observing its price p .³⁴ At the moment of taking their pricing decisions, firms do not know about their rival's quality level. I denote firm i 's profit as a function of its price p , its true quality level θ , the perceived quality level $\tilde{\theta}$ and the expected price of its rival $E_\theta(p_j)$: $\pi_i(p, \theta, \tilde{\theta} | E_\theta(p_j))$, $i \neq j$.

Definition 2. A symmetric separating perfect Bayesian equilibrium consists of a pair of price (P_L^s, P_H^s) and beliefs $\phi^s(\cdot)$ such that, for $i, j = A, B$, $i \neq j$:

- i.* $\pi_i(P_L^s, \theta_L, \theta_L | E_\theta(p_j)) \geq \max_p \pi_i(p, \theta_L, \phi^s(p) | E_\theta(p_j))$
- ii.* $\pi_i(P_H^s, \theta_H, \theta_H | E_\theta(p_j)) \geq \max_p \pi_i(p, \theta_H, \phi^s(p) | E_\theta(p_j))$
- iii.* $\phi^s(P_H^s) = 1$ and $\phi^s(P_L^s) = 0$
- iv.* $E_\theta(p_j) = \lambda P_H^s + (1 - \lambda)P_L^s$.

The third condition defines the beliefs at the separating equilibrium. With these beliefs, the first two incentive conditions insure that, at the separating equilibrium, a firm must have no incentive to deviate from the equilibrium price corresponding to its quality level. To solve this equilibrium I follow the technique of [Daughety and Reinganum \(2007\)](#) that consists in first solving *i.* and *ii.* constraints to obtain best response functions as a function of $E_\theta(p_j)$ and second, using *iv.* to solve the equilibrium prices.

The next Proposition exposes the refined symmetric separating perfect Bayesian equilibrium. As there are several candidates to the equilibrium, I use the Intuitive Criterion so as to narrow down to one solution (the details are relegated to the Appendix).

³⁴Note that consumer's inference about the quality level of a product only depends on its price and not on its rival's price. Indeed, as firm is ignorant of its rival's type at the moment it decides for its own price, there is no reason for consumers to infer any information about a product quality level from observing the price posted by its rival. [Fudenberg and Tirole \(1991\)](#) refers to as "no signaling what you don't know".

Proposition 18. *Using the Intuitive Criterion, there is a unique refined symmetric separating perfect Bayesian equilibrium with prices (P_L^s, P_H^s) and beliefs ϕ^s such as:*

$$\begin{aligned} P_L^s &= t + \theta_L + \frac{\alpha}{2}\lambda\Delta(\eta - 1), \\ P_H^s &= t + \theta_H + \Delta\left(\frac{\alpha}{2}(1 + \lambda)(\eta - 1) + \alpha - 1\right), \\ \phi^s(p) &= 0 \text{ when } p < P_H^s \text{ and } \phi^s(p) = 1 \text{ when } p \geq P_H^s. \end{aligned}$$

with $\eta = \lambda + ((\lambda - 1)^2 + \frac{4t}{\alpha\Delta})^{\frac{1}{2}} > 1$.

By re-expressing P_H^s as: $P_H^s = P_L^s + \frac{\alpha}{2}\Delta(\eta + 1)$, I obtain that high quality level selects higher price than low quality level, namely $P_H^s > P_L^s$. As in a monopoly setting, at the signaling equilibrium, upward distortion of the price is used to signal higher quality level.³⁵ In what follows I will use the notation Π_{mr}^s to denote the signaling equilibrium profit for a firm whose quality level is m ($m = L, H$) facing a rival of quality level r ($r = L, H$).

Notice that I implicitly preclude the existence of a symmetric separating price equilibrium with zero profit. For this, I need to restrict the parameters so as to guarantee an interior equilibrium both *ex ante* and *ex post*. These restrictions are exposed in the proof of the Proposition.

3.4.3. Comparison of the realized profits in the two equilibrium

[Daughety and Reinganum \(2008b\)](#) compare the realized profits in the equilibrium of complete information with free disclosure and the equilibrium of incomplete information with price signaling. First, they show that realized profits are higher in the price signaling equilibrium for firms of the same quality level. Second, they show that this is also the case for a low quality level facing a high quality level. One can ask whether these two results hold when the disclosure is not free anymore but firms pays a certification fee (sunk cost) and labeling royalties (per-unit cost). In fact, it is pretty straightforward to obtain that, if disclosure was only a sunk cost, their results still hold. Indeed, a sunk cost only decreases the complete information profit by a constant which can only reinforce their result. The true question is then how royalties affect [Daughety and Reinganum \(2008b\)](#)'s results. To do so, I consider the case in which only the high quality pays for the disclosure with positive

³⁵For more details on this equilibrium see [Daughety and Reinganum \(2007\)](#).

royalties $k_H > 0$ and disclosure is free for the low quality $k_L = 0$; this generates a maximal differentiation. Also, for sake of simplicity, I assume that certification fees are negligible and are worth zero $K_L = K_H = 0$.

IDENTICAL QUALITY LEVELS. First, when a firm has the same quality as its rival, it is immediate to find that, in my model as in [Daughety and Reinganum \(2007\)](#), they get a better realized profit with signaling than with a disclosure, i.e. $\Pi_{mm}^s > \Pi_{mm}^d$, $m = L, H$. This comes from the fact that there is a crucial difference in the pricing decision between signaling and disclosure. When firms signal, they choose their price without knowing their rival's quality level. On the contrary, with the disclosure, firms know the quality of their rival before taking their pricing decision. Indeed, at the equilibrium, a firm infers the quality level of its rival from observing the label (or none). This implies that, if both signaling and disclosure attenuate price competition, they do it in different ways. On one hand, price signaling reduces price competition as a function of the distribution of quality levels. Indeed, if a firm expects its rival to be of high quality level with a high probability, it selects a higher signaling price which relaxes price competition. The higher the prior proportion of high quality level, the lower price competition will be. On the other hand, the disclosure relaxes price competition as a function of the realized vertical differentiation and if there is any, and the gap between the royalties paid by firms. It follows that when both firms are the same quality level, disclosure prices take into account the fact that there is no vertical differentiation and firms pay the same amount of royalties. On the contrary, the signaling prices do not take into account the absence of vertical differentiation (only as a probability). Price competition is therefore less intense with signaling and firms get higher profits with signaling than disclosure. I therefore see that the presence of royalties does not affect the first result of [Daughety and Reinganum \(2007\)](#). This is due to the fact that when firms have the same quality level they pay the same amount of royalties which does not create any additional differentiation.

DIFFERENT QUALITY LEVELS. I will see that, in some cases, the second result of [Daughety and Reinganum \(2007\)](#) according to which a low quality level facing a high quality level gets higher profit with signaling than with disclosure does not hold when disclosure comprises royalties. First, the next proposition states that higher royalties benefit to low quality firm.

Proposition 19. *For any values of royalties that respect the entry condition (3.12), the disclosure*

profit of a high quality level facing a low quality level decreases with royalties, i.e. $\frac{\partial \Pi_{HL}^d}{\partial k_H} \leq 0$, and the profit of a low quality level facing a high quality level increases with royalties, i.e. $\frac{\partial \Pi_{LH}^d}{\partial k_H} \geq 0$.

To understand this proposition, see that royalties have two effects on these profits. The first effect adversely affects low and high quality levels. Royalties reduce the demand addressed to the high quality level which then reduces its profit and increases the one of the low quality level. The second effect is that royalties relax the intensity of price competition which benefits to both high and low quality levels. For royalties that respect the entry conditions, the proposition however tells us that, the high quality level does not benefit from higher royalties. The effect of softening price competition is not high enough to compensate for the loss of competitiveness due to paying for the disclosure while the low quality level does not pay.

It follows that royalties paid by a high quality level will affect the distributional impact of the disclosure, namely the ordering of prices, quantities and profits. The next proposition exposes how the size of royalties determines these orderings, and in particular, which of the high or low quality level has the highest profit.

Proposition 20. *At the full disclosure equilibrium where only high quality levels pay for disclosure, prices, quantities and profits, as a function of own and rival's quality levels, are ordered as follows:*

a. *for low values of royalties, i.e. $\Delta(\alpha - 1) > k_H > (\alpha - 1)\Delta - 3t$:*

$$i \quad P_{HL}^d > P_{HH}^d > P_{LL}^d > P_{LH}^d;$$

$$ii \quad D_{HL}^d > D_{LL}^d = D_{HH}^d > D_{LH}^d;$$

$$iii \quad \Pi_{HL}^d > \Pi_{HH}^d = \Pi_{LL}^d > \Pi_{LH}^d.$$

b. *for high values of royalties, i.e. $(\alpha - 1)\Delta + 3t - 3\sqrt{2tc} > k_H > \Delta(\alpha - 1)$:*

$$i \quad P_{HH}^d > P_{HL}^d > P_{LH}^d > P_{LL}^d;$$

$$ii \quad D_{LH}^d > D_{LL}^d = D_{HH}^d > D_{HL}^d;$$

$$iii \quad \Pi_{LH}^d > \Pi_{LL}^d > \Pi_{HH}^d > \Pi_{HL}^d.$$

This proposition tells us that these ordering vary whether the optimal level of royalties

is lower or higher than the threshold $(\alpha - 1)\Delta$.³⁶ When royalties are not too large (case *a.*), the effect of vertical differentiation is stronger than the effect of royalties. The ordering is actually the same as if disclosure was free.³⁷ Due to vertical differentiation, price, demand and profit are lowest for a low quality level facing a rival of high quality level (and reversely highest for a firm whose quality level is high facing a rival of low quality level). Now, when royalties are sufficiently large (case *b.*), the ranking of prices, demands and profits are modified with respect to a free disclosure. In this case, the effect of royalties overcomes the effect of vertical differentiation. As a result of the high quality level prices being higher, the size of the market addressed to a high quality level is lower than the one addressed to a low quality level. So, a low quality level always gets a higher profit than a high quality level.

The question is whether this reversal of the ordering of disclosure profits due to royalties may be high enough for a low quality facing a high quality level to get higher realized profit with disclosure than signaling. The next proposition tells us that, in some circumstances, this is the case.

Proposition 21. *For well chosen values of parameters t, α, Δ and λ , for any royalties such that $k_H \in [(\alpha - 1)\Delta - 3t + \frac{3}{2}\sqrt{(\alpha\Delta(\eta - 1) + 2t)(\alpha\Delta\lambda(\eta - 1) + 2t)}, (\alpha - 1)\Delta + 3t - 3\sqrt{2tc}]$, the realized profit of a low quality facing a high quality is higher with disclosure than with signaling, i.e. $\Pi_{LH}^d \geq \Pi_{LH}^s$.*

This result tell us that, for some values of the parameters, there exist some high levels of royalties for which a low quality level facing a high quality level gets higher realized profits in the equilibrium of complete information with disclosure than in the price signaling equilibrium.³⁸ This result differs with the Proposition 7 of [Daughety and Reinganum \(2007\)](#). The difference comes from the fact that, in their model, because disclosure is free a low quality level always prefers signaling. In my model, there exists some levels of royalties that relax price competition in a way that can benefit to the low quality level.

Future research could consist in studying the interplay between price signaling and

³⁶Note that this threshold corresponds to the minimum of the ex ante profit for a firm that would not know yet their quality level.

³⁷For more details on the ordering with free disclosure see [Daughety and Reinganum \(2007\)](#).

³⁸Notice however that for other values of parameters, the realized profit of a low quality facing a high quality is always higher with signaling for any values of royalties that respect the entry conditions, i.e. $\Pi_{LH}^s > \Pi_{LH}^d$. See the proof of the proposition for more details on this case.

third-party labeling in duopoly. This represents several challenges. First, one needs to define the link between the two forms of communication: price and label. This question is central as this will affect how consumers form beliefs about the quality level. Second, the middlemen need to offer a disclosure that will respect incentives and participation. These constraints may be complex to take into account due to the fact that, as I saw in that extension, disclosure affects competition between the two firms.³⁹

3.5. Conclusion

This paper studied a disclosure strategy that consists of two steps — certification and labeling — and that involves two middlemen: the certifier and the label owner. I showed how the presence of these two middlemen affects market pricing, the cost of disclosure and the sharing of the surplus. The study from the OCDE ([Prag, Lyon, and Russillo \(2016\)](#)) shows an increasing number of privately owned informational schemes. My model could explain this tendency because a private label owner, either for-profit or from the industry, is in a strategic position to capture the surplus that could otherwise be captured by a certifier. In particular, in a monopoly, I saw that a for-profit label owner sets a price for the label and captures most or all of the disclosure surplus. Alternatively, a label owner defending the industry can prevent a certifier from capturing the disclosure surplus, either by monetizing the label or making it free and encouraging competition between certifiers. This last result may explain some cases that are observed in reality. For instance, with only two certifiers verifying their label, the industry association BioSuisse gets 64% of their revenue from selling their organic food label.

In this paper, I shed light on an aspect of the disclosure that is often neglected: the presence of two middlemen. Future research on this topic could investigate, as mentioned above, the interplay between price signaling and third-party labeling in duopoly. Also, in my model, certification and labeling are complementary and a single firm pays for both of them. One could consider cases in which certification and labeling also have benefits on their own and cases where they are paid by two different entities. For instance, a producer

³⁹Remark that this should be related to the line of research that analyses third-party labeling in a competitive market for a credence product. See for instance [Baksi and Bose \(2007\)](#) and [Mason \(2011\)](#). This differs however in the fact that, price signaling cannot play any role in those models because firms are assumed to be in perfect competition. Consumers infer quality from the label only.

can pay for the certification of a good before selling it to a retailer, who can then pay for the label themselves.

3.6. Appendix

Proof of Proposition 16. When certifiers are in perfect competition, they choose $K_H = c$. Taking that into account, the label owner's program writes:

$$\begin{aligned} & \max_{k_H} \pi^d(\theta_H, k_H) - c \\ & \text{s.t. } \pi^d(\theta_H, k_H) - \pi^s(\theta_H) \geq c. \end{aligned}$$

In this case, because the disclosure profit is decreasing with royalties, i.e. $\pi_k^d(\theta, k) = -(1 - F(p^d(\theta, k) - v(\theta))) \leq 0$, the best choice for the label owner is nil royalties. Now, when the certifier is alone, they choose $K_H(k_H) = \pi^d(\theta_H, k_H) - \pi^s(\theta_H)$ and the label owner's program writes:

$$\begin{aligned} & \max_{k_H} \pi^s(\theta_H) \\ & \text{s.t. } \pi^d(\theta_H, k_H) - \pi^s(\theta_H) \geq c. \end{aligned}$$

In this case, there is no way for the label owner to influence the profit of the monopoly. The label owner is indifferent between any k_H that respects the monopolist's participation constraint, namely $k_H \in [0, \tilde{k}]$. \square

Proof of Proposition 17. I am looking for a Bertrand equilibrium with vertical and horizontal differentiation in which quality levels are common knowledge. Maximizing firm's i profit (3.10) with respect to p_i gives the functions of best responses for firms $i = A, B$:

$$p_A(p_B) = \frac{t + \alpha(\theta_A - \theta_B) + p_B + \theta_A + k(\theta_A)}{2} \quad (3.15)$$

$$p_B(p_A) = \frac{t - \alpha(\theta_A - \theta_B) + p_A + \theta_B + k(\theta_B)}{2}. \quad (3.16)$$

Using (3.15) into (3.16) I obtain the equilibrium prices:

$$P_{AB}^d = t + \frac{\alpha(\theta_A - \theta_B) + 2\theta_A + \theta_B + 2k(\theta_A) + k(\theta_B)}{3}$$

$$P_{BA}^d = t + \frac{-\alpha(\theta_A - \theta_B) + 2\theta_B + \theta_A + 2k(\theta_B) + k(\theta_A)}{3}.$$

Using equilibrium prices in the expressions of profit and demand, I obtain the equilibrium profits and demands. \square

Proof of Corollary 4. For a firm of quality level $m = L, H$ facing a rival $r = L, H$, the derivatives of its price and demand with respect to its own and rival's quality level are:

$$\frac{\partial P_{mr}^d}{\partial \theta_m} = \frac{\alpha + 2 + 2\dot{k}(\theta_m)}{3}, \quad \frac{\partial P_{mr}^d}{\partial \theta_r} = \frac{-\alpha + 1 + \dot{k}(\theta_r)}{3},$$

$$\frac{\partial D_{mr}^d}{\partial \theta_m} = \frac{\alpha - 1 - \dot{k}(\theta_m)}{6t}, \quad \frac{\partial D_{mr}^d}{\partial \theta_r} = \frac{-\alpha + 1 + \dot{k}(\theta_r)}{6t}.$$

The derivative of its profit with respect to its own quality level is:

$$\begin{aligned} \frac{\partial \Pi_{mr}^d}{\partial \theta_m} &= \left(\frac{\partial P_{mr}^d}{\partial \theta_m} - 1 - \dot{k}(\theta_m) \right) D_{mr}^d + (P_{mr}^d - k(\theta_m) - \theta_m) \frac{\partial D_{mr}^d}{\partial \theta_m} - \dot{K}(\theta_m) \\ &= \frac{\alpha - 1 - \dot{k}(\theta_m)}{3} D_{mr}^d + (P_{mr}^d - k(\theta_m) - \theta_m) \frac{\partial D_{mr}^d}{\partial \theta_m} - \dot{K}(\theta_m), \end{aligned}$$

and the derivative of its profit with respect to his rival's quality level is:

$$\frac{\partial \Pi_{mr}^d}{\partial \theta_r} = \frac{\partial P_{mr}^d}{\partial \theta_r} D_{mr}^d + (P_{mr}^d - k(\theta_m) - \theta_m) \frac{\partial D_{mr}^d}{\partial \theta_r}.$$

The signs of the derivatives are derived directly from expressions above. \square

Proof of Proposition 18. With full information, the demand addressed to firm $i = A$, corresponds to the consumer indifferent between consuming product A or B , namely $\tilde{x} = \frac{1}{2} + \frac{\alpha(\theta_A - \theta_B) - (p_A - p_B)}{2t}$. Now, I consider scenario in which consumers do not observe quality levels and firms do not know their rival's quality level. In this case, when firm i sets a price p , its true quality level is θ and the perceived quality level is $\tilde{\theta}$, the demand firm's i

expects (not knowing its rival's j type) is:

$$\frac{1}{2} + \frac{\alpha(\tilde{\theta} - \mu) - (p - E_{\theta}(p_j))}{2t}$$

with $\mu = \lambda\theta_H + (1 - \lambda)\theta_L$. It follows that, a firm i 's profit as a function of its price p , its true quality level θ and the perceived quality level $\tilde{\theta}$ writes:

$$\pi_i(p, \theta, \tilde{\theta} | E_{\theta}(p_j)) = (p - \theta) \left(\frac{1}{2} + \frac{\alpha(\tilde{\theta} - \mu) - (p - E_{\theta}(p_j))}{2t} \right), \quad i, j = A, B; i \neq j.$$

I introduce the subscripts m and r for quality levels θ_m and θ_r , where m and r can be H or L . To denote the profit of a firm charging price p , whose actual type is m and whose perceived type is r , I use a notation:

$$\pi_{mr}(p) = (p - \theta_m) \left(d_r - \frac{p}{2t} \right)$$

with $d_r = \frac{1}{2} + \frac{\alpha(\tilde{\theta}_r - \mu) + E_{\theta}(p_j)}{2t}$. Without signaling consideration, the price maximizing π_{mr} would be $\rho_{mr} = \frac{2td_r + \theta_m}{2}$ and the associated profit $\pi_{mr} = \frac{(2td_r - \theta_m)^2}{8t}$. These prices are actually the best responses to $E_{\theta}(p_j)$ and are ordered as: $\rho_{HH} > \rho_{LH} > \rho_{HL} > \rho_{LL}$.

In order to guarantee an interior equilibrium, I will restrict the parameters both for *ex ante* and *ex post*. First I consider *ex ante* restrictions. To ensure that there is always a profitable price for a firm, regardless of the consumer's perceptions of quality and regardless of the rival firm's expected price, I need $2td_m > c_r$ for all m, r . The most stringent constraint is $2td_L - \theta_H > 0$, that is $t + \alpha(\theta_L - \lambda\theta_H - (1 - \lambda)\theta_L) + E_{\theta}(p_j) - \theta_H > 0$. Recognizing that λ may be arbitrarily close to 1 and $E_{\theta}(p_j)$ close to 0, I use the following sufficient condition:

Assumption 10. $t - \alpha\Delta > \theta_H$.

For the *ex post* restrictions, I will verify afterwards that the price cost margin and quantities are positive at the equilibrium for the different combinations of m and r , namely that: $2td_L > \theta_H$, $2td_L > \theta_L$, $2td_H > \theta_H$ and $2td_H > \theta_L$.

To derive the separating equilibrium price, I follow the same method as [Daughety and Reinganum \(2007\)](#), that consists of three steps:

1. I derive the best response function for a firm i as a function of $E_\theta(p_j)$.
2. I then use the equilibrium condition on $E_\theta(p_j)$ (condition *iv.* of the Definition 2) and solve for a fix point.
3. The resulting solution (denoted $E_\theta(P^s)$) is then substituted back into the best response functions so as to obtain the equilibrium prices (denoted P_L^s and P_H^s).

Step 1. I previously derived the best response functions ignoring signaling considerations. I now want to take into account the signaling considerations and derive a separating best response functions. The separating best response functions should be such that each quality level prefers to play its best response than mimicking the best response of the other quality level to be perceived as such. Firms have incentive to distort their price from their best response in order to be perceived as H but not as L (that is the most belief anyway). It follows that, when a firm is perceived as being of low quality level, the best response and associated profit of a low quality level is ρ_{LL} and $\pi_{LL} = \frac{(2td_L - \theta_L)^2}{8t}$ and, ρ_{HL} and $\pi_{HL} = \frac{(2td_L - \theta_H)^2}{8t}$ for a firm of high quality level. Since firms has an incentive to be perceived as high quality level, at a separating equilibrium the best response price for high quality level p should respect two constraints. First, it should prevent low quality level from distorting its price in order to be perceived as high quality level. Concurrently, the price should provide a profit high enough for high quality level to prefer to be perceived as high quality level instead of selecting ρ_{HL} and being perceived as low quality level. It follows that, the candidate to a separating price p at the equilibrium should respect the following set of constraints:

$$\left\{ p|(p - \theta_L) \left(d_H - \frac{p}{2t} \right) \leq \frac{(2td_L - \theta_L)^2}{8t} = \pi_{LL} \text{ and } (p - \theta_H) \left(d_H - \frac{p}{2t} \right) \geq \frac{(2td_L - \theta_H)^2}{8t} = \pi_{HL} \right\}.$$

Solving these two inequalities, I obtain two sets of conditions: $p \in [0, r_2] \cup [r_1; +\infty]$ and $p \in [r_4, r_3]$ with

$$r_1 = \frac{(2td_H + \theta_L) + 2t [(d_H - d_L)(d_H + d_L - \frac{\theta_L}{t})]^{\frac{1}{2}}}{2}, r_2 = \frac{(2td_H + \theta_L) - 2t [(d_H - d_L)(d_H + d_L - \frac{\theta_L}{t})]^{\frac{1}{2}}}{2},$$

$$r_3 = \frac{(2td_H + \theta_H) + 2t [(d_H - d_L)(d_H + d_L - \frac{\theta_H}{t})]^{\frac{1}{2}}}{2}, r_4 = \frac{(2td_H + \theta_H) - 2t [(d_H - d_L)(d_H + d_L - \frac{\theta_H}{t})]^{\frac{1}{2}}}{2}.$$

From their expressions and using the fact that $2td_m > \theta_r$ for all m, r , I find that $r_3 > r_4$ and $r_1 > r_4 > r_2$. Denoting $\Delta = \theta_H - \theta_L$, I distinguish two cases:

- i. if $[d_H + d_L - \frac{\theta_L}{t}]^{\frac{1}{2}} - [d_H + d_L - \frac{\theta_H}{t}]^{\frac{1}{2}} > \frac{\Delta}{2t[d_H - d_L]^{\frac{1}{2}}}$, then $r_1 > r_3$ and there is no solution for p .
- ii. if $\frac{\Delta}{2t[d_H - d_L]^{\frac{1}{2}}} \geq [d_H + d_L - \frac{\theta_L}{t}]^{\frac{1}{2}} - [d_H + d_L - \frac{\theta_H}{t}]^{\frac{1}{2}}$, then $r_3 > r_1 > r_4$ and the solution p is in the interval $[r_1, r_3]$.

Using $d_H - d_L = \frac{\alpha\Delta}{2t}$, I can simplify and obtain

- i. if $[d_H + d_L - \frac{\theta_L}{t}]^{\frac{1}{2}} - [d_H + d_L - \frac{\theta_H}{t}]^{\frac{1}{2}} > [\frac{\Delta}{2t\alpha}]^{\frac{1}{2}}$, then $r_1 > r_3$ and there is no solution for p .
- ii. if $[\frac{\Delta}{2t\alpha}]^{\frac{1}{2}} \geq [d_H + d_L - \frac{\theta_L}{t}]^{\frac{1}{2}} - [d_H + d_L - \frac{\theta_H}{t}]^{\frac{1}{2}}$, then $r_3 > r_1 > r_4$ and the solution p is in the interval $[r_1, r_3]$.

I want to consider cases in which there is a solution, for this reason I rule out case *i*. and focus on case *ii*. The next question is to know whether in case *ii*. the best response price $\rho_{HH} = \frac{(2td_H + \theta_H)}{2}$ belongs to the interval of prices that respect the condition of a separating equilibrium. Using the assumption so that $2td_m > c_r$ for all m, r , I find that the entire interval involves prices in excess of ρ_{HH} . Since the best response ρ_{HH} is not within the interval of prices, the high quality level is forced to distort its price upwards.

There is now a full interval of candidates $([r_1, r_3])$ for the best separating response for high quality level. I use an equilibrium refinement to narrow down to one solution. I use the Intuitive Criterion according to which the firm of high quality H distorts its best response to the minimum extent necessary to deter mimicry by the low quality level L .⁴⁰ The firm i thus chooses the lower bound of the interval so as distort the less possible the price. This means that, the pair of separating best response functions is $(\rho_L^s(E_\theta(p_j)) = \rho_{LL}, \rho_H^s(E_\theta(p_j)) = r_1)$.

Step 2. According to the definition of the separating Bayesian equilibrium, the equilibrium expected price $E_\theta(P^s)$ is solution to the equation:

$$X = \lambda\rho_H^s(X) + (1 - \lambda)\rho_L^s(X). \quad (3.17)$$

⁴⁰See [Daughety and Reinganum \(2007\)](#) for a discussion on the justification to use this refinement in this situation.

Let $Y = X - \theta_L$, using the best response, (3.17) becomes:

$$Y = t + \lambda (2\alpha\Delta(Y + \gamma))^{\frac{1}{2}} \quad (3.18)$$

with $\gamma = t + \frac{\alpha(1-2\lambda)\Delta}{2}$.⁴¹ Let $W = (2\alpha\Delta(Y + \gamma))^{\frac{1}{2}}$ and change variable again so that (3.18) becomes:

$$W^2 - \lambda 2\alpha\Delta W - 2\alpha\Delta(\gamma + t) = 0.$$

Solving this second-degree equation, I find one positive solution $W^* = \alpha\Delta\eta$ with $\eta = \lambda + ((\lambda - 1)^2 + \frac{4t}{\alpha\Delta})^{\frac{1}{2}}$. Now using W^* , (3.17) and (3.18) I obtain:

$$E_\theta(P^s) = t + \lambda\alpha\Delta\eta + \theta_L. \quad (3.19)$$

Step 3. I can now obtain the expression of the ex-post equilibrium price substituting $E_\theta(P^s)$ into $\rho_L^s(E_\theta(p_j))$ and $\rho_H^s(E_\theta(p_j))$ to obtain:

$$\begin{aligned} P_L^s &= t + \theta_L + \frac{\alpha}{2}\lambda\Delta(\eta - 1) \\ P_H^s &= t + \theta_H + \Delta\left(\frac{\alpha}{2}(1 + \lambda)(\eta - 1) + \alpha - 1\right). \end{aligned}$$

I can now verify the *ex post* restrictions $2td_m > \theta_r$ for all m, r . To have $2td_L > \theta_H$, I must assume that

Assumption 11. $2t > \Delta(1 - \lambda\alpha(\eta - 1))$.

All the other restrictions are verified at the equilibrium. □

Proof of Proposition 19. Taking the derivative of the disclosure profit of high quality level facing low quality level, I obtain $\frac{\partial \Pi_{HL}^d}{\partial k_H} = \frac{-(\alpha-1)\Delta + k_H - 3t}{9t}$. I thus obtain, that, for values of royalties that respect the entry condition (3.12), $\frac{\partial \Pi_{HL}^d}{\partial k_H} \leq 0$. Similarly, I obtain the derivative of the disclosure profit of low quality level facing high quality level $\frac{\partial \Pi_{LH}^d}{\partial k_H} = \frac{-(\alpha-1)\Delta + k_H + 3t}{9t}$. I then deduce that, taking into account the entry condition (3.12), $\frac{\partial \Pi_{LH}^d}{\partial k_H} \geq 0$. □

⁴¹The expression under the square root is positive for any $\gamma > 0$, i.e. $t > \frac{\alpha(2\lambda-1)\Delta}{2}$, which is not a very constraining hypothesis.

Proof of Proposition 20. When only high quality levels pay for disclosure, equilibrium price, demand and profit expressions remain the same as in Proposition 17 but with $k_L = K_L = K_H = 0$, namely

$$\begin{aligned}
P_{HH}^d &= t + \theta_H + k_H, \quad P_{LL}^d = t + \theta_L, \\
P_{HL}^d &= t + \frac{\alpha\Delta}{3} + \frac{2\theta_H + \theta_L}{3} + \frac{2k_H}{3}, \quad P_{LH}^d = t - \frac{\alpha\Delta}{3} + \frac{2\theta_L + \theta_H}{3} + \frac{k_H}{3}; \\
D_{HH}^d &= D_{LL}^d = \frac{1}{2}, \\
D_{HL}^d &= \frac{1}{2} + \frac{(\alpha-1)\Delta - k_H}{6t}, \quad D_{LH}^d = 1 - D_{HH}^d = \frac{1}{2} - \frac{(\alpha-1)\Delta - k_H}{6t}; \\
\Pi_{HH}^d &= \frac{1}{2}t, \quad \Pi_{LL}^d = \frac{1}{2}t, \\
\Pi_{HL}^d &= \left(\frac{3t + (\alpha-1)\Delta - k_H}{3} \right)^2 \frac{1}{2t}, \quad \Pi_{LH}^d = \left(\frac{3t - (\alpha-1)\Delta + k_H}{3} \right)^2 \frac{1}{2t}.
\end{aligned}$$

For the price ordering, it is clear by inspection that $P_{HH}^d > P_{LL}^d$, $P_{HL}^d > P_{LH}^d$, $P_{HL}^d > P_{LL}^d$. Moreover, by computing $P_{LH}^d - P_{LL}^d = \frac{(1-\alpha)\Delta + k_H}{3}$, I obtain two sub-cases for the complete price ordering. With similar methods, I rank the demands. Concerning profits ranking, it is straightforward to show that $\Pi_{LL}^d > \Pi_{HH}^d$. Also,

$$\begin{aligned}
\Pi_{LL}^d - \Pi_{LH}^d &= ((\alpha-1)\Delta - k_H)(k_H - (\alpha-1)\Delta + 6t), \\
\Pi_{HL}^d - \Pi_{HH}^d &= (k_H - (\alpha-1)\Delta)(k_H - (\alpha-1)\Delta - 6t), \\
\Pi_{LH}^d - \Pi_{HL}^d &= K_H + \frac{2}{3}(k_H - (\alpha-1)\Delta).
\end{aligned}$$

In addition, with $k_L = K_L = K_H = 0$, the set of entry conditions (3.11), (3.12), (3.13) and (3.14) simplifies to:

$$(\alpha-1)\Delta + 3t - 3\sqrt{2tc} \geq k_H \geq (\alpha-1)\Delta - 3t. \quad (3.20)$$

Therefore by reducing the values of royalties with this entry condition (3.20), I obtain the different cases of profit ordering exposed in Proposition 20. \square

Proof of Proposition 21. Taking the difference between the realized profits $\Pi_{LH}^d - \Pi_{HL}^s$ I obtain an equation of second degree in k_H . This difference is negative for $k_H \in [k_{H1}, k_{H2}]$ and

positive for other values of royalties where

$$k_{H1} = (\alpha - 1)\Delta - 3t - \frac{3}{2}\sqrt{(\alpha\Delta(\eta - 1) + 2t)(\alpha\Delta\lambda(\eta - 1) + 2t)}$$

$$k_{H2} = (\alpha - 1)\Delta - 3t + \frac{3}{2}\sqrt{(\alpha\Delta(\eta - 1) + 2t)(\alpha\Delta\lambda(\eta - 1) + 2t)}$$

Taking into account the entry condition (3.20) to limit the possible values of royalties, I differentiate two cases. In the first case, when the parameters t, α, Δ and λ are such that $(\alpha - 1)\Delta + 3t - 3\sqrt{2tc} \geq k_{H2}$, this implies that for all royalties $k_H \in [k_{H2}, (\alpha - 1)\Delta + 3t - 3\sqrt{2tc}]$, I have $\Pi_{LH}^d \geq \Pi_{LH}^s$. In the second case, when the values of parameters t, α, Δ and λ are such that $k_{H2} > (\alpha - 1)\Delta + 3t - 3\sqrt{2tc}$, this means that there is no royalties that both respect the entry condition (3.20) and such that $\Pi_{LH}^d \geq \Pi_{LH}^s$. In this case, for royalties respecting the entry condition, it is always the case that $\Pi_{LH}^s > \Pi_{LH}^d$. \square

ADDITIONAL FORMULA - SIGNALING. At the separating signaling equilibrium, quality levels are correctly inferred so that the formula for equilibrium demands and profits are given by: $D_{mr}^s = \frac{1}{2} + \frac{\alpha(\theta_m - \theta_r) - (P_m^s - P_r^s)}{2t}$ and $\Pi_{mr}^s = (P_m^s - \theta_m)D_{mr}^s$ with $m, r = H, L$. Further using the expressions of the equilibrium prices P_L^s and P_H^s , I obtain:

$$D_{HL}^s = \frac{1}{2} - \frac{\alpha\Delta(\eta - 1)}{4t}, \quad D_{LH}^s = \frac{1}{2} + \frac{\alpha\Delta(\eta - 1)}{4t}, \quad D_{HH}^s = D_{LL}^s = \frac{1}{2},$$

$$\Pi_{LL}^s = (P_L^s - \theta_L) D_{LL}^s = \frac{1}{2} \left(t + \frac{\alpha}{2} \lambda \Delta (\eta - 1) \right),$$

$$\Pi_{HH}^s = (P_H^s - \theta_H) D_{HH}^s = \Pi_{LL}^s + \Delta \left(\frac{\alpha(\eta + 1) - 2}{2} \right),$$

$$\Pi_{LH}^s = (P_L^s - \theta_L) D_{LH}^s = \left(t + \frac{\alpha}{2} \lambda \Delta (\eta - 1) \right) \left(\frac{1}{2} + \frac{\alpha\Delta(\eta - 1)}{4t} \right),$$

$$\Pi_{HL}^s = (P_H^s - \theta_H) D_{HL}^s = \left(t + \Delta \left(\frac{\alpha}{2} (1 + \lambda) (\eta - 1) + \alpha - 1 \right) \right) \left(\frac{1}{2} - \frac{\alpha\Delta(\eta - 1)}{4t} \right).$$

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