Three Essays About the Interaction Between Economic Regulation and Entry

Maria Paula Vicente Sarmento

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Orientada por:

António Abílio Garrido da Cunha Brandão

Faculdade de Economia

Universidade do Porto

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Biographic Note

Maria Paula Vicente Sarmento was born on the 2nd of March of 1967 in Porto, Portugal.

She holds a *Licenciatura em Economia* since 1990 and a degree of *Mestre em Economia* since 1997, both from Faculdade de Economia da Universidade do Porto. Her Master's dissertation entitled "*Crescimento de Empresas*" has been supervised by Professor Alberto Castro.

She has taught at Faculdade de Economia da Universidade do Porto since 1992: Introductory Economics (1992-1995), Microeconomics (1995), Industrial Organisation (1995-1999) and Economics of Technology (1999-2000).

She has also taught at Faculdade de Engenharia da Universidade do Porto (1997-2000), at Universidade Católica - Centro Regional do Porto (1992-1995; 1998-1999), and at Instituto de Estudos Superiores Financeiros e Fiscais (1990-1998).

She is a researcher of CETE – Research Center on Industrial, Labour and Managerial Economics since 1997.

Between 1990 and 1992 she worked as economist at the research department of the Stock Exchange of Porto.

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Abstract

This dissertation comprises three essays on the interaction between economic regulation and entry. In the first essay we investigate how an incumbent firm can use the regulatory policy and the informational advantage to protect its monopolistic position. This question is studied through the construction of a signal game, under which we assume that the regulator has less information about demand than the firms. We conclude that there is an equilibrium in which entry is deterred and, if demand is high, there will be insufficient entry. The final result on welfare depends on the trade-off between short-run benefits (lower price) and long-run benefits (stronger competition).

In the second essay we study the way a multiproduct firm, regulated through a dynamic price cap, can develop a price strategy that uses the regulatory policy to deter entry. We consider a firm that initially operates as a monopolist in two markets but faces potential entry in one of the markets. We conclude that the regulated firm can have the incentive to block the entry. This strategy leads to the reduction of the price in both markets. However, the final effect of the entry deterrence strategy on total consumer surplus is not always positive.

In the third essay we compare two instruments of access price regulation, cost-based and retail-minus, with the full deregulation hypothesis. We consider an upstream monopolist firm that sells a vital input to an independent firm and to a subsidiary firm in the downstream market. We conclude that retail-minus regulation avoids foreclosure and leads to better results than cost-based regulation in terms of investment level and consumer surplus. Moreover, retail-minus regulation allows a higher consumer surplus than deregulation as long as the regulator carefully defines the retail-minus instrument.

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Chapter 1

Introduction

In several European countries network industries, such as telecommunications, energy and transports, had been privatised during the 1980s and 1990s. Until then these sectors frequently were public monopolies. The privatisation was, in most cases, followed by the creation of independent regulatory authorities with the purpose of defining and implementing the regulatory policy in each sector. In parallel, or with some time discrepancy, the entry of new firms were allowed in some markets, or at least, in some segments of those markets.

Contrary to Europe, the United States has a long tradition in the regulation of private monopolies. Telecommunication and power utilities, for example, have been regulated since the beginning of the last century. These sectors were considered natural monopolies (essential due to large scale economies) and the regulatory policy was implemented to guarantee that the monopolist firms did not take advantage of their market power through the practice of excessively high prices.[1] Therefore, the modifications in network industries in the United States, that began in the late 1970s, but became widespread especially in the 1980s, were not derived from privatisation but from the significant change in the characteristics of regulatory policy.

One of the most important changes in regulation was the gradual substitution of the traditional instruments of regulation, namely the rate of return regulation, by incentive regulation instruments, especial price caps, but also others like profit sharing, banded rate of return regulation or yardstick regulation.[2] In the present context incentive regulation means the implementation of regulatory instruments that give more flexibility to the firms, in particular concerning price definition, and allow the firms to directly benefit from cost reductions and from successful innovations. Incentive regulation is commonly opposed to the utilisation of regulation instruments that directly restrain firms' earnings, as happens with rate of return regulation. The

[1] For a brief history of economic regulation in the United States see, for instance, Viscusi *et al.* (2001). For a comprehensive review of the evolution of telecommunications industry in the United States see, for example, Brock (2002).

[2] For a recent and detailed description of incentive regulation instruments see Sappington (2002) or Vogelsang (2002). Joskow and Schmalensee (1986) is a reference paper about incentive regulation.

telecommunications sector provides an example of this modification in the regulatory instruments used. According to data collected by Ai and Sappington (2002) for the United States, 50 states were using rate of return regulation and none using price cap regulation in 1985. By 1999, only 12 states maintained the rate of return regulation while 35 were using price cap regulation and three states other forms of incentive regulation.

Another crucial modification in the regulatory policy was the openness to competition of some network industries, or of some segments of those industries. The entry of new firms completely changed the structural characteristics of the industries. One example of a deep process of market deregulation and liberalisation is the air transport sector in the United States. The deregulation process started in 1978 with the end of entry and price regulation and later, in 1985, involved the abolishment of the sectorial regulator, the Civil Aeronautics Board.[3] Other network industries, like telecommunications or energy, are passing through a more gradual process of deregulation and liberalisation. The liberalisation of network industries in other countries, from Eastern Europe, Latin America and Asia, are also taking place especially since the 1990s.[4]

The liberalisation tendency observed since the 1980s can be explained not only by the political, social and economic environment favourable to the introduction of competition but also because of the huge technological development that deeply transformed several markets. One of the major modifications due to technological progress is related to the importance of the economies of scale which justified many of the regulatory interventions. The technological evolution leads several authors to share the opinion expressed by Joskow (2002) that *"technological changes in these sectors* [networks industries] *over time have reduced the significance of economies*

[3]For a concise description of the regulation policy of the air transport sector in the United States see Bailey (2002).

[4]Estache *et al.* (2002), and the references included therein, present a description of the liberalisation tendency observed in the telecommunications sector in Latin America. Newbery (2000) includes a synthesis of the recent evolution of network industries in several Eastern Europe countries.

of scale, economies of scope, and/or economies of vertical integration and increased opportunities to replace regulated monopoly in some segments of these industries with competitive markets." Additionally, as pointed by Crew and Kleindorfer (1999, p.1) *"allowing entry into regulated monopolies undermines the traditional structure of these industries and of regulation itself."* Moreover, the openness of some segments to new firms raises questions about how regulation and entry interact because they coexist, at least during an initial phase of the liberalisation process. *"When entry occurs in an industry that has been liberalized, price regulation often continues, at least for a period."* (Armstrong *et al.*, 1994, p.129)

In face of regulation and of new competitors it is expected that the incumbent firm behaves in a different way, possibly in a strategic way to protect its especial position in the market. Also, it is expected that the regulatory authorities, when defining the regulatory policy, take in consideration not only the effects of the policy in the attractiveness of entry but also the possible reactions of the incumbent firm to regulation and to entry. These reactions of firms and regulator to the possibility of entry were the reality that motivated our interest in the relation between economic regulation and entry.

The present work studies the behaviour of the three agents mentioned above, the regulatory authority, the incumbent firm, and the entrant firm, regarding the interaction between economic regulation and the liberalisation of the markets. In the present work we do not intent to provide a comprehensive analysis of the relation between economic regulation and entry (that is done for instance by Crew and Kleindorfer, 1999). Our approach is to identify especific problems under the broad subject of the interaction between economic regulation and entry, and analyse them in detail in each of the chapters.

In Chapters 2 and 3 we study how the incumbent firm reacts to potential entry knowing the regulatory policy that is in force. In both chapters we assume that the regulatory policy is exogenously defined. More specificaly, in both chapters we analyse the strategic utilization of the regulatory policy by the incumbent firm in order to protect its monopoly position from potential entry. While sharing the

fundamental question, Chapters 2 and 3 differ in the regulatory policy considered. In Chapter 2 we assume that the regulator decides the number of firms that can operate in the industry (entry regulation) while in Chapter 3 the regulator interferes with price definition. In Chapter 4 the interaction between economic regulation and entry is studied from a different perspective because the attention is directed at the definition of the regulatory policy. In particular, in Chapter 4 we compare three different regulatory approaches in terms of the impact on entry.

Additionally, in Chapter 2 it is assumed that the regulator has an information disadvantage in relation to the regulated firm while in Chapter 3, and also in Chapter 4, we assume that all the agents have symmetric information. Therefore, in Chapter 2 a Bayesian model in the sense defined by Baron (1989) and Vogelsang (2002) is presented. This means that the equilibrium of the game depends on regulator's a priori information represented by the subjective probabilities given by the regulator to each possible situation. In contrast, in Chapters 3 and 4 non-Bayesian regulatory mechanisms under which the regulatory authority bases its policy on observable variables are presented. Hence, the modelisation presented in Chapters 3 and 4 involves the application of games with complete information.

By their construction Chapters 2, 3 and 4 can be read independently. Each chapter represents an investigation work that includes the definition of the question in study, the presentation of a survey of the relevant literature for that especific question, the description and resolution of the theoretical model used to answer the problem in place and the presentation of the conclusions about the question in study. However, the three chapters are at the same time related because they represent a particular approach of a general question about the interaction between economic regulation (entry regulation, regulation of retail prices and access price regulation) and entry.

The question studied in Chapter 2 concerns the behaviour of an incumbent firm that operates in a market subject to entry regulation and where it is assumed that the regulatory authority has less information than the firm regarding the size of the market demand. Our question is to characterise the conditions under which the incumbent firm uses the regulatory policy and the informational advantage to protect

its monopolistic position in the market. The above question is studied through the construction of a signal game inspired by the literature about entry deterrence with asymmetric information, in particular in the model of Milgrom and Roberts (1982). We assume that although the regulatory authority does not observe the demand, it considers the market price in the period pre-regulation as a signal about demand size. As the incumbent firm knows this behaviour of the regulatory authority, it strategically defines the price of the pre-regulation period in order to influence the regulator's decision.

Under our model entry regulation is justified by the Excess Entry Theory applied by Mankiw and Winston (1997) to oligopoly markets with homogenous product. The main argument is that in the presence of scale economies, entry can bring more benefits to new firms than to social welfare because business stealing effects might occur. In this case, there will be excessive entry from the social welfare point of view. The excessive entry problem is strengthened by the strategic behaviour of the incumbent firm in the presence of asymmetric information unfavourable to the regulatory authority.

In the model developed we assume that if the regulator knew the demand size it would authorise the entry of a relatively high number of new firms if demand was high but if, on the contrary, demand size was low the regulator would only authorise a small number of firms to enter the market. As the regulator does not observe demand, the incumbent firm's strategy is to convince the regulator that demand is low. The implementation of this strategy is made through the choice of a low price in the period pre-regulation. With the signalling model presented we proved that, under some conditions, the choice of a low price by the incumbent firm belongs to a Pooling Perfect Bayesian Equilibrium. At this equilibrium the regulator only authorises the entry of a small number of new firms, which benefits the incumbent firm.

In order to study the impact of the type of competition after entry and the impact of the existence of two incumbent firms in the first period on the equilibrium strategies we consider a particular case of the model. We assume a linear demand, variable

costs normalised to zero and only one entrant. Regarding the type of competition after entry we conclude for the existence of the Pooling Perfect Bayesian Equilibrium described in the general model as long as the duopoly interaction expected for the second period leads to a price above a critical level. Cournot competition is an example of this case. In relation to the second point we conclude that the existence of two incumbent firms in the first period does not change the general conclusion of the signal game, because the duopolists have the incentive to tacitly cooperate in the implementation of the pooling equilibrium in order to deter the entry of a third firm.

In Chapter 3 we study how a multiproduct firm, regulated through a dynamic price cap, can develop a price strategy that uses the regulatory policy to deter entry. We consider that the regulated firm initially operates as a monopolist in two markets but, in the second period, entry is possible in one of those markets. We assume that entry is blocked in one of the markets because of technological, legal or other entry barriers whose study is beyond the scope of this chapter.

Also considering a multiproduct regulated firm, Armstrong and Vickers (1993) compared the effects on entry and welfare of two types of price cap regulation: the definition of a cap for each price (separate caps) and the definition of a maximum value for the average of the prices in the two markets (average cap). Armstrong and Vickers concluded that the average price cap leads to a lower price in the competitive market (in order to deter entry) and to a higher price in the captive market in relation to the regulation with separate caps. Our analysis differs from the Armstrong and Vickers's model mainly because we are not comparing two types of regulation (we assume the average price cap) and we consider a dynamic framework that allows us to study the strategic manipulation of prices by the incumbent firm.

In our study the regulatory policy is characterised by the definition of a price cap on the average price, considering equal weights for each price in each period. Therefore, the strategic manipulation of price weights is not possible. More precisely, the regulatory policy is described in the following way: in the first period the price cap is exogenously set assuming a value such that the firm can not choose the monopoly

price simultaneously in both markets; in the second period the price cap is equal to the average price observed in the first period. This temporal linkage of prices justify the designation of dynamic price cap commonly used in the literature about price cap regulation.

From the comparison of two alternative strategies for the incumbent firm, entry accommodation and entry deterrence, we conclude that if the entry cost is higher than a critical level the regulated firm has incentive to follow an anticompetitive price policy. This strategy involves the definition of low prices in the first period, which strategically blocks entry. It is worthwhile to remark that the low prices chosen by the incumbent firm in the first period are only credible as an entry deterrence strategy because the regulatory policy guarantee that the average price of the second period can not be higher than the average price of the first period. This means that the credibility of the entry deterrence strategy is given by the temporal linkage between prices set by the regulatory policy.

Additionally, we find that the price reduction in the potential competitive market necessary to deter entry is lower with average cap regulation than with the regulation of each individual price. This result reveals the more aggressive behaviour of the incumbent firm in face of entry when it is subject to average price cap regulation. It also confirms the Armstrong and Vickers's concern about this type of price cap regulation.

Another result of the model is that under the entry deterrence strategy the regulated firm reduces the price not only in the competitive market but also in the captive market. However, the final effect of the entry deterrence strategy on total consumer surplus is not always positive, because with this strategy the incumbent firm maintains the monopolistic position in both markets. On the contrary, the entry accommodation strategy leads to a lower price in one of the markets because of the Stackelberg competition.

The question studied in Chapter 4 is about the definition of the price of access to the incumbent's firm's network. This question is integrated in the discussion of one-way

access which is concerned with the provision of inputs by an incumbent network to new entrants. The one-way access discussion has implicitly the idea that only one firm (the entrant) needs the other firm's network access to provide the final service to consumers. The literature of networks commonly distinguishes one-way access (or just access, in the terminology used by Vogelsang, 2003) from two-way access (or interconnection - Vogelsang, 2003). Two-way access concerns reciprocal access between two networks that rely upon each other to provide the final service.

In Chapter 4 the discussion of access price definition is made considering that the network access is a vital input to provide the final service to consumers, the incumbent firm is monopolist in the production of this input and also is vertically integrated, competing with its clients in the downstream segment of the market. Under this framework two different instruments of access price regulation are compared with the full deregulation hypothesis. Using the first instrument, called cost-based regulation, the regulator sets the access price equal to the marginal cost of providing the access. With the second instrument, called retail-minus regulation, the regulator sets the minimum difference between the retail price and the access price. It is also assumed that the downstream market is an unregulated duopoly with Stackelberg competition. The structure of this model was inspired by the market for broadband internet connectivity with ADSL technology. In several European countries, as in Portugal, for instance, this market is characterised by the existence of an incumbent vertically integrated firm (typically the historical operator), that provides access to its network to independent firms. Commonly, the incumbent firm also has a dominant position in the retail market which justify the adoption of Stackelberg competition with the leadership of the subsidiary firm.

The idea behind the access price regulation is that the emergence of competition at the retail segment of the market might be a precursor to competition at the wholesale segment, the ultimate goal of complete deregulation. Therefore, at the initial stage of the deregulation process, some assistance to entrants firms might be necessary to allow the emergence of competition at the retail level. However, if the regulator sets the access price at very low levels the incumbent firm's incentive to

undertake investments that improve the network quality decreases, which has deep consequences for market development. To account for this feature in our model we consider that the retail demand function is direct and positively sensitive to network investment undertake by the upstream firm. The comparison between the three different mechanisms of access price definition considers essentially its effects on the position of the independent firm in the downstream market, on the incentive to invest by the upstream monopolist, and on consumer surplus.

We conclude that retail-minus regulation avoids foreclosure, as cost-based regulation does. However, retail-minus regulation, if prudently defined, leads to better results than cost-based regulation in terms of investment level and consumer surplus. Moreover, retail minus regulation allows a higher consumer surplus than deregulation of access price as long as the regulator carefully defines the minimum value of the difference between the retail price and the access price.

Finally, we discuss the proximity between retail-minus and Efficient Component Pricing Rule (ECPR) concepts. We conclude that the two mechanisms, although sharing some features, can lead to different results. This happens because retail-minus is essentially an ad-hoc rule to define the margin between retail price and access price in an environment where the retail price is endogenously defined. On the contrary, ECPR definition assumes that the retail price is exogenously defined.

Overall, in Chapter 4 we conclude that retail-minus regulation can be a good option for the regulatory authority in a transitory phase from a monopoly structure to a deregulated oligopoly structure in the downstream market.

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Chapter 2

Entry Regulation under Asymmetric Information About Demand: A Signalling Model Approach

2.1 Introduction

Asymmetric information is an important feature of the relationship between regulated firms and regulatory authorities. When firms have more information than the regulatory authorities it might be expected that they try to influence the regulator's decision to their own benefit. Commonly, the regulatory authority has the perception of its lack of information about market or firm characteristics, but it is under those constraints that it has to define the regulatory policy. *"The fact that regulatory agencies spend some time and resources collecting data on firms and the whole activity related to auditing shows that regulators recognize their informational needs in order to properly perform their tasks."* (Gasmi, *et al.*, 2002, p.436). This is the general context in which Chapter 2 is developed. The particular question studied is related with entry regulation under asymmetric information conditions. This means that we consider a benevolent regulator who has to decide about the number of new firms that are allowed to enter in an industry not regulated in other dimensions.

The tendency for liberalisation and deregulation of several utilities observed in most of the European countries in the last decades has reduced the intervention of the authorities in the definition of the number of firms that participate in each industry. The air transport sector is an example of this trend. However, we can advance several arguments, either theoretical or resulting from empirical observation, that support the actual importance of entry regulation. In some sectors a large number of firms might decrease social welfare, because of scale economies, network externalities or entry costs but, from an individual standpoint, the industry can be attractive. This is the Excess Entry Theory applied by Mankiw and Winston (1997) to oligopoly markets.

Additionally, in recently privatised industries, with partial liberalisation, entry is gradual and controlled. This is happening, for instance, in mobile telecommunications where, because of the scarcity of a vital input, the radio spectrum, new firms need the regulator's approval to enter. Before conceding licenses, regulators define

the number of firms that can operate in the industry. The policy of the British regulator in the mobile segment of the telecommunications industry provides an example of entry regulation. In 1985, the regulator authorised the entry of two firms (Cellnet and Vodafone) following the model applied in the United States for the mobile telephone market. In 1991, two further mobile operators were licensed with the guarantee of no further entry before 2005 (Newbery, 2000, p.323).

In this chapter we study how the incumbent firms might use their private information to influence the regulator's decision about the number of new firms allowed to enter in the industry. We assume that the firms have private information about market demand. We can indicate several arguments to justify the regulator's inferior knowledge of the characteristics of market demand. Firms have a closer and more frequent contact with their customers than the regulatory authority that necessarily has a more distant position. Firms have a superior knowledge of the quality of the products, and of the expected reaction of the customers to that same quality in terms of the quantity demanded at any price. Finally, firms frequently devote significant resources to marketing studies to improve their perception about demand features (Lewis and Sappington, 1988).

We consider that, although the regulator has less information than the firms about the demand size, it can observe the market price in the period before regulation is implemented. Then, the regulator takes the price as a signal of demand size. Knowing the regulator's behaviour, the incumbent firms might strategically define the price in the period before regulation is implemented. The methodology used to study the firms' and regulator's decisions involves the construction of a signal game in which the regulator is the uninformed player.

The signalling model developed in this chapter is related with the literature on entry deterrence with asymmetric information, in particular with the model of Milgrom and Roberts (1982). However, Milgrom and Roberts's model does not consider a regulated industry. From this perspective, the model of Kim (2001b) is closer to our model as it deals especifically with entry regulation under asymmetric information. However, our approach departs from Kim's model in several dimensions: we assume

asymmetric information about demand, instead of private information about costs, we analyse the oligopoly case and we adopt a general approach, in terms of demand and cost functions characteristics. Mankiw and Whinston's (1986) model about excess entry inspired the general approach developed. Prior to the article of Mankiw and Whinston the idea of excess entry in a homogenous market was studied by von Weizsäcker (1980) and Perry (1984). These authors emphasised the essential role of scale economies as a cause of excess entry. Suzumura and Kiyono (1987) also reached the excess entry result for a homogenous product market and Cournot competition considering a more general approach.

From the literature about imperfect information concerning demand it is also important to mention the model developed by Riordan (1985). The author considers a two period model where firms compete in quantities and, although they do not know the demand function, they draw inferences about it from the observation of prices in the past. Riordan concluded that firms choose larger first-period quantities than in static Nash equilibrium with perfect information in order to cause a lower price that leads the rival firms to think that demand is lower.

The strategic utilisation of entry regulation by the incumbent firm was also studied by Kim (1997) in an environment of perfect information. The author considers that the decision variables of the firms are the capacity and the quantities produced. Under this framework, Kim conclude that the incumbent firm strategically induces the benevolent regulator to deny new entry and this strategy leads to lower social welfare than the one observed without entry regulation.

From the signal model developed in this chapter we conclude that, in equilibrium, the incumbent firms chooses a relatively low price in the period before regulation, whether demand is low or high. The purpose of this strategy is to signal a low demand and thus to induce the regulator to allow the entry of a small number of firms. With this strategy the incumbent firms uses the entry regulation to protect their market from strong competition.

The structure of Chapter 2 is the following: section 2.2 describes a model inspired

on Mankiw and Whinston model of Excess Entry that shows how incumbent firms can use private information about demand to deter entry. To gain insight into this conclusion a particular case assuming linear demand, no variable costs and only one entrant is presented in section 2.3. Section 2.3.1 considers the oligopoly interaction in the second period and section 2.3.2 considers the existence of two incumbent firms in the first period. Finally, section 2.4 presents the main conclusions of Chapter 2.

2.2 The Model with Asymmetric Information and Entry Regulation

2.2.1 Introduction

Mankiw and Whinston (1986) proved that in an industry with homogeneous product, fixed costs of entry and where *"the equilibrium output per firm declines as the number of firms grows"* (Mankiw and Whinston, 1986, p.49), free entry implies excess entry from a social welfare point of view.

We show that the introduction of asymmetric information and entry regulation in the Mankiw and Whinston's framework allows the incumbent firms to manipulate the regulator's decision about entry. This strategy might lead to a small number of firms in the industry compared to the number that the regulator would allow if there were symmetric information about demand.

The introduction of asymmetric information is made considering that the regulator does not know the demand size, in spite of knowing the general features of the demand. Nevertheless, the regulator supposes, a priori, that demand size can be low (D^L) or high (D^H). Under both cases we consider that the Mankiw and Whinston assumptions are valid. Therefore, we consider the following assumptions.

Assumption 2.1: The aggregate equilibrium output after entry increases with the number of entrants and approaches some finite bound.

Assumption 2.2: Each firm's equilibrium output falls with entry (business stealing effect).

Assumption 2.3: The equilibrium price after entry is not below marginal cost for a relevant number of entrants.

Because of the excess entry problem that exists with free entry under the above assumptions, the regulator defines the maximum number of firms that can enter in the industry (entry regulation). We assume that if the regulator had perfect knowledge of the demand size it would authorise the entry of n^L new firms if demand was low, or n^H new firms if demand was high with $n^L < n^H$. This numbers, n^L and n^H, are the ones that maximise the social welfare indicator when demand is low or high, respectively. Considering that $W^i(n^j)$ represents the social welfare indicator when demand is of type i ($i = L,\ H$) and the number of new firms authorised by the regulator is n^j ($j = L, H$) the condition previously mentioned is described by the following assumption:

Assumption 2.4 i) $W^L(n^L) > W^L(n^H)$ and ii) $W^H(n^L) < W^H(n^H)$

To direct our attention on the regulator's and incumbent firms's decisions we assume that all potential entrants want to enter in the industry. This means that, after entry, the entrants' profits are positive regardless of the demand size. This condition (described by Assumption 2.5) guarantee that entry is not blocked by the value of the fixed cost.

Assumption 2.5: The entrants' profit in the second period are positive both with D^L and D^H, for a relevant number of new firms

Assumptions 2.3 and 2.5 are defined for "a relevant number of entrants". We assume that this is relatively low number of firms. This hypothesis is necessary so that entry is profitable which gives the incentive to new entries of firms in the market. Besides, the assumption of a relatively low number of entrants is suitable in our model that intends to understand industries where there is a natural limit to the number of firms. Furthermore, this consideration is also present in Assumption 2.1 when it

is considered the existence of an upper finite bound for the aggregate equilibrium output after entry.

The main hypothesis of the paper is that the regulator does not know the demand size. However, we assume that before deciding how many new firms can enter, the regulator observes the price defined by the incumbent firms, and considers it as a signal of demand size. The incumbent firms know the regulator's decision process so they strategically choose the price in the pre-regulation period. For simplification, in a first analyse of the model we assume that initially there is only one firm in the market.

Under the above hypothesis we demonstrate that choosing the optimal price corresponding to low demand, even if demand is high, belongs to a Pooling Perfect Bayesian Equilibrium in a signalling game, under two requirements. The first requirement is that the fall in social welfare is stronger when the regulator wrongly chooses n^H (because the optimal number is n^L) than when wrongly chooses n^L (because the optimal number is n^H). The second requirement is that the incumbent firm highly valuates the fact of sharing the market with a small number of firms.

2.2.2 Time of the Game

The time of the game is the following:

- At stage zero Nature selects demand size, D^L or D^H with probability r and $1-r$ (with $0 < r < 1$), respectively. Afterwards, the incumbent firm observes Nature's choice. We assume that the demand size chosen at this stage does not change in the subsequent stages of the game.

- At stage one the incumbent firm chooses the price (the first period's price).

- At stage two there are some firms that wish to enter regardless of the demand size. However, the regulator defines the maximum number of new firms to avoid excess entry. This number depends on the demand size perceived by regulator: it will be

n^L if the regulator thinks that demand is low or n^H otherwise. Therefore, in the second period, the industry will be an oligopoly with n^L+1 or n^H+1 firms. Finally, the oligopolistic interaction between the firms leads to the establishment of another price (the second period's price).

The payoffs of the regulator and firms are the following: the incumbent firm's payoff is the sum of the profits of the two periods (supposing a discount factor of one); the regulator's payoff is measured by social welfare (defined as the sum of consumer surplus and firms' profits) in the second period; the entrants' payoff is their profit in the second period.

It is important to emphasise that the relevant payoff for the regulator's decision is defined considering only the second period's results. This happens because the regulator's decision about entry is taken at the beginning of the second stage. However, from consumers perspective, the outcomes of both periods are important. Therefore, to evaluate the model's results[1] we define a social welfare measure sensible to the results of both periods.

In the description of the signalling game (represented in Figure 2.1, Appendix C2) we assume the following terminology:

a) $\pi_1^i(P^k)$ represents the monopolist profit in the first period when demand is of type i and the first period's price is P^k $(k = L, H)$. If $i = k$ the monopolist has the maximum profit; if $i \neq k$ the monopolist is giving up some profit.

b) $\pi_2^i(n^j)$ represents the incumbent firm's profit in the second period when demand is of type i and there are n^j new firms. If $i = j$ social welfare is maximised. If $i \neq j$ we can identify two cases:

- $i = L$ and $j = H$, thus demand is low but the regulator allows the entry of n^H new firms. In this case there is excess entry.

- $i = H$ and $j = L$, thus demand is high but the regulator only allows the entry

[1] See section 2.2.6.

of n^L new firms. In this case there is insufficient entry but, from the incumbent firm's point of view, this is a favourable situation because in the second period it will face few competitors.

c) The parameters p and q represent the regulator's updated beliefs about the size of demand after observing the price. Hence, p represents the probability of low demand if the first period's price is P^H and q represents the probability of low demand if the first period's price is P^L.

d) The strategies of the players (incumbent firm and regulator) have to specify how they behave in every possible scenario in which they are called to act. Therefore, in our game, the players' strategies are represented by a pair of values. For the incumbent firm the pair (P^x, P^y) means that it chooses price P^x if demand is D^L and it chooses price P^y if demand is D^H. For the regulator the pair (n^w, n^z) means that the regulator chooses to allow the entry of n^w new firms if the incumbent firm had chosen a price equal or below P^x, and the regulator chooses to allow the entry of n^z new firms otherwise.

2.2.3 Some Concepts About Signal Games

In the model previously described private information is formalised with a signal game. In the next section we demonstrate the existence of a Perfect Bayesian Equilibrium of that game. To clarify the concepts used we present a brief revision of the characteristics of dynamic games with incomplete information, from which the signal game is a special case. We follow very closely the exposition of Gibbons (1992) and Rasmusen (2001).

A dynamic game with incomplete information is a game with more than one decision stage and where at least one player does not know all of the game rules.[2] A game with incomplete information can be transformed into a game with complete but

[2]Game rules are collectively the players, actions, payoffs and information (Rasmusen, 2001, p.12).

imperfect information (Harsanyi transformation) without changing its fundamental characteristics. Then, we can treat the equilibria of the new game as the equilibria of the original game. With Harsanyi transformation the new game has complete information because game rules are known to all players. However, as at least there is one moment when the player with the next move does not know the complete history of the game thus far, the game has imperfect information (Gibbons, 1992, p.148).

The Harsanyi transformation is made through the introduction of a special player, Nature, who is indifferent over all possible outcomes. Nature is the first player to make a choice. At the beginning of the game all players have the same beliefs about Nature's choice (that is, all have the same prior probabilities). However, only some players observe Nature's choice. Notice that the players with less information know the game rules, namely the possible choices of Nature, but do not know, at the moment of their decision, the action chosen by Nature. The model described in this chapter is a dynamic game with imperfect information. Initially the regulator and the incumbent firm have the same prior beliefs about the demand size chosen by Nature. However, the regulator has less information than the incumbent firm because it can not observe Nature's choice of demand size, while the incumbent firm acquires that knowledge.

A signal game is a particular case of dynamic games with incomplete information, in which the player with more information takes a decision that is observed by the uninformed player. This decision is considered by the less informed player as a signal about what he does not know. In our model the incumbent firm chooses the price for the first period, which is observed by the regulator before the regulatory decision is made. The regulator considers the first period's price a signal about the demand size. Therefore, the regulator updates its beliefs about demand size with the additional information (the first period's price) and then decides how many new firms are allowed to enter in the market.

The equilibrium concept used in our dynamic game with imperfect information is the Perfect Bayesian Equilibrium. This concept is strong enough to rule out from

the equilibrium concept the strategies that imply no credible threats and implausible strategies (Gibbons, 1992, p.173). To described the features of the Perfect Bayesian Equilibrium we use the following basic concepts from game theory:

- The strategies (s_1, s_2) for players 1 and 2 respectively, are a Nash equilibrium of pure strategies if s_1 is the strategy that implies the maximum payoff to player 1 given that player 2 chooses strategy s_2 and, simultaneously, s_2 is the strategy that implies the maximum payoff to player 2 given that player 1 chooses strategy s_1.

- An information set for a player is a collection of decision nodes at which the player has to make a choice and, when the play of the game reaches a node of the information set, the player does not know which node from the set has been reached when there is more than one node (Gibbons, 1992, p.119). The information set can be a singleton or have more than one node. In the latter situation it is necessary to define the probability distribution to all possible nodes. For example, in our signal game the regulator's information set for the price P^L has two nodes: one regarding low demand and the other regarding high demand. The corresponding probabilities to each node are, respectively, q and $1-q$. For the price P^H there is another information set, also with two nodes, with associated probabilities p and $1-p$, for low and high demand, respectively. In the graphical representation of the game (Figure 2.1, Appendix C2) the regulator's information sets are represented by the dotted lines connecting the two nodes that belong to the same information set.

- An information set is on the equilibrium path when it will be reached with positive probability if the game is played according to the equilibrium strategies (Gibbons, 1992, p.178).

- An information set is off the equilibrium path when it is certain that it will not be reached if the game is played according to the equilibrium strategies (Gibbons, 1992, p.178).

A Perfect Bayesian Equilibrium of a dynamic game with imperfect information consists of strategies and beliefs of the players that satisfy the following conditions:

1. Each player's strategy is his best decision given the players' beliefs and the equilibrium strategy of the others players. This means that the strategies of the Perfect Bayesian Equilibrium must also be a Nash equilibrium.

2. *"At each information set, the player with the move must have a belief about which node in the information set has been reached by the play of the game. For nonsingleton information set, a belief is a probability distribution over the nodes in the information set. For singleton information set, the player's belief puts probability one on the single decision node"* (Gibbons, 1992, p.177).

3. *"At information sets on the equilibrium path, beliefs are determined by Bayes's rule and the players' equilibrium strategies"* (Gibbons, 1992, p.178).

Bayes' rule is a rational way of updating the players' beliefs when they receive additional information. The application of Bayes's rule in our signal game is as follows. By assumption, the prior beliefs of the players are r and $1-r$ for low and high demand, respectively, that is, $Prob(D^L) = r$ and $Prob(D^H) = 1-r$. The regulator does not observe Nature's choice but observes the first period's price choosed by the incumbent firm and knows that the firm had observed Nature's choice. With this information the regulator updates the beliefs about Nature's choice. The updated beliefs are represented by the probabilities that Nature had chosen D^L (or D^H) conditional on the observed price P, that is, $Prob(D^L|P)$ (and $Prob(D^H|P)$). The beliefs' updating process depends on the equilibrium strategies. Knowing that:

$$Prob(P^L) = Prob(P^L|D^L)Prob(D^L) + Prob(P^L|D^H)Prob(D^H) \text{ and}$$

$$Prob(P^L, D^L) = Prob(P^L|D^L)Prob(D^L) = Prob(D^L|P^L)Prob(P^L)$$

$$\text{then } Prob(D^L|P^L) = \frac{Prob(P^L|D^L)Prob(D^L)}{Prob(P^L|D^L)Prob(D^L) + Prob(P^L|D^H)Prob(D^H)}$$

This is the application of Bayes' rule to obtain the probability of D^L given the observation of P^L. To calculate this probability we must know $Prob(P^L|D^L)$ and $Prob(P^L|D^H)$, that is, we need to know the firm's decision about price in equilibrium. This means that it is not possible to update the beliefs independently of the equilibrium strategy. Let us suppose that the equilibrium prices are (P^L, P^L). Then, $Prob(P^L|D^L) = Prob(P^L|D^H) = 1$. Therefore, $Prob(D^L|P^L) = \frac{1\times r}{1\times r+1\times(1-r)} = r$. Using the same methodology we obtain $Prob(D^H|P^L) = \frac{1\times(1-r)}{1\times r+1\times(1-r)} = 1-r$.

Notice that when we consider that the equilibrium prices are (P^L, P^L) we conclude that the updated beliefs coincide with the prior beliefs. This result is explained by the fact that the regulator does not obtain additional information from the observation of the prices because the incumbent firm chooses price P^L whatever the demand size. These types of strategies are called pooling strategies. Under a pooling strategy the informed player sends the same signal regardless of Nature's choice. Pooling strategies are in opposition to separating strategies under which the informed player decides in a different way according to Nature's choice. A Perfect Bayesian Equilibrium is pooling (or separating) if the equilibrium strategy of the informed player is pooling (or separating).

The pooling equilibrium has an important interpretation when the informed player chooses the same signal with the objective of not revealing information to the other player. This strategy of the informed player is called by Fudenberg and Tirole (1986) signal jamming and it is illustrated by Rasmusen (2001) with the limit pricing model. The central feature of signal jamming is the fact that the informed player uses the signal not with the intention to convey information, but as a way to conceal that information from the other player (Rasmusen, 2001).

2.2.4 The Pooling Equilibrium

The signal game presented above (and represented in Figure 2.1 in Appendix C2) has a Pooling Perfect Bayesian Equilibrium described by Proposition 2.1:

Proposition 2.1: The strategies and beliefs represented by $[(P^L, P^L), (n^L, n^H), (q = r, p)]$ are a Perfect Bayesian Equilibrium for any $p < p^*$ if

$$r[W^L(n^L) - W^L(n^H)] > (1 - r)[W^H(n^H) - W^H(n^L)] \qquad (1)$$

$$\pi_1^H(P^L) + \pi_2^H(n^L) > \pi_1^H(P^H) + \pi_2^H(n^H) \qquad (2)$$

$$\text{with} \qquad p^* = \frac{W^H(n^H) - W^H(n^L)}{[W^L(n^L) - W^L(n^H)] + [W^H(n^H) - W^H(n^L)]}$$

This Pooling Perfect Bayesian Equilibrium can be described in the following way: whatever the demand size, the incumbent firm chooses the price that maximises the profit when demand is low. The objective of this strategy is to keep unclear to the regulator whether demand size is enough to accommodate many new firms. The regulator observes this price and updates its beliefs: the probability of low demand if the observed price is P^L becomes r and the probability of low demand if the observed price is P^H becomes $p < p^*$. Then, the regulator allows the entry of n^L firms if the price is P^L, or n^H firms if the price is P^H. At the equilibrium described, the incumbent firm strategically uses the entry regulation and the private information about demand to induce the regulator to protect its market from competition.

Proof of Proposition 2.1

Following the description of Perfect Bayesian Equilibrium presented in the previous section we prove Proposition 2.1 in three steps. First, we prove that the best regulator's response after observing the price P^L is to choose n^L. At this step we assume (P^L, P^L) as the incumbent firm's equilibrium strategy and that the regulator's updated beliefs are $(q = r, p)$. Second, we prove that (P^L, P^L) is the incumbent firm's best decision considering that (n^L, n^H) and $(q = r, p)$ are the regulator's equilibrium strategy and the updated beliefs, respectively. Finally, we prove that the best regulator's response after observing the price P^H is to choose n^H. We assume (P^L, P^L)

and $(q = r, p)$ as the equilibrium strategy of the incumbent firm and the regulator's updated beliefs, respectively.

Notice that under the Perfect Bayesian Equilibrium, the equilibrium strategies depend on the updated beliefs and the updated beliefs depend on the equilibrium strategies. Therefore, the Perfect Bayesian Equilibrium is defined by a combination of strategies and beliefs.

First step: If (P^L, P^L) is an equilibrium strategy for the incumbent firm then the regulator's information set corresponding to P^L is on the equilibrium path. Hence, the regulator's belief is updated by Bayes' rule and the incumbent firm's strategy. According to the exposition in the previous section we have $q = r$, the prior belief. Given this belief and the equilibrium strategy (P^L, P^L), the regulator's best response following P^L is to choose n^L if:

$$qW^L(n^L) + (1-q)W^H(n^L) > qW^L(n^H) + (1-q)W^H(n^H)$$

$$\text{which implies } r[W^L(n^L) - W^L(n^H)] > (1-r)[W^H(n^H) - W^H(n^L)] \qquad (1)$$

The interpretation of condition (1) is straightforward: if the first period's price is P^L the regulator will choose n^L when the difference in social welfare from choosing the wrong number of new firms is bigger with low demand than with high demand, and those differences are weighted by the probability of each demand type. This seems a quite plausible hypothesis especially if entry involves sunk costs that, by definition, will be completely lost if some of the new firms authorised to enter by the regulator are forced to exit the industry in the near future. Also, the negative impact of the exit of new firms on regulator's image might justify the regulator's aversion to entrants failure (Mariñoso *et al.*, 2002).

Second step: To determine if the incumbent firm is willing to choose P^L whatever the demand size, we need to compare the payoffs of choosing P^L with the payoffs

of choosing P^H. To make this comparison we must specify how the regulator would react to P^H. Notice that the incumbent firm's payoffs of choosing P^L are $\pi_1^L(P^L) + \pi_2^L(n^L)$ when demand is D^L and $\pi_1^H(P^L) + \pi_2^H(n^L)$ when demand is D^H because we have already proved that the regulator's optimal response to P^L is n^L under the verification of condition (1).

If the regulator's response to P^H is n^L the incumbent firm's payoff is $\pi_1^L(P^H) + \pi_2^L(n^L)$ when demand type is D^L, which is below the payoff corresponding to P^L, $\pi_1^L(P^L)+\pi_2^L(n^L)$. When demand type is D^H the incumbent firm's payoff is $\pi_1^H(P^H)+\pi_2^H(n^L)$, which is greater than the payoff corresponding to P^L, $\pi_1^H(P^L) + \pi_2^H(n^L)$. Then, if the regulator's response to P^H is n^L it is not possible to define the incumbent firm's strategy.

If, on the contrary, the regulator's response to P^H is n^H the incumbent's payoff is $\pi_1^L(P^H)+\pi_2^L(n^H)$ when demand type is D^L, which is below the payoff corresponding to P^L, $\pi_1^L(P^L) + \pi_2^L(n^L)$. When demand type is D^H the incumbent firm's payoff is $\pi_1^H(P^H) + \pi_2^H(n^H)$, which is below the payoff corresponding to P^L if

$$\pi_1^H(P^L) + \pi_2^H(n^L) > \pi_1^H(P^H) + \pi_2^H(n^H) \qquad (2)$$

Then, if there is an equilibrium in which the incumbent firm's strategy is (P^L, P^L) the regulator's response to P^H must be n^H, because, under condition (2), we conclude that choosing P^L is always the best strategy for the incumbent firm. Then, by now, we assume that the regulator's strategy is (n^L, n^H).

Condition (2) represents the strong preference of the monopolist for sharing the market with few firms rather than with many firms, which seems quite intuitive. We can interpret condition (2) by saying that the limit price strategy is attractive to the incumbent firm when demand is D^H, that is, the incumbent firm prefers to lose some profit in the first period and share the market with few firms in the second period, than to maximise the profit in the first period and share the market with many firms in the second period.

Third step: Finally, we must consider the regulator's belief at the information set corresponding to P^H and the optimality of choosing n^H given this belief. At the second step we need to assume that the regulator's decision after P^H is n^H in order to obtain the result that the firm choice of P^L leads to higher payoffs than the choice of P^H, regardless of the demand size. Now we must prove that n^H is the best regulator's decision after observing P^H. Choosing n^H, as a response to P^H, is optimal for the regulator if

$$pW^L(n^H) + (1-p)W^H(n^H) > pW^L(n^L) + (1-p)W^H(n^L)$$

$$\Rightarrow \qquad p < \frac{W^H(n^H) - W^H(n^L)}{[W^L(n^L) - W^L(n^H)] + [W^H(n^H) - W^H(n^L]}$$

This condition provides that the updated belief p (which is the belief corresponding to the information set off the equilibrium path) is sufficiently low. Considering that $W^i(n^i) - W^i(n^j)$ with $i \neq j$, represents the damage on social welfare resulting from a wrong decision by the regulator, and as condition (1) guarantee that the fall in social welfare is stronger when the regulator wrongly chooses n^H than when it wrongly chooses n^L, p^* has a relatively small value. The idea behind this condition is the following: for n^H to be the best regulator's decision after observing P^H it is necessary that the probability of low demand after observing the price P^H is lower than the critical value p^*. This means that if the regulator observes P^H it is almost convinced that demand is high.

2.2.5 Other Potential Equilibria

The strategy (P^L, P^L), and the corresponding Perfect Bayesian Equilibrium, has a central role in Chapter 2. This happens because we eliminate from the analysis all other strategies[3] that could constitute a Perfect Bayesian Equilibrium with the

[3]In the model describe we only consider pure strategies, that is, the possible actions for each player. Pure strategies are in opposition to mixed strategies that are defined by the probability

following justifications.

First, it is important to notice that even with no threat of entry the incumbent firm would never choose prices greater than P^L if demand is D^L and/or prices greater than P^H if demand is D^H. Hence, with the possibility of entry, the incumbent firm does not consider prices above the optimal levels.

Second, the strategy (P^L, P^H) can not be a separating Perfect Bayesian Equilibrium, with (n^L, n^H) and $(q = 1, p = 0)$ for regulator' strategy and beliefs, respectively, if condition (2) is true. This is demonstrated in Appendix A2.1.

Third, the existence of a pooling equilibrium with (P^1, P^1) and $P^1 < P^L$ requires additional conditions relative to the equilibrium (P^L, P^L). Also, under these conditions there are multiple equilibria because P^1 is not unique. Furthermore, all the pooling equilibria with (P^1, P^1) and $P^1 < P^L$ imply payoffs for the incumbent firm below the corresponding equilibrium payoffs with (P^L, P^L), if the profit function in the first period is monotonically increasing with price for $P < P^H$ when D^H. This is an additional reason for excluding these cases from the analysis. The description of the equilibria referred is presented in Appendix A2.2.

Fourth, strategies (P^1, P^H) with $P^1 < P^L$ can constitute a separating Perfect Bayesian Equilibrium under some conditions described in Appendix A2.3. However, we eliminate these strategies from the study using the same argument invoked in the preceding case: the fact that the equilibrium payoffs of the incumbent firm under the strategy (P^L, P^L) dominate those under (P^1, P^H) for all $P^1 < P^L$.

Fifth, strategies (P^L, P^2) with $P^L < P^2 < P^H$ can not belong to a separating Perfect Bayesian Equilibrium, even with (n^L, n^H), $q = 1$ and $p = 0$, because when demand type is D^H the incumbent firm has no incentive to choose $P^2 < P^H$. For any $P > P^L$ the regulator allows the entry of n^H firms, so the best firm's response is to maximise the profit in the first period which implies the price P^H. Then, we have the strategy (P^L, P^H) explained above.

distribution of the possible actions.

2.2.6 Interpretation of the Pooling Perfect Bayesian Equilibrium

As the main objective of this chapter is to analyse the impact of asymmetric information on entry regulation, we compare the final outcome of the pooling equilibrium $[(P^L, P^L), (n^L, n^H), (q = r, p)]$ with the outcome that would be obtained if the regulator had symmetric information about demand.

In the definition of the number of firms that are allowed to enter in the industry the regulator only cares about the social welfare in the second period. However, to evaluate the effects of the private information about demand on social welfare we need to consider both periods. This is because the incumbent firm's behaviour in the first period depends on the regulatory policy which has consequences on total welfare. Considering that W_1 and W_2 represent the social welfare in the first and second periods, respectively, we have the following results:

Table 2.1 - Social Welfare

		W_1	W_2
Symmetric Information			
D^L	n^L	$W^L(P^L)$	$W^L(n^L)$
D^H	n^H	$W^H(P^H)$	$W^H(n^H)$
Pooling Equilibrium			
D^L	n^L	$W^L(P^L)$	$W^L(n^L)$
D^H	n^L	$W^H(P^L)$	$W^H(n^L)$

If demand is D^L the asymmetric information does not have any impact on social welfare. However, if demand is D^H the regulator would like to have n^H new firms but, as a result of the incumbent firm's strategy, the regulator will only allow n^L new firms. The asymmetric information creates a problem of insufficient entry if

D^H.

We describe a situation where the regulator has to decide about entry and fears the problem of excess entry. At the same time the regulator has less information about demand than the incumbent firm. If demand is high these conditions induce the incumbent firm to adopt a limit price strategy and, in the end, the result is insufficient entry. However, the pooling equilibrium motivated by asymmetric information about demand does not have only negative consequences in spite of the insufficient entry. The implementation of the limit price strategy has positive consequences in the short run (first period) resulting from the lower price. Hence, considering both periods, the final result is negative from a social point of view only if

$$W^H(P^L) + W^H(n^L) < W^H(P^H) + W^H(n^H)$$

In the description of the signal game we assumed that the role of the regulator was to decide how many new firms could operate in the industry. We call this policy direct entry regulation. However, we can give a broader interpretation of the role of the regulator in the present game. We can consider that choosing n^j means that the regulator will take some actions to remove entry obstacles and to encourage the entry of n^j new firms. These actions will be more intensive if j is high. Then, we can interpret the results of the signal game in the context of indirect entry regulation which we define as the regulator's decisions that influence the number of firms in the industry.[4] With this interpretation we conclude that, in the pooling equilibrium described, the incumbent firm has the incentive to induce the regulator not to develop too intensive actions in the promotion of entry.

We can illustrate this interpretation with an example from the European airline industry. In the late 1990s several alliances and mergers between airline companies occurred in Europe. According to the European legislation when mergers have economic consequences at the European level, that is, crossing the national level,

[4]This is the perspective adopted, for example, by De Fraja (1997) in the study of the impact of regulation on entry.

they have to be authorised by the European Commission. Furthermore, when the companies involved in the mergers have a significant number of overlapping routes, the European Commission makes a detail analysis of the impact on competition. However, the European Commission only considers the hypothesis of adopting an active role in the merger process if the market demand is of significant size.[5] If the market demand is perceived as narrow, the European Commission does not take actions to encourage new entry, even if the merger creates a monopoly.

When demand size is significant and the merger can have important benefits (an increase in efficiency, in particular), the European Commission's past approach has been to authorise the merger while, at the same time, imposing several obligations to the incumbent firms in order to promote entry. These obligations can be, for example, to make available some landing and take-off slots at congested airports, to reduce the frequencies of some flights, to enter into interlining arrangements with the entrants, to open the frequent flyer programmes to the entrants' customers.[6] According to our model, if the incumbent firms can convince the Commission that demand is narrow, the intensity of the obligations designed to promote entry might be weak, and then entry is less likely.

The asymmetric information between the firms and the regulator plays a central role in the described process. Firms have a deeper knowledge of the market characteristics and can manipulate many variables, including the price, as in the signal model presented above. In the airline industry firms can also use the network definition as a powerful variable to manipulate the size of the demand perceived by outside entities. The substitution between direct and indirect flights (the ones with one or more stopovers) has a strong impact on the perceived demand size of each route.[7]

[5] For example, in the evaluation of the competition features in the Lufthansa/SAS process the European Commission only considered routes with capacity exceding 30.000 seats per year (Stragier, 2001).

[6] For a detail description of the European Commission policy for airline mergers see Stragier (2001).

[7] In the United States there are empirical evidence of this type of incumbent firms' strategy, under which the incumbent firms use the route definition as an instrument variable to deter entry (Transportation Research Board, 1999).

2.3 The Model with Linear Demand, No Variable Costs and One Entrant

In the present section we describe the previous signal game in a particular case in order to study two features: the impact of the type of competition between firms in the second period if entry occurs, and the impact of the existence of two incumbent firms in the first period. In relation to the first point we conclude for the existence of the Pooling Perfect Bayesian Equilibrium described above as long as the duopoly interaction expected for the second period leads to a price above a critical level. Cournot competition is presented as an example of this case. In relation to the second point, we conclude that even if there are two incumbent firms in the first period, the pooling strategy with the optimal price when demand is D^L belongs to a Perfect Bayesian Equilibrium.

We study the particular case characterised by linear and stationary demand given by $Q = \theta - P$, no variable costs and only one potential entrant. The parameter θ can assume two values, θ^L or θ^H, with $\theta^L < \theta^H$, representing low or high demand, respectively. F represents the fixed cost per period borne by each firm that operates in the market. We assume that the regulator knows the demand function $Q = \theta - P$, but it does not know the value of θ. However, the regulator knows that θ can be equal to θ^L or to θ^H.

2.3.1 Duopoly Competition in the Second Period

Considering the demand function $Q = \theta - P$ and the fixed cost F, we have the following standard results for the first period:

a) Monopoly with profit maximisation:

$$Q = \frac{\theta}{2} \quad ; \quad P = \frac{\theta}{2} \quad ; \quad \pi = \frac{\theta^2}{4} - F \quad ; \quad W = \frac{3}{8}\theta^2 - F$$

b) Monopoly without profit maximisation:

$$\pi = P(\theta - P) - F \;\; ; \;\; W = \frac{(\theta - P)^2}{2} + P(\theta - P) - F$$

The application of the signal game previously described requires the verification of Assumptions 2.4 and 2.5.[8] Considering that $\widetilde{P}$ and $\tilde{q}_i$ $(i = 1, 2)$ represent, respectively, the optimal price and optimal individual quantities for the duopoly case, in the second period when demand is low, we can write Assumptions 2.4i) and 2.5 as following:

Assumption 2.4i) with linear demand:

$$W^L(n = 0) > W^L(n = 1) \Rightarrow \frac{3}{8}(\theta^L)^2 - F > \frac{(\theta^L - \widetilde{P})^2}{2} + \tilde{q}_1\widetilde{P} - F + \tilde{q}_2\widetilde{P} - F$$

Assumption 2.5 with linear demand: $\pi_2 > 0 \Rightarrow \tilde{q}_2\widetilde{P} - F > 0$

Assumption 2.5 requires that the fixed cost F has an upper bound. This guarantee that entry is not blocked by the level of the fixed cost. However, by Assumption 2.4i), the fixed cost can not be excessively low because in that case the regulator would prefer to allow entry for every demand size. In the regulator's perspective, if F is too low the benefits of the duopoly (resulting from the price decrease) overtake the damage resulting from the cost duplication. Then, from Assumption 2.4i), we have $F > \frac{(\theta^L)^2 - 4\widetilde{P}^2}{8}$, or equivalently, $\widetilde{P} > \frac{\sqrt{(\theta^L)^2 - 8F}}{2}$. Therefore, the application of the signal model for linear demand is relevant for every duopoly behaviour in the second period as long the duopoly price is above the critical value $\frac{\sqrt{(\theta^L)^2 - 8F}}{2}$.

Cournot competition is an example of the duopoly behaviour described above. Therefore, to illustrate this conclusion we present the results considering Cournot competition in the second period. To characterise the signal game with Cournot competition we use the following standard results:

[8] For linear demand and zero marginal costs, Assumptions 2.1 to 2.3 are verified.

$$q_1 = q_2 = \frac{\theta}{3} \ ; \ P = \frac{\theta}{3} \ ; \ Q = \frac{2}{3}\theta$$

$$\pi = \frac{\theta^2}{9} - F \ ; \ W = \frac{4}{9}\theta^2 - 2F$$

For this particular case, Assumptions 2.4 and 2.5 have the following definitions:

Assumption 2.4 with Cournot competition: $\frac{5}{72}(\theta^L)^2 < F < \frac{5}{72}(\theta^H)^2$

Assumption 2.5 with Cournot competition: $F < \frac{(\theta^L)^2}{9}$

Assumption 2.5 guarantee that the entrant is always willing to enter in the market. Assumption 2.4 guarantee the existence of the regulator's problem resulting from its lack of information about the demand size. Notice that if F is outside that range defined by Assumption 4, the regulator does not face any dilemma as long as the fixed cost is known (as we assume). If F is too large ($F > \frac{5}{72}(\theta^H)^2$) social welfare is higher with monopoly even when demand is D^H, because of cost duplication resulting from entry. If F is too low ($F < \frac{5}{72}(\theta^L)^2$) social welfare is higher with two firms than with monopoly even when demand is D^L, because the positive effect of the price decrease overtake the negative consequence of cost duplication.

Applying Proposition 2.1 to the case of Cournot competition in the second period we conclude that:

$[(\frac{\theta^L}{2}, \frac{\theta^L}{2}), (n = 0, n = 1), (q = r, p)]$ is a Perfect Bayesian Equilibrium for any $p < p^*$ if

$$r(\theta^L)^2 + (1-r)(\theta^H)^2 < \frac{72}{5}F \qquad (1)_C$$

$$\text{and} \quad \frac{(\theta^H)^2}{9} < \frac{\theta^L}{2}(\theta^H - \frac{\theta^L}{2}) \qquad (2)_C$$

$$\text{with} \qquad p^* = \frac{(\theta^H)^2 - \frac{72}{5}F}{(\theta^H)^2 - (\theta^L)^2}$$

It is important to note that for low demand and if entry occurred, the second period's price would be $\widetilde{P} = \frac{\theta^L}{3}$. By Assumption 2.4, this price is above the critical level $\frac{\sqrt{(\theta^L)^2-8F}}{2}$.

When the duopoly competition in the second period is quite intense and leads to a duopoly price below the critical level $\frac{\sqrt{(\theta^L)^2-8F}}{2}$, the regulator's problem about entry authorisation ceases to exist. This happens because the positive effect on social welfare of the price reduction overtakes the negative consequence of the cost duplication, and even if demand is low the regulator prefers to allow entry. The Stackelberg competition illustrates this case. The standard results for Stackelberg competition with two firms are the following:

$$q_2 = \frac{\theta - q_1}{2} \qquad \text{reaction function of firm 2}$$

$$q_1 = \frac{\theta}{2} \;\; ; \;\; q_2 = \frac{\theta}{4} \;\; ; \;\; P = \frac{\theta}{4}$$

$$\pi_1 = \frac{\theta^2}{8} - F \;\; ; \;\; \pi_2 = \frac{\theta^2}{16} - F \;\; ; \;\; W = \frac{15}{32}\theta^2 - 2F$$

To guarantee that entry is not blocked for both demand types it is necessary to assume that $F < \frac{(\theta^L)^2}{16}$ (Assumption 2.5). However, this is not compatible with Assumption 2.4i) because, for the values of F that verify Assumption 2.5, the regulator is always willing to authorise the entry. Then, the regulator does not face any dilemma about its decision even without knowing the demand size. Therefore, in this case, the signal game described in the previous section is not relevant. We can immediately reach this conclusion by observing that the optimal Stackelberg price when demand is low $\frac{\theta^L}{4}$ is below the critical value $\frac{\sqrt{(\theta^L)^2-8F}}{2}$ for $F < \frac{(\theta^L)^2}{16}$.

We conclude that the application of the signal model described in the previous section when we assume that the demand has a linear specification requires a moderate degree of post-entry competition.

2.3.2 Duopoly Competition in the First Period

In this subsection we assume that in the first period there are two competing firms with Cournot behaviour. As before, we assume that the regulator does not observe the quantities but can only observe the price of the first period. We also assume that this price continues to be the signal sent by the firms. Therefore, we describe the game using as principal reference the price but keeping in mind that the quantity is the firms' decision variable.

In the description of the game we use the following standard results:

a) Duopoly (Cournot) without profit maximisation:

$$q_1 = q_2 = \frac{1}{2}(\theta - P) \; ; \; \pi = \frac{1}{2}(\theta - P)P - F$$

$$W = \frac{(\theta - P)^2}{2} + P(\theta - P) - 2F$$

b) Oligopoly with three firms (Cournot) and with profit maximisation:

$$q_i = \frac{\theta}{4} \qquad i = 1, 2, 3 \quad ; \quad P = \frac{\theta}{4}$$

$$\pi_i = \frac{\theta^2}{16} - F \qquad W = \frac{15}{32}(\theta)^2 - 3F$$

Assumptions 2.4 and 2.5 require the following conditions concerning the parameters: $\frac{7}{288}(\theta^L)^2 < F < \frac{7}{288}(\theta^H)^2$ and $F < \frac{(\theta^L)^2}{16}$, respectively. We prove that the previous

game (represented in Figure 2.2, Appendix C2) has a Pooling Perfect Bayesian Equilibrium described by Proposition 2.2.

Proposition 2.2: $[(\frac{\theta^L}{3}, \frac{\theta^L}{3}), (n = 0, n = 1), (q = r, p)]$ is a Perfect Bayesian Equilibrium for any $p < p^*$ if

$$r(\theta^L)^2 + (1-r)(\theta^H)^2 < \frac{288}{7}F \qquad (1)_D$$

$$\text{and} \qquad \frac{(\theta^H)^2}{16} < \frac{1}{2}(\theta^H - \frac{\theta^L}{3})\frac{\theta^L}{3} \qquad (2)_D$$

$$\text{with} \qquad p^* = \frac{(\theta^H)^2 - \frac{288}{7}F}{(\theta^H)^2 - (\theta^L)^2}$$

The proof of Proposition 2.2 is similar to the proof of Proposition 2.1 and is described in Appendix B2.

Condition $(1)_D$ says that if the expected value of θ^2 is not "too high" (that is, is not above $\frac{288}{7}F$), the damage on social welfare caused by entry when demand type is D^L is higher than the social welfare damage caused by not allowing entry when demand size is D^H. This condition has an intuitive interpretation. If the expected value of θ^2 is relatively high this means that even the low demand is not "too low", and then the authorisation of entry when demand size is D^L does not cause a significant damage to social welfare.

Condition $(2)_D$ says that, in the incumbent firms' perspective, it is worthwhile to follow the limit price strategy when demand is high if the optimal individual payoff corresponding to the 3-firms oligopoly is lower than the non-optimal individual payoff corresponding to 2-firms oligopoly.

The pooling equilibrium described in Proposition 2.2 requires that the incumbent firms choose the quantities that maximise the profit when demand is D^L even if demand is, in fact, D^H. Then, if demand is D^H, both incumbent firms are giving

up some profit in the first period. This conclusion raises immediately the question about the incentive to deviate from the pooling strategy by one firm, supposing that the other firm does not deviate, in order to maximise the individual payoff. We prove that this incentive does not exist. Therefore, the pooling strategy described in Proposition 2.2 implies a tacit coordination between the incumbent firms to induce entry regulation.

To prove the previous conclusion we use the following results of the game:

a) If demand is D^H, but both firms want $\frac{\theta^L}{3}$ as the market price in the first period in order to convince the regulator that demand is D^L, each firm must choose the quantity $q^{PE} = \frac{1}{2}(\theta^H - \frac{\theta^L}{3})$. According to the regulator's equilibrium strategy, entry is not allowed and then the individual payoff is $\frac{1}{2}(\theta^H - \frac{\theta^L}{3})\frac{\theta^L}{3} - F + \frac{(\theta^H)^2}{9} - F$.

b) Alternatively, if each firm decides to maximise the first period's profit without caring about the regulatory policy, the individual quantity will be $\frac{\theta^H}{3}$. In the second period entry is authorised and the individual payoff is $\frac{(\theta^H)^2}{9} - F + \frac{(\theta^H)^2}{16} - F$.

According to condition $(2)_D$, the payoff described in a) is greater than the payoff described in b).

Next, we prove that if one firm (for instance, firm 2) assumes that the other incumbent firm chooses the quantity corresponding to the pooling equilibrium when demand is D^H ($q_1^{PE} = \frac{1}{2}(\theta^H - \frac{\theta^L}{3})$) it is not possible to find a value of q_2 that implies a payoff greater than the one obtained with the pooling equilibrium strategy. We can identify two different cases for the choice of q_2:

i) $q_2 < q^{PE}$ and then $P > \frac{\theta^L}{3}$, so entry is allowed.

ii) $q_2 \geq q^{PE}$ and then $P \leq \frac{\theta^L}{3}$, so entry is not allowed.

If firm 2 assumes $q_1 = q^{PE}$, then the inverse demand function perceived by firm 2 is $P = \theta^H - \frac{1}{2}(\theta^H - \frac{\theta^L}{3}) - q_2$. The profit function of the first period for firm 2 is $\pi_2 = [\theta^H - \frac{1}{2}(\theta^H - \frac{\theta^L}{3}) - q_2]q_2 - F$. This function has a maximum for $q_2 = (\frac{\theta^H}{4} + \frac{\theta^L}{12})$.

Let $q_2^* = (\frac{\theta^H}{4} + \frac{\theta^L}{12})$. It follows that $q_2^* < q^{PE}$.

Under case i), the best decision for firm 2 is $q_2 = q_2^*$. However, as $\pi_2(q_2^*) + \frac{(\theta^H)^2}{16} < \pi_2(q_2^{PE}) + \frac{(\theta^H)^2}{9}$, choosing $q_2 = q^{PE}$ implies a smaller payoff than choosing $q_2 = q_2^*$.

Under case ii), the best choice for firm 2 is $q_2 = q^{PE}$ because the profit function is decreasing for all values of q_2 such that $q_2 > q_2^*$ and we know that $q^{PE} > q_2^*$. Hence, the best choice is $q_2 = q^{PE}$. Choosing $q_2 = q^{PE}$ corresponds to the pooling equilibrium strategy. Therefore, we prove that the incumbent firms do not have any incentive to share the output in an asymmetric way.

We conclude that in the signal game described by Proposition 2.2 there is no incentive for any firm to deviate from the pooling equilibrium strategy. Then, in the first period, there is tacit collusion between the incumbent firms in order to lead the regulator to the decision to not allow entry. Armstrong *et al.* (1999, p.109) argue that an increase in collusion between the incumbent firms can be a negative consequence of entry regulation implemented to prevent excess entry. In the signal model described above the tacit agreement between the incumbent firms and Cournot behaviour is enough to manipulate the regulator's decision and allow the incumbent firms to be protect from competition.

2.4 Conclusions

In this chapter we study the price strategy of an incumbent firm that operates in a regulated market. We assume that the regulatory authority decides how many new firms can enter in the market. Additionally, we consider that the regulatory authority has less information than the firms regarding the market demand.

Being aware of its informational advantage, the incumbent firm uses the price of the period pre-regulation as a signal about demand size. This signal is address to the regulator with the objective of manipulate its decision about entry.

From the signalling model presented we prove that the choice of a low price by the incumbent firm belongs to a Pooling Perfect Bayesian Equilibrium. At this equilibrium the regulator authorises the entry of a small number of new firms, whether demand size is low or high. This decision benefits the incumbent firm.

The existence of the equilibrium referred above requires two conditions. First, the negative impact on social welfare must be greater when the regulator wrongly allows the entry of a high number of firms than when wrongly allows the entry of a small number of firms. Second, the incumbent firm must highly valuate the fact of sharing the market with few firms.

The overall effect on social welfare of the price strategy described depends on the trade-off between short-run benefits (resulting from the lower price in the first period) and long-run benefits (resulting from the strong competition in the second period).

In order to study the impact of the type of competition after entry and the impact of the existence of two incumbent firms in the first period on the equilibrium strategies, we consider a particular case of the model. We assume linear demand, variable costs normalised to zero and only one entrant. Regarding the type of competition after entry we conclude for the existence of the Pooling Perfect Bayesian Equilibrium described in the general model as long as the duopoly interaction expected for the second period leads to a price above a critical level. Cournot competition is an example of this case. In relation to the second point we conclude that the existence of two incumbent firms in the first period does not change the general conclusion of the signal game, because the duopolists have the incentive to tacitly cooperate in the implementation of the pooling equilibrium in order to deter the entry of a third firm.

Appendix A2

A2.1. The separating equilibrium $[(\mathbf{P^L}, \mathbf{P^H}), (\mathbf{n^L}, \mathbf{n^H}), (\mathbf{q = 1}, \mathbf{p = 0})]$

If (P^L, P^H) is an equilibrium strategy, both regulator's information sets are on the equilibrium path. Hence, the beliefs are updated by Bayes' rule and the incumbent firm's strategy. From the strategy (P^L, P^H) we know that $Prob(P^L|D^L) = 1$ and $Prob(P^H|D^H) = 1$. By definition we know that:

$Prob(P^L) = Prob(P^L|D^L)Prob(D^L) + Prob(P^L|D^H)Prob(D^H) = r$ and

$Prob(P^H) = Prob(P^H|D^L)Prob(D^L) + Prob(P^H|D^H)Prob(D^H) = 1 - r$

Then, $p = Prob(D^L|P^H) = \frac{Prob(P^H|D^L)Prob(D^L)}{Prob(P^H)} = 0$

and $q = Prob(D^L|P^L) = \frac{Prob(P^L|D^L)Prob(D^L)}{Prob(P^L)} = 1$

Given these updated beliefs, the regulator best response is (n^L, n^H) because:

- If P^L and n^L the regulator's payoff is $W^L(n^L)$; if P^L and n^H the regulator's payoff is $W^L(n^H) < W^L(n^L)$, by Assumption 2.4.

- If P^H and n^L the regulator's payoff is $W^H(n^L)$; if P^H and n^H the regulator's payoff is $W^H(n^H) > W^H(n^L)$, by Assumption 2.4.

Now we must check if (P^L, P^H) is the best response to (n^L, n^H). When demand type is D^L and the incumbent firm's choice is P^L the regulator's decision is n^L. Then, the incumbent firm's payoff is $\pi_1^L(P^L) + \pi_2^L(n^L)$, which is above the payoff of choosing P^H, $\pi_1^L(P^H) + \pi_2^L(n^H)$. Hence, the incumbent firm has no incentive to deviate from the choice of P^L when demand is D^L.

When demand type is D^H and the incumbent firm's choice is P^H, the regulator's decision is n^H. Then, the incumbent firm's payoff is $\pi_1^H(P^H) + \pi_2^H(n^H)$ which, by condition (2), is below the payoff corresponding to P^L. Hence, when demand type is

D^H the firm has an incentive for deviate from the decision P^H. Therefore, (P^L, P^H) can not belong to a Perfect Bayesian Equilibrium with the verification of condition (2). Only if condition (2) is not verified (P^L, P^H) can belong to a separating equilibrium in which the incumbent firm reveals the demand size. This means that if the limit price strategy is not attractive when demand is high, the firm prefers to receive the monopoly profits of the first period and share the market with many firms in second period. Rasmusen (2001, p.286) labels this separating equilibrium as no-strategic because the incumbent firm chooses the price that maximise the profit without caring about entry regulation. This separating equilibrium only occurs if the value of being a monopolist is not "too" high and, therefore, the incumbent firm is not interested in giving up some of the first period's profits to maintain the monopoly position.

A2.2. The pooling equilibrium $[(\mathbf{P^1}, \mathbf{P^1}), (\mathbf{n^L}, \mathbf{n^H}), (\mathbf{q = r}, \mathbf{p})]$ with $\mathbf{P^1 < P^L}$

1. If (P^1, P^1) is an equilibrium strategy for the incumbent firm then the regulator information set corresponding to P^1 is on the equilibrium path. Hence, the regulator's belief is updated by Bayes' rule and the incumbent firm's strategy. Therefore, $q = r$, the prior belief. Given this belief, the regulator's best response following P^1 is to choose n^L if

$$qW^L(n^L) + (1-q)W^H(n^L) > qW^L(n^H) + (1-q)W^H(n^H).$$

This is condition (1) of Proposition 2.1.

2. To determine if the incumbent firm is willing to choose P^1 to both demand sizes we need to compare the payoffs from choosing P^1 with the payoffs of choosing the alternative price to P^1. As P^1 is lower than P^L, the alternative to P^1 is not equal under D^L or D^H. If demand type is D^L the best alternative to P^1 is P^L, while if demand type is D^H the best alternative to P^1 is P^H.

If the regulator's response to $P > P^1$ is n^L the incumbent firm's payoff is $\pi_1^L(P > P^1) + \pi_2^L(n^L)$ when demand type is D^L, which is greater than the payoff with P^1, $\pi_1^L(P^1) + \pi_2^L(n^L)$. If, on the contrary, demand type is D^H the payoff is $\pi_1^H(P > P^1) + \pi_2^H(n^L)$, which is greater than the payoff with P^1, $\pi_1^H(P^1) + \pi_2^H(n^L)$. Then, if (P^1, P^1) belongs to an equilibrium the regulator response to $P > P^1$ can not be n^L.

If the regulator's response to $P > P^1$ is n^H the incumbent firm's payoff is $\pi_1^L(P > P^1) + \pi_2^L(n^H)$ when demand type is D^L or is $\pi_1^H(P > P^1) + \pi_2^H(n^H)$ when demand type is D^H. From the comparison of these payoffs with the corresponding payoffs when the incumbent firm chooses P^1 we conclude that the incumbent firm does not choose $P > P^1$ for D^L or D^H when the regulator response to $P > P^1$ is n^H as long as the following conditions are meet:

$\pi_1^L(P > P_1) + \pi_2^L(n^H) < \pi_1^L(P^1) + \pi_2^L(n^L)$ and

$\pi_1^H(P > P_1) + \pi_2^H(n^H) < \pi_1^H(P^1) + \pi_2^H(n^L)$.

Therefore, to have an equilibrium with (P^1, P^1) is necessary to impose that the limit price strategy is attractive for the incumbent firm both when D^L and D^H.

3. Choosing n^H is the best regulator's response to $P > P^1$ if

$pW^L(n^H) + (1-p)W^H(n^H) > pW^L(n^L) + (1-p)W^H(n^L)$ which implies $p < p^*$.

We conclude that the existence of a Perfect Bayesian Equilibrium with (P^1, P^1) and $P^1 < P^L$ require one more condition than the pooling equilibrium with (P^L, P^L). Furthermore, this result has another problem: there are many values of P^1 that verify the conditions mentioned above, so there are multiple pooling equilibria of this type. An additional reason to eliminate these pooling equilibria from the analyses is the fact that for any $P^1 < P^L$, and if the profit function in the first period for D^H is monotonically increasing for $P^1 < P^H$, the equilibrium payoffs with (P^1, P^1) are below the equilibrium payoffs with (P^L, P^L). Hence, we conclude that the firm would never be interested in choosing (P^1, P^1) with $P^1 < P^L$.

A2.3. The separating equilibrium $[(\mathbf{P^1}, \mathbf{P^H}), (\mathbf{n^L}, \mathbf{n^H}), (\mathbf{q = 1}, \mathbf{p = 0})]$ with $\mathbf{P^1 < P^L}$

If (P^1, P^H) with $P^1 < P^L$ is an equilibrium strategy, then q=1 and p=0. With these updated beliefs the best regulator's response is the strategy (n^L, n^H).

It is necessary to verify if (P^1, P^H) is the best incumbent firm's response to (n^L, n^H). If D^L and P^1 the incumbent firm payoff is $\pi_1^L(P^1)+\pi_2^L(n^L)$, which must be compared with $\pi_1^L(P^H) + \pi_2^L(n^H)$. If D^H and P^H the incumbent firm's payoff is $\pi_1^H(P^H) + \pi_2^H(n^H)$, which must be compared with $\pi_1^H(P^1) + \pi_2^H(n^L)$. Then, the existence of a Perfect Bayesian Equilibrium with (P^1, P^H) and $P^1 < P^L$ requires that $\pi_1^L(P^1) + \pi_2^L(n^L) > \pi_1^L(P^H) + \pi_2^L(n^H)$ and $\pi_1^H(P^H) + \pi_2^H(n^H) > \pi_1^H(P^1) + \pi_2^H(n^L)$. However, if these conditions are meet we have multiple equilibria because there are multiple values of P^1 that verify the conditions described.

Additionally, we can observe that, for all the equilibria with (P^1, P^H) and $P^1 < P^L$, the equilibrium payoffs of the incumbent firm are always below the equilibrium payoffs corresponding to the strategy (P^L, P^L). Hence, we decide not to study the equilibria with (P^1, P^H) and $P^1 < P^L$. Notice that the equilibrium payoff corresponding to (P^L, P^L) are

$$\pi_1^L(P^L) + \pi_2^L(n^L) \quad \text{if} \quad D^L \qquad \text{(a)}$$

and $$\pi_1^H(P^L) + \pi_2^H(n^L) \quad \text{if } D^H \qquad \text{(b)}$$

and the equilibrium payoff corresponding to (P^1, P^H) are

$$\pi_1^L(P^1) + \pi_2^L(n^L) \text{ if } D^L \qquad \text{(c)}$$

and $$\pi_1^H(P^H) + \pi_2^H(n^H) \text{ if } D^H \qquad \text{(d)}$$

As (a)>(c) and (b)>(d) by condition (2), the equilibrium with (P^L, P^L) dominates the equilibria with (P^1, P^H) and $P^1 < P^L$.

Appendix B2

Proof of Proposition 2.2

1. If $(\frac{\theta^L}{3}, \frac{\theta^L}{3})$ is an equilibrium strategy for the incumbent firms then the regulator's information set corresponding to $\frac{\theta^L}{3}$ is on the equilibrium path. Hence, the regulator's belief is updated by Bayes' rule and the incumbent firm's strategy. Then, $q = r$. Given this updated belief, the regulator's best response following $\frac{\theta^L}{3}$ is to choose $n = 0$ if

$$q[\tfrac{4}{9}(\theta^L)^2 - 2F] + (1-q)[\tfrac{4}{9}(\theta^H)^2 - 2F] > q[\tfrac{15}{32}(\theta^L)^2 - 3F] + (1-q)[\tfrac{15}{32}(\theta^H)^2 - 3F]$$

which implies $r(\theta^L)^2 + (1-r)(\theta^H)^2 < \frac{288}{7}F \qquad (1)_D$

2. To determine if the incumbent firms want to choose the quantities that imply the price $\frac{\theta^L}{3}$ for both demand sizes, we need to compare the resulting payoffs with the payoffs derived from the choice of the quantities that imply the price $\frac{\theta^H}{3}$. To make this comparison we must specify how the regulator would react to $\frac{\theta^H}{3}$.

If the regulator's response to $\frac{\theta^H}{3}$ is $n = 0$, the payoff of each incumbent firm is $\frac{1}{2}(\theta^L - \frac{\theta^H}{3})\frac{\theta^H}{3} - F + \frac{(\theta^L)^2}{9} - F$ when demand is D^L, which is below the payoff corresponding to $\frac{\theta^L}{3}$. When demand is D^H the payoff of each incumbent firm is $\frac{(\theta^H)^2}{9} - F + \frac{(\theta^H)^2}{9} - F$, which is greater than the payoff corresponding to $\frac{\theta^L}{3}$.

If the regulator's response to $\frac{\theta^H}{3}$ is $n = 1$, the payoff of each incumbent firm is $\frac{1}{2}(\theta^L - \frac{\theta^H}{3})\frac{\theta^H}{3} - F + \frac{(\theta^L)^2}{16} - F$ when demand is D^L, which is below the payoff corresponding to $\frac{\theta^L}{3}$. When demand is D^H each incumbent firm payoff is $\frac{(\theta^H)^2}{9} - F + \frac{(\theta^H)^2}{16} - F$, which is below the payoff corresponding to $\frac{\theta^L}{3}$ if

$$\frac{(\theta^H)^2}{9} - F + \frac{(\theta^H)^2}{16} - F < \frac{1}{2}(\theta^H - \frac{\theta^L}{3})\frac{\theta^L}{3} - F + \frac{(\theta^H)^2}{9} - F \Rightarrow$$

$$\Rightarrow \frac{(\theta^H)^2}{8} < (\theta^H - \frac{\theta^L}{3})\frac{\theta^L}{3} \qquad (2)_D$$

Then, if there is an equilibrium in which the incumbent strategy is $(\frac{\theta^L}{3}, \frac{\theta^L}{3})$ the regulator response to $\frac{\theta^H}{3}$ must be $n = 1$.

3. Choosing $n = 1$ is optimal for the regulator as a response to $\frac{\theta^H}{3}$ if

$$p\left[\frac{15}{32}(\theta^L)^2 - 3F\right] + (1-p)\left[\frac{15}{32}(\theta^H)^2 - 3F\right] > p\left[\frac{4}{9}(\theta^L)^2 - 2F\right] + (1-p)\left[\frac{4}{9}(\theta^H)^2 - 2F\right] \Rightarrow$$

$$\Rightarrow p < \frac{(\theta^H)^2 - \frac{288}{7}F}{(\theta^H)^2 - (\theta^L)^2}$$

Appendix C2

Figure 2.1 - Signal Game

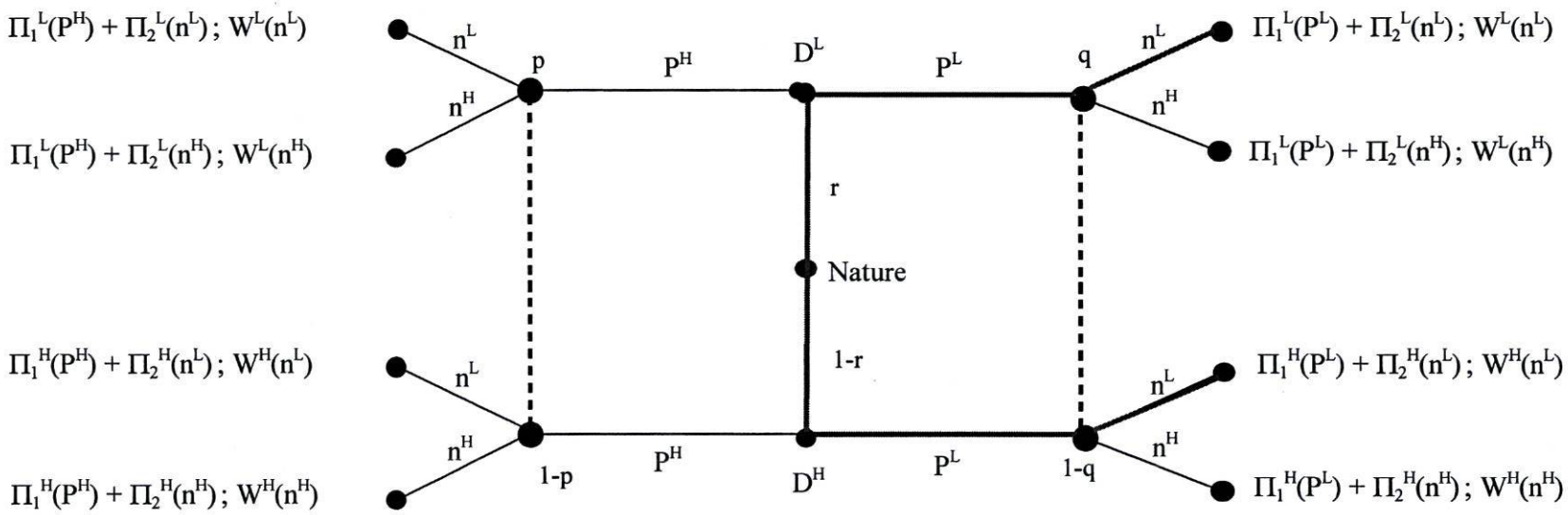
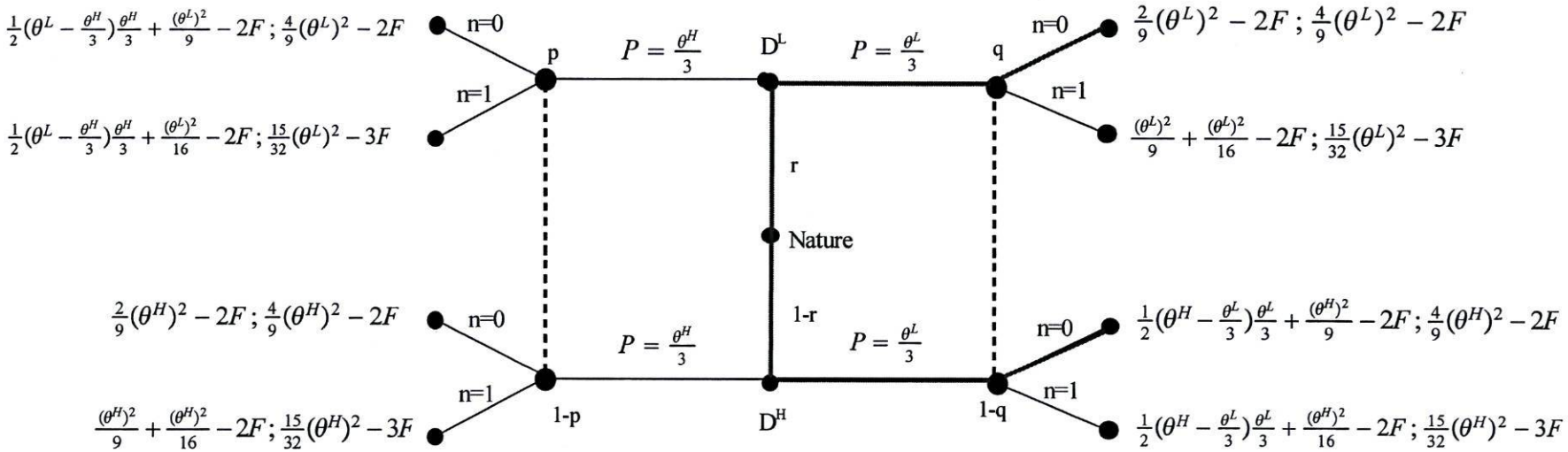


Figure 2.2 - Signal Game with Two Incumbent Firms



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Chapter 3

Entry Deterrence and Entry Accommodation Strategies of a Multiproduct Firm Regulated with Dynamic Price Cap

3.1 Introduction

Price cap regulation was an important innovation in regulatory policy in the 1980s. Since then it has been extensively applied in many economic sectors and countries around the world. The properties of price cap widely contribute to this development. Under price cap regulation the regulated firm has the right to keep all the profits, which preserves the incentives to achieve higher levels of cost efficiency,[1] and to introduce innovation. Furthermore, under price cap regulation the regulated firm has a greater flexibility to adjust prices, in particular when the price cap is applied to a set of prices. Finally, the administrative costs of regulation can be reduced in relation to others types of regulation (as rate-of-return regulation) because price cap is a simpler and more transparent mechanism of regulation. In spite of these positive features price cap regulation also has some drawbacks which, however, did not prevent its development and spreading to many economic sectors.

We can indicate at least three main drawbacks of price cap regulation. The first is that price cap regulation may allow prices to diverge significantly from realised costs, which can reduce welfare (Sappington, 2002). The second drawback is the incentive to the degradation of the product's quality as a way to reduce costs. To overcome this problem price cap regulation is frequently supplemented with controls on quality levels. The third drawback is related with the incentive to make long run investments. If the regulated firm knows that the regulator will adjust the price cap in order to let the consumers benefit from higher productivity, the incentive to realise investments decreases. Furthermore, there is also the problem of regulator's credibility, in particular in the face of long-life assets. After the realisation of the investment in those assets, the regulator might be tempted to reduce the price cap, making it impossible to recover the sunk costs. The anticipation of this behaviour might lead the firm to go back on its investment program. Gilbert and Newbery (1994) study this hold up problem and argue that the rate-of-return regulation

[1] Cabral and Riordan (1989), demonstrated, throught a highly stylised model, that price cap regulation promotes the investment in cost reduction, compared to cost of service regulation, provided the future price caps are not too low.

can be superior to price regulation when it comes to investment promotion. This argument is further developed by Newbery (2000).

The application of price cap regulation was first described by Littlechild (1983)[2] in the report about the regulation of British Telecom after its privatisation and studied further by many authors.[3]

Typically the regulated firms are multiproduct firms and price cap regulation is used in this context with many different forms. It is worthwhile to distinguish theoretically two forms of price cap regulation applied to multiproduct firms:[4] the regulation with fixed weights and the average revenue regulation. Under the former type of regulation the firm is constrained to choose prices such that an index of those prices is not greater than a cap defined by the regulator. The particularity of this form of regulation is that the prices's weights are fixed. For example, the prices's weights can be the quantities demanded at some vector of prices taken as reference. Under the latter type of regulation the firm is constrained to choose prices such that the total revenue divided by total output (the average revenue) is no greater than the price cap. This type of regulation is appropriate when the firm's cost depends only on total output, such as in the production of gas or electricity. In these cases the firm produces a single physical product that sells in different markets (different geographical markets or different types of consumers). Under average revenue regulation, prices's weights are endogenous to the firm because they depend on the prices chosen by the firm. This feature allows the manipulation of prices's weights by the regulated firm that leads to undesirable welfare results (Armstrong *et al.*, 1999).

Both forms of regulation previously described are static. However, in this chapter we consider the regulation of a multiproduct firm in a dynamic context, that is, we consider that the present prices are influenced by the prices of the previous

[2]Quoted from Armstrong *et al.* (1994).

[3]For a comprehensive analysis of price cap regulation see, for example, Armstrong *et al.* (1994), Laffont and Tirole (1993), Sappington (2002) and Vogelsang (2002).

[4]For a detailed description of the two types of regulation referred to see Bradley and Price (1988), Armstrong and Vickers (1991) and Armstrong *et al.* (1994).

periods. Under dynamic price cap regulation the firm is constrained to choose a vector of prices P^t in period t such that an index of those prices $I^t(P^t)$ is below a price cap $\bar{P}^t$. The index $I^t(P^t)$ and the cap $\bar{P}^t$ can vary over time. The first analysis of the dynamic properties of price cap regulation was done by Vogelsang and Finsinger (1979). Under their model the prices in period t must be such that with these prices the output of the previous period cost to consumers no more than the total observed cost of period t-1. Assuming that Q^{t-1} and $C(Q^{t-1})$ are, respectively, the vector of outputs of period t-1 and the corresponding total cost for the n products of the firm, the authorised vectors of prices P^t must obey the following condition: $\sum_{i=1}^{n} P_i^t Q_i^{t-1} \leq C(Q^{t-1})$. The Vogelsang-Finsinger model has an important long run property: the prices tend to the Ramsey prices,[5] which are a second best solution. However, this property requires very strong assumptions:

1) The regulator must observe Q^{t-1} and $C(Q^{t-1})$.

2) The cost function must exhibit decreasing ray average costs (that is, for $\lambda > 1, C(\lambda Q) \leq \lambda C(Q)$). This means that if all outputs of the firm are proportionally increased, then total cost increases less than proportionally, which is an assumption of "natural monopoly" for a multiproduct firm.

3) The firm must be myopic (that is, the regulated firm chooses the prices that maximise its current profits but ignores the effect of the current prices on the constraint in subsequent periods);

4) Cost and demand functions have to be stable over time.

Moreover, the desirable properties of the Vogelsang-Finsinger mechanism in the long

[5]The Ramsey prices were first characterised by Ramsey (1927) and analysed further by Boiteux (1956) and Baumol and Bradford (1970), among others. The Ramsey prices maximise the aggregate consumer surplus subject to the firm breaking even constraint. Under the assumption that consumer demands are independent, the Ramsey prices (P^*) make the price cost margins for each product i inversely proportional to the corresponding price demand elasticity. Formally we have: $\frac{P_i^* - Cmg}{P_i^*} = \frac{\lambda}{\eta_i}$, where η_i is the price demand elasticity and $\lambda \geq 0$ are the Ramsey numbers chosen so that the prices P^* satisfy the zero profit condition.

run can be altered by the strategic manipulation of price structure conducted by the (non-myopic) regulated firm. Sappington (1980) demonstrated that this strategic manipulation can even reduce total welfare to below the level achieved in the absence of any regulation.

Another important example of dynamic price cap regulation is the tariff basket regulation.[6] Under this mechanism the prices in period t must be such that, with these prices, the output of the previous period cost to consumers no more than it cost with the prices of period t-1. Then, the authorised price vector P^t must be such that $\sum_{i=1}^{n} P_i^t Q_i^{t-1} \leq \sum_{i=1}^{n} P_i^{t-1} Q_i^{t-1}$. Unlike the Vogelsang-Finsinger mechanism, the tariff basket scheme does not require that the regulator has information about past costs. Furthermore, the tariff basket regulation has fixed prices's weights within the period but, as one period's prices determine the next period's weights, the weights are endogenous over time. This price cap mechanism is based on a chained Laspeyres price index. A chained Laspeyres price index uses the quantities of the last period as price weights. It is different from a simple Laspeyres index where the price weights are the quantities of a fixed base period. This mechanism of dynamic price cap also leads to prices that obey the Ramsey rule. However, unlike the Vogelsang-Finsinger mechanism that leads the firm to zero profits, the tariff basket mechanism allows positive profits in the long run.[7]

The tariff basket mechanism is applied to many regulated firms as, for example, to AT&T in the United States and to British Telecom and water companies in the United Kingdom (Cowan, 1998). In the practical applications of this mechanism the regulator also considers the general growth of prices and the productivity increases.

[6] For a detailed description of this dynamic price cap scheme see Brennan (1989).

[7] We say that the prices obey the Ramsey rule (which is slightly different from saying that prices are Ramsey prices) if they maximise the aggregate consumer surplus provided that the firm is able to obtain a given level of profits. As we described before, the Ramsey prices require that the firm's profit is zero and, for that, the Ramsey numbers λ are chosen appropriately. If the values of λ are different from the Ramsey numbers, the firm can obtain positive profits. The tariff basket regulation allows such positive profits in the long run while the Vogelsang-Finsinger mechanism leads to the particular case of Ramsey prices.

Then, the authorised price vector P^t must be such that $\sum_{i=1}^{n} P_i^t Q_i^{t-1} \leq (1 + RPI - X)\sum_{i=1}^{n} P_i^{t-1} Q_i^{t-1}$, where RPI is the Retail Price Index increase and X is an expected productivity growth factor. The definition of X is made periodically (3 years is the common periodicity) and allows the regulator to adjust, in a rather ad-hoc way, the price cap to adequate levels to its perspective. If the regulator considers that the firm is obtaining excessive profits it can set a higher value for X that will tighten the price cap. For example, in the period 1984-1997 the British regulator for the telecommunication industry (Oftel)[8] raised the value of X applied to British Telecom prices on three different occasions (Armstrong, *et al.*, 1999). Additionally, the regulator might allow some price adjustments to reflect especific cost items that are outside the firm's control and are observable (cost passthrough). For instance, the British regulator of the largest airports in the United Kingdom, the British Airport Authority (BAA), allowed the inclusion of 75% of the extra costs with security in the price definition during the regulatory period of 1987-1992 (Armstrong, *et al.*, 1999).

In the report mentioned above, Littlechild (1983) describes price cap regulation applied to monopolist firms. After market liberalisation, and once competition was in place, there would be no justification for regulatory policy. However, the development of competition usually requires time and meanwhile the existence of a regulated dominant firm that faces actual or potential competition by small new firms is observed. In some sectors, where the regulatory authority considered that a mature phase in terms of competition has been achieved, as in the telecommunications retail market in the United Kingdom, the price cap regulation has been gradually removed.

However, price cap regulation continues to be an important mechanism in the regulation of networks, in particular in the regulation of access prices. For example, access price caps are used in the telecommunications in the United Kingdom and in

[8] At that time the British regulator for the telecommunication industry was the Office of Telecommunications (Oftel). Since the begining of 2004 Oftel was replaced by the Office of Communications (Ofcom) that also aggregate other regulatory authorities.

the United States for long distance access charges (Vogelsang, 2003). In the context of access price regulation, Laffont and Tirole (1996) developed the concept of global price cap, which includes under the same cap the retail price and the access price. With this concept the access is considered as one of the products of the multiproduct monopolist.

The study of entry in markets where there is an incumbent firm regulated by price cap have already been studied before. Bös and Nett (1990), considering only one market and the existence of capacity constraints, showed that for high capacity costs of the entrant, the incumbent is able to deter entry. However, in Bös and Nett's model there is only one decision about the price which does not allow the study of strategic price definition.

Armstrong and Vickers (1993) compare two types of price regulation applied to a multiproduct firm that operates simultaneously both in a potential competitive market and in a captive market. Under one type of regulation there are separate caps for each price, while under the other the firm faces an average cap, meaning that the average price can not exceed a limit imposed by the regulatory authority. The authors conclude that under average cap the firm has an incentive to choose a lower price in the competitive market (to deter entry) and a higher price in the captive market than it would have in the case of separate caps. However, the comparison of the two types of price regulation is also developed in a static framework which does not allow the study of strategic manipulation of the prices by the regulated firm.

The main question of this chapter is defined in a dynamic setting, similar to the tariff basket regulation, where entry is admissible. However, we assume that the prices's weights are not only fixed within the period but are also exogenous. Hence, the regulated firm can not use strategically the price weights.

The intertemporal manipulation of prices's weights by a monopolist regulated firm in the context of tariff basket regulation was studied by Foreman (1995) and Law (1997). Law analyses the pricing strategy of a firm that is not regulated in the first period but correctly anticipate tariff basket regulation for the second period.

Therefore, the emphasis of Law's model is in the weight manipulation in the period before a cap is imposed. Differently, Foreman analyses the strategic manipulation of price weights by a firm that is subject to regulation in both periods. Foreman assumes that the price cap is equal in both periods and exogenously defined by the regulator. In spite of considering different models, both Foreman and Law conclude that the strategic manipulation of price weights by the monopolist regulated firm can have negative consequences on aggregate welfare.

Differently from Law and Foreman models, we assume that the prices's weights are fixed, that entry is possible in one of the markets and that the price cap of the second period is endogenously defined. The last feature mentioned brings our approach closer to the model of Iozzi (2001). However, we consider a multiproduct firm while Iozzi considers only one market.[9] The consideration of a multiproduct firm regulated by an average cap rises especific questions related to the credibility of the entry deterrence strategy, which are discussed in this chapter.

Our purpose is to study the way a multiproduct firm, regulated through a dynamic price cap, can develop a price strategy that uses the regulation mechanism to deter entry. We consider a regulated firm that initially operates as monopolist in two markets but, in the second period, entry is possible in one of those markets. We conclude that if the fixed entry cost is above a critical level then the regulated firm has the incentive to follow an anticompetitive policy in the market where entry is possible. This conclusion is in the same line as the concerns of Armstrong and Vickers (1993) about the regulation of a multiproduct firm with an average cap instead of separate caps. However, under our model the entry deterrence strategy leads to the reduction of the price not only in the market where entry is possible but also in the captive market. In spite of this, the final effect of the entry deterrence strategy on consumer surplus is not always positive.

While the central question of Chapter 3 is the study of a multiproduct firm price

[9] Another structural difference between our model and Iozzi's model relies in the richer assumption of product differentiation adopted by Iozzi, while we assume that products are homogenous in the duopoly case.

strategy, we initially present a simple model with only one market to establish some useful results. The model with one market follows very closely the model developed by Iozzi (2001). The structure of Chapter 3 is the following: section 3.2 presents a model of dynamic price cap considering only one market; in section 3.3 the model is extended to the consideration of two markets, one where entry is possible and other where entry is blocked (by technological, legal or other entry barriers); in section 3.4 the effects of the entry deterrence strategy on consumer surplus are analysed, and finally, section 3.5 presents the main conclusions of Chapter 3.

3.2 The Model with One Market

3.2.1 Introduction

We adopt a very simple framework with two decision periods to highlight the strategic behaviour of the regulated firm. In the first period the regulated firm (firm $\underline{i}$) is monopolist but in the second period entry is possible. If entry occurs the incumbent firm decides in the second period the quantity and price considering the reaction function of the new firm (firm $\underline{e}$) in its profit function. In the duopoly case we consider Stackelberg competition.[10] The entrant decides whether or not to enter after observing the first period's price. Entry occurs if firm $\underline{e}$ forecasts strictly positive profits and, in that case, firm $\underline{e}$ bears a fixed entry cost of f^2.

We suppose that the marginal production costs are known, equal and normalised for zero to both firms. We assume linear and stationary demand given by $p_t(q_{ti}, q_{te}) = 1 - q_{ti} - q_{te}$, if there is entry, or $p_t(q_i, 0) = 1 - q_{ti}$, if entry does not occur, where p_t is the market price in period t, q_{ti} is the incumbent's quantity in period t and q_{te} is the entrant's quantity in period t. The latter expression also represents the demand

[10] We assume Stackelberg competition because this model allows the introduction of asymmetric behaviour between the incumbent firm and the entrant firm. Additionally, as we consider that the market price is regulated, the assumption that the firms have a small capacity to rapidly adjust the price is acceptable.

function in the first period.

The incumbent firm is subject to dynamic price cap regulation with the following features: in the first period the price cap ($\overline{p_1}$) is exogenously set by the regulator assuming a value such that the firm is not allowed to choose the monopoly price. Therefore, the regulatory constraint for the first period is $p_1 \leq \overline{p_1}$ and $\overline{p_1} \in (0, \frac{1}{2})$. In the second period the price cap is equal to the observed price of the first period, that is, $\overline{p_2} = p_1$.

The time of the game is the following: at stage 1 the incumbent firm chooses the price p_1 subject to $p_1 \leq \overline{p_1}$. At stage 2 there are two sequential decisions: first, the entrant firm chooses whether or not to enter and, after that decision, the incumbent firm decides the price and quantity[11] subject to the price cap of the second period.

We consider a game with perfect information, thus each player anticipates what will happen in subsequent stages of the game. Hence, the resolution of the game will be done by backward induction considering the two subgames of the second period that result from the entry decision.

The payoff of firm $\underline{e}$ is given by its second period profit while the payoff of firm $\underline{i}$ is given by the sum of its profits in both periods assuming a discount factor of one.

3.2.2 The Entry Accommodation Strategy

Firm $\underline{e}$ decides to enter if its forecasted profit is strictly positive. The profit function of firm $\underline{e}$ is $\pi_{2e} = p_2 q_{2e} - f^2$. From the first order condition we obtain the reaction function of firm $\underline{e}$, $q_{2e} = \frac{1-q_{2i}}{2}$, and the optimal profit for firm $\underline{e}$, $\pi_{2e} = \frac{(1-q_{2i})^2}{4} - f^2$.

[11] Through Chapter 3 the incumbent's strategy is usually described by the price, although we have in mind that, if entry occurs in the second period, the decision variable is the quantity.

The problem faced by the incumbent firm in the second period is:

$$Maximise_{q_{2i}} \quad \pi_{2i}$$

$$subject\ to \qquad p_2 \leq \overline{p_2}$$

Considering the reaction function of firm e, the Lagrangian function is defined as

$$L = \frac{1 - q_{2i}}{2} q_{2i} - \lambda(\frac{1 - q_{2i}}{2} - \overline{p_2})$$

Using the Kuhn-Tucker Theorem to solve the constrained maximisation problem we obtain the following results:

$$q_{2i} = \frac{1}{2}; q_{2e} = \frac{1}{4}; p_2 = \frac{1}{4} \quad \text{if} \quad \overline{p_2} \geq \frac{1}{4}$$

$$\text{or } q_{2i} = 1 - 2\overline{p_2}; q_{2e} = \overline{p_2}; p_2 = \overline{p_2} \quad \text{if} \quad \overline{p_2} < \frac{1}{4}$$

Therefore $p_2 = \min\left\{\frac{1}{4}, \overline{p_2}\right\}$ and $\pi_{2i} = \begin{cases} \frac{1}{8} & \text{if } \overline{p_2} \geq \frac{1}{4} \\ (1 - 2\overline{p_2})\overline{p_2} & \text{if } \overline{p_2} < \frac{1}{4} \end{cases}$

In the first period the incumbent firm chooses the price that allows the highest profit under the constraint imposed by the initial price cap. The incumbent firm's problem is:

$$Maximise_{q_1} \quad \pi_1$$

$$subject\ to \quad p_1 \leq \overline{p_1}$$

As $\overline{p_1} < \frac{1}{2}$, the best possible price is $\overline{p_1}$ and thus $\pi_1 = (1-\overline{p_1})\overline{p_1}$. Given the regulatory rule, the second period's price cap is equal to the initial price cap, that is, $\overline{p_2} = \overline{p_1}$ because, by definition, $\overline{p_2} = p_1$ and we previously obtained the result $p_1 = \overline{p_1}$. Therefore, the incumbent firm's payoff in the subgame of entry accommodation is defined as:

$$\Pi^{Accom} = \begin{cases} (1-\overline{p_1})\overline{p_1} + \frac{1}{8} & \text{if } \overline{p_1} \geq \frac{1}{4} \\ (1-\overline{p_1})\overline{p_1} + (1-2\overline{p_1})\overline{p_1} & \text{if } \overline{p_1} < \frac{1}{4} \end{cases}$$

As we want to concentrate our attention on the effects of the incumbent firm's price strategy on entry we eliminate from the analysis those situations where entry is blocked by the value of the entry cost. Then, we only consider the values of f such that $\pi_{2e} = \frac{1}{16} - f^2 > 0$ which implies $f < \frac{1}{4}$ if $\overline{p_1} \geq \frac{1}{4}$ or $\pi_{2e} = \overline{p_1}^2 - f^2 > 0$ which implies $f < \overline{p_1}$ if $\overline{p_1} < \frac{1}{4}$. These admissible values of f are described by Assumption 3.1.

Assumption 3.1: Assume $f < \min\left\{\frac{1}{4}, \overline{p_1}\right\}$.

3.2.3 The Entry Deterrence Strategy

Under Assumption 3.1, entry occurs unless the incumbent firm adopts a credible entry deterrence strategy. To prevent entry, firm $\underline{i}$ has to choose in the first period a price p_1 such that, with the second period's price cap derived from p_1, the quantity q_{2i} that maximises the incumbent's profit of the second period does not allow strictly positive profits for the entrant. If firm $\underline{i}$ chooses the quantity $q_{2i} = 1 - 2f$ in the

second period then the best decision for the entrant firm, given by its reaction function, is $q_{2e} = f$. These quantities lead to $p_2 = f$ and $\pi_{2e} = 0$. The quantity $q_{2i} = 1 - 2f$ is the best decision for the incumbent firm if $\overline{p_2} = f$. Notice that if $\overline{p_2} = f$ then the closest possible price to $\frac{1}{4}$ (which is the optimal duopoly price) is f. Then, if $p_2 = f$ we have $1 - q_{2i} - \frac{1-q_{2i}}{2} = f$ which implies $q_{2i} = 1 - 2f$.

To obtain f as the price cap in the second period, the first period's price must be equal to f. Then, the first period's profit of the incumbent firm is $\pi_1 = f(1-f)$.

If, under $\overline{p_2} = f$, the best decision for the incumbent firm leads to $\pi_{2e} = 0$ then firm i stays alone in the market, and thus its second period's profit is $\pi_{2i} = f(1-f)$. Consequently, the payoff of the incumbent firm in the subgame without entry is given by $\Pi^{Deter} = 2f(1-f)$.

3.2.4 Comparison of Payoffs

From the comparison of firm's i payoffs in the two subgames we can describe the equilibrium of the game in the following proposition:

Proposition 3.1: Let $f^* = \begin{cases} \frac{1}{2} - \frac{1}{4}\sqrt{3 - 8\overline{p_1} + 8\overline{p_1}^2} & \text{if } \overline{p_1} \geq \frac{1}{4} \\ \frac{1}{2} - \frac{1}{2}\sqrt{1 - 4\overline{p_1} + 6\overline{p_1}^2} & \text{if } \overline{p_1} < \frac{1}{4} \end{cases}$. If $f \geq f^*$ the equilibrium prices are $p_1 = p_2 = f$ and there will be no entry. If $f < f^*$ the equilibrium prices are $p_1 = \overline{p_1}$ and $p_2 = \min\left\{\frac{1}{4}, \overline{p_1}\right\}$ and entry will occur.

Proof of Proposition 3.1[12]: Consider that $\overline{p_1} \geq \frac{1}{4}$. Then $\Pi^{Deter} - \Pi^{Accom} = 2f(1-f) - (1-\overline{p_1})\overline{p_1} - \frac{1}{8}$. This is a concave second degree equation in f whose roots are $f_1 = \frac{1}{2} - \frac{1}{4}\sqrt{3 - 8\overline{p_1} + 8\overline{p_1}^2}$ and $f_2 = \frac{1}{2} + \frac{1}{4}\sqrt{3 - 8\overline{p_1} + 8\overline{p_1}^2}$. By Assumption 3.1 we know that $f < \frac{1}{4}$. As $f_2 > \frac{1}{4}$ the entry deterrence strategy allows a greater payoff than the entry accommodation strategy if $f > f_1$.

Assume now that $\overline{p_1} < \frac{1}{4}$. Then $\Pi^{Deter} - \Pi^{Acom} = 2f(1-f) - (1-\overline{p_1})\overline{p_1} - (1 - 2\overline{p_1})\overline{p_1}$. This is a concave second degree equation in f whose roots are $f_1 = \frac{1}{2} -$

[12]The proof of Proposition 3.1 follows the proof of Proposition 3 in Iozzi (2001).

$\frac{1}{2}\sqrt{1-4\overline{p_1}+6\overline{p_1}^2}$ and $f_2 = \frac{1}{2}+\frac{1}{2}\sqrt{1-4\overline{p_1}+6\overline{p_1}^2}$. By Assumption 1 we know that $f < \overline{p_1}$. As $f_2 > \overline{p_1}$ the deterrence strategy allows a greater payoff than the accommodation strategy if $f > f_1$.

We conclude that if the entry cost is higher than a critical value (f^*) the incumbent firm chooses an anticompetitive strategy. With this strategy the price will be lower than the initial price cap to induce a decrease in the price cap of the following period. The entrant firm observes the second period's price cap and decides not to enter. Although in the first period the price is more distant from the optimal monopoly price, in the second period firm $\underline{i}$ is alone in the market and, if $f > f^*$, this is better than accommodate entry.

Notice that the accommodation payoff does not depend on the entry cost while the deterrence payoff is increasing with f. Then, to small values of f, it is less likely to have entry deterrence. Also notice that the deterrence payoff is independent of $\overline{p_1}$ while the accommodation payoff is increasing with $\overline{p_1}$. From the results we find that the critical value of f is increasing with $\overline{p_1}$. Thus, to high values of $\overline{p_1}$ it is less likely to have entry deterrence. The intuition behind this result is the following: if the regulatory policy is not too tight (that is, $\overline{p_1}$ is not too low) the incumbent firm's profit derived from the entry accommodation strategy is relatively high and easily assumes higher values than the incumbent firm's profit that would result from the entry deterrence strategy. Then, the critical value of f must be higher to high values of $\overline{p_1}$. These conclusions are also reached by Iozzi (2001).

From the results previously described it is important to emphasise that it is the regulatory policy that confers credibility to the commitment of choosing a lower price in the second period. The price reduction in the first period is a credible threat of a lower price in the second period because the temporal linkage of prices set by regulation guarantee that result. Without the dynamic price cap regulation described before the incumbent firm was not able to deter entry.

3.3 The Model with Two Markets

3.3.1 Introduction

In this model we assume the same hypothesis as above with the following exceptions:

1. Firm i operates in markets A and B. We assume that entry is not possible in market A (because of legal, technological or other entry barriers) while entry is possible in market B.

2. In the first period the regulator exogenously sets the maximum value for the average price ($\overline{p_1}$) considering equal weights for prices in both markets[13], such that $\frac{p_1^A+p_1^B}{2} \leq \overline{p_1}$ with $\overline{p_1} \in \left(0, \frac{1}{2}\right)$. This means that firm i is not able to choose simultaneously the optimal monopoly price in both markets. In the second period the average price cap will be the average price observed in the previous period, assuming the same price weights as before.

The time of the game is the following: at stage 1 the incumbent firm chooses prices[14] p_1^A and p_1^B subject to $\frac{p_1^A+p_1^B}{2} \leq \overline{p_1}$. At stage 2 there are two sequential decisions: first, the entrant firm chooses whether or not to enter and, after that decision, the incumbent firm decides the quantities subject to the second period's price cap. Given the nature of the game, the resolution will be done by backward induction considering the two subgames of the second period that result from the entry decision.

[13]The rationale for considering different price weights is the possibility to best represent the relative impact on consumers of a price change (Sappington, 2002). A given price change will have a higher effect on consumers if the products involved in the price change have an important weight on the consumer pattern. The relative quantities or the relative revenues of the products supplied by the regulated firm are the most frequent employed weights. Our simplified hyphothesis of having equal weights for both products can be supported by the assumption that the two products have a similar weight on total consumption pattern. Moreover, our hypothesis eliminated the possibility of strategic manipulation of price weights by the regulated firm. As mentioned above this has already been studied by other authors (Foreman, 1995; Law, 1997).

[14]In the first period the incumbent firm is monopolist, so it is indifferent to define the problem in quantities or prices.

The payoff of firm e is given by its second period profit while the payoff of firm i is given by the sum of its profits in both periods and in both markets, assuming a discount factor of one.

3.3.2 The Entry Accommodation Strategy

As in the model presented in the previous section, firm e decides to enter if its forecast profit is strictly positive. The profit function of firm e is $\pi_{2e} = p_2^B q_{2e}^B - f^2$. From the first order condition we obtain the reaction function of firm e, $q_{2e}^B = \frac{1-q_{2i}^B}{2}$, and the optimal profit for firm e, $\pi_{2e} = \frac{(1-q_{2i}^B)^2}{4} - f^2$.

The problem faced by the incumbent firm in the second period is:

$$Maximise_{q_2^A, q_{2i}^B} \qquad \pi_{2i} = p_2^A q_2^A + p_2^B q_{2i}^B$$

$$subject\ to \qquad \frac{p_2^A + p_2^B}{2} \leq \overline{p_2}$$

Considering the reaction function of firm e, the Lagrangian function is

$$L = (1 - q_2^A)q_2^A + \frac{1 - q_{2i}^B}{2} q_{2i}^B - \lambda(1 - q_2^A + \frac{1 - q_{2i}^B}{2} - 2\overline{p_2})$$

Using the Kuhn-Tucker Theorem to solve the constrained maximisation problem we obtain the following results:

$$(q_2^A = \frac{1}{2}; p_2^A = \frac{1}{2}) \text{ and } (q_{2i}^B = \frac{1}{2}; q_{2e}^B = \frac{1}{4}; p_2^B = \frac{1}{4}) \text{ if } \overline{p_2} \geq \frac{3}{8}$$

or

$$(q_2^A = \frac{3-4\overline{p_2}}{3}, p_2^A = \frac{4}{3}\overline{p_2}) \text{ and } (q_{2i}^B = \frac{3-4\overline{p_2}}{3}; q_{2e}^B = \frac{2}{3}\overline{p_2}; p_2^B = \frac{2}{3}\overline{p_2}) \text{ if } \overline{p_2} < \frac{3}{8}$$

Notice that the results for the second period depend on the level of the second period's price cap. If $\overline{p_2} \geq \frac{3}{8}$ the constraint is not binding and thus firm i chooses the optimal quantities in both markets: the optimal monopoly quantity in market A ($\frac{1}{2}$) and the optimal quantity as a Stackelberg leader in market B ($\frac{1}{2}$). If the second period's price cap is relatively low ($\overline{p_2} < \frac{3}{8}$) the regulatory constraint is binding and thus the optimal quantities are not possible. To maximise the second period's profit under the constraint, firm i chooses the same quantity in both markets ($\frac{3-4\overline{p_2}}{3}$), which leads to a higher price in the captive market ($\frac{4}{3}\overline{p_2}$) than in market B ($\frac{2}{3}\overline{p_2}$). It is worthwhile to emphasise that, when $\overline{p_2} < \frac{3}{8}$, the prices and quantities depend directly on $\overline{p_2}$.

Considering the above results, the second period's profit for firm i is:

$$\pi_{2i} = \begin{cases} \frac{3}{8} \text{ if } \overline{p_2} \geq \frac{3}{8} \\ \frac{2}{3}\overline{p_2}(3-4\overline{p_2}) \text{ if } \overline{p_2} < \frac{3}{8} \end{cases}$$

In the first period the incumbent firm chooses the prices that allow the higher profit under the constraint imposed by the initial price cap. Then firm i solves the problem:

$$Maximise_{q_1^A, q_1^B} \quad \pi_{1i} = p_1^A(1-p_1^A) + p_1^B(1-p_1^B)$$

$$subject\ to \quad \frac{p_1^A + p_1^B}{2} \leq \overline{p_1}$$

The solution of the problem is $p_1^A = p_1^B = \overline{p_1}$, because we are assuming $\overline{p_1} < \frac{1}{2}$. As markets A and B are equal, except for the possibility of entry, there is no reason to price discrimination. Then, the best strategy for firm i in the first period is to choose the same price in both markets and, as far as possible, close to the optimal monopoly price. Then, the first period's profit for the incumbent firm is $\pi_1 = 2(1-\overline{p_1})\overline{p_1}$.

With both prices equal to $\overline{p_1}$, the average price in the first period will also be $\overline{p_1}$. Therefore, the price cap in the second period will be the initial price cap: $\overline{p_2} = \overline{p_1}$.

Considering the previous results, the incumbent firm's payoff in the case of entry accommodation is given by:

$$\Pi^{Accom} = \begin{cases} 2(1-\overline{p_1})\overline{p_1} + \frac{3}{8} & \text{if } \overline{p_1} \geq \frac{3}{8} \\ 4\overline{p_1} - \frac{14}{3}(\overline{p_1})^2 & \text{if } \overline{p_1} < \frac{3}{8} \end{cases}$$

Notice that if $\overline{p_1} \geq \frac{3}{8}$ the optimal duopoly prices are possible in the second period. When $\overline{p_1} < \frac{3}{8}$ the regulatory constraint is binding and, consequently, the equilibrium prices depend on the price cap.

As before we want to concentrate our attention on the effects of the incumbent firm's price strategy upon entry. Hence, we eliminate from the analysis those situations where entry is blocked by the entry cost. Then, we only consider the values of f such that $\pi_{2e} = \frac{1}{16} - f^2 > 0$ which implies $f < \frac{1}{4}$ if $\overline{p_1} \geq \frac{3}{8}$ and $\pi_{2e} = \frac{4}{9}(\overline{p_2})^2 - f^2 > 0$ which implies $f < \frac{2}{3}\overline{p_1}$ if $\overline{p_1} < \frac{3}{8}$. These admissible values of f are described by Assumption 3.2.

Assumption 3.2: Assume $f < \min\{\frac{1}{4}, \frac{2}{3}\overline{p_1}\}$.

3.3.3 The Entry Deterrence Strategy

In the discussion of the model with two markets we study the entry deterrence strategy payoff assuming $\overline{p_1} < \frac{3}{8}$. This means that we are only considering values of $\overline{p_1}$ for which the regulator knows that, if entry occurs, the optimal prices (the optimal monopoly price in market A and the optimal duopoly price in market B) are not possible.

If firm e forecasts weakly negative profits it decides not to enter in market B. Therefore, if the incumbent firm wants to deter entry it has to define the first period's

prices, p_1^A and p_1^B, such that the resulting second period's price cap, $\overline{p_2}$, leads the entrant to expect $\pi_{2e} \leq 0$. For this price cap $\overline{p_2}$ entry does not occur and thus the incumbent firm chooses the prices that maximise the second period's profit under the constraint imposed by $\overline{p_2}$. The incumbent's problem in the second period, when entry has not occurred, is

$$Maximise_{q_2^A,\, q_{2i}^B} \qquad \pi_{2i}$$

$$subject\ to \qquad \frac{p_2^A + p_2^B}{2} \leq \overline{p_2}$$

and the solution is $p_2^A = p_2^B = \overline{p_2}$.

In the first period the incumbent firm has to take two decisions: first it has to define the level of $\overline{p_2}$ that deters entry and, second, it has to define the first period's prices that maximise its profits and lead to the level of $\overline{p_2}$ previously found. We analyse each decision at a time. The level of $\overline{p_2}$ that deters entry with credibility must guarantee that the best decision for the incumbent firm in face of $\overline{p_2}$ does not allow strictly positive profits for the entrant. From the previous section we know that the optimal profit for firm $\underline{e}$ is $\pi_{2e} = \frac{(1-q_{2i}^B)^2}{4} - f^2$ and, when firm $\underline{i}$ maximise its profit, the quantity offered in market B by firm $\underline{i}$ is $q_{2i}^B = \frac{3-4\overline{p_2}}{3}$. Therefore, when both firms are maximising their profits under the price cap $\overline{p_2}$, the entrant's profit is given by $\pi_{2e} = \frac{4}{9}\overline{p_2}^2 - f^2$. The values of $\overline{p_2}$ that verify the condition $\pi_{2e} \leq 0$ are $\overline{p_2} \leq \frac{3}{2}f$.

The second decision of the incumbent firm is the definition of p_1^A and p_1^B that maximise the first period's profit and lead to a price cap not above $\frac{3}{2}f$. Having in mind that $\overline{p_2} = \frac{p_1^A + p_1^B}{2}$, the incumbent firm's problem is:

$$Maximise_{p_1^A,\, p_1^B} \quad \pi_1$$

$$subject\ to \quad \frac{p_1^A + p_1^B}{2} \leq \frac{3}{2}f$$

The solution of this problem is $p_1^A = p_1^B = \frac{3}{2}f$ because markets A and B are identical. Then, the profit of the first period for the incumbent firm is $\pi_1 = 2(\frac{3}{2}f)(1-\frac{3}{2}f)$ and the final payoff with no entry is $\Pi^{Deter} = 4(\frac{3}{2}f)(1-\frac{3}{2}f)$.

Before proceeding with the payoffs comparison it is important to explain the credibility of the price reduction in the first period as an entry deterrence strategy. We know that if the first period's prices are $p_1^A = p_1^B = \frac{3}{2}f$ the second period's price cap is $\frac{3}{2}f$. For this price cap, if entry occurs, the Stackelberg competition leads the entrant's profit to zero. Then, the entrant firm decides not to enter. If, on the contrary, the first period's prices are above $\frac{3}{2}f$ the entrant's profit will be positive in case of entry and Stackelberg competition. Hence, the first period's prices are not credible as a threat to the entrant because, after entry, the incumbent's payoff is greater with entry accommodation than with entry fighting. The incumbent's payoff with entry accommodation and the second period's price cap equal to $\overline{p_2}$, would be $\Pi = 2\overline{p_2}(1-\overline{p_2}) + \frac{2}{3}\overline{p_2}\,(3-4\overline{p_2})$ and the incumbent's payoff with entry fighting and the second period's price cap equal to $\overline{p_2}$ would be

$$\Pi = \begin{cases} 2\overline{p_2}(1-\overline{p_2}) + f(1-2f) + (2\overline{p_2} - f)(1 - 2\overline{p_2} + f) & \text{if } \overline{p_2} < \frac{1}{4} + \frac{f}{2} \\ 2\overline{p_2}(1-\overline{p_2}) + f(1-2f) + \frac{1}{4} & \text{if } \overline{p_2} \geq \frac{1}{4} + \frac{f}{2} \end{cases}$$

Notice that the fighting strategy requires $p_2^B = f$. This price results from the incumbent's decision of offering the quantity $1-2f$ in order to cause zero profits for the entrant in case of entry. With $p_2^B = f$ the price for market A might be the optimal monopoly price if $\overline{p_2} \geq \frac{1}{4} + \frac{f}{2}$, or has to be $2\overline{p_2} - f$ if $\overline{p_2} < \frac{1}{4} + \frac{f}{2}$. Whatever the case, we conclude that if $\overline{p_2} > \frac{3}{2}f$ the incumbent's payoff is greater with entry accommodation. This means that if $\overline{p_2} > \frac{3}{2}f$ entry would occur (see the proof in

Appendix A3.1).

This argument can be applied exactly in the same way to demonstrate that, after the definition of the first period's prices at the level of the initial price cap ($p_1^A = p_1^B = \overline{p_1}$), fighting entry is not a credible strategy (see the proof in Appendix A3.2). The extensive form representation of the game (presented in Appendix C3) allows a better understanding of all the possible strategies previously described.

3.3.4 Comparison of Payoffs

As we are assuming $\overline{p_1} < \frac{3}{8}$, the relevant payoffs to compare are $\Pi^{Accom} = 4\overline{p_1} - \frac{14}{3}(\overline{p_1})^2$ and $\Pi^{Deter} = 4(\frac{3}{2}f)(1 - \frac{3}{2}f)$.

From the comparison of firm's i payoffs in the two subgames we can describe the equilibrium of the game with the following proposition:

Proposition 3.2: Assume $\overline{p_1} < \frac{3}{8}$ and $f^* = \frac{1}{3} - \frac{1}{9}\sqrt{9 - 36\overline{p_1} + 42\overline{p_1}^2}$. If $f \geq f^*$ the equilibrium prices are $p_1^A = p_1^B = p_2^A = p_2^B = \frac{3}{2}f$ and there will be no entry. If $f < f^*$ entry will occur and the equilibrium prices are $p_1^A = p_1^B = \overline{p_1}$, $p_2^A = \frac{4}{3}\overline{p_1}$ and $p_2^B = \frac{2}{3}\overline{p_1}$.

Proof of Proposition 3.2: See Appendix A3.3.

From the previous analysis we can identify three different cases regarding the entry decision. Assuming $\overline{p_1} < \frac{3}{8}$ we know that:

i) If $f \geq \frac{2}{3}\overline{p_1}$ entry is "naturally" blocked. This means that even if the incumbent firm does not adopt any action with the aim of avoiding entry, entry will not occur. This case was eliminated from the analysis by Assumption 2.

ii) If $f^* \leq f < \frac{2}{3}\overline{p_1}$ entry can be "strategically" blocked. In this case the incumbent firm has the incentive to choose the prices of the first period that blocked entry in the second period. The first period's prices that prevent entry and maximise the

first period's profit of the incumbent firm are $p_1^A = p_1^B = \frac{3}{2}f$. With those prices the incumbent firm guarantee that the condition that prevents entry is verified, that is, $f \geq \frac{2}{3}\overline{p_2}$.

iii) If $f < f^*$ entry occurs. This means that for small values of f the reduction in the second period's price cap, through the reduction in the first period's prices, is not credible as a threat to entry.

We conclude that the incumbent firm follows an anticompetitive strategy if the fixed costs of entry are above a critical level. Therefore, we demonstrate that the concern of Armstrong and Vickers (1993) about the average price cap regulation also has support in a dynamic environment. However, in our model the entry deterrence strategy leads to a price reduction not only in the market where entry is possible but also in the captive market. This is a quite different result from Armstrong and Vickers' (1993) one, as they conclude that the incumbent firm reduces the price in one market to avoid entry, but increases the price in the captive market to compensate any loss. In our model when the entry cost is above a critical value, the incumbent firm adopts a strategic behaviour in the first period. This strategic behaviour is characterised by the definition of the first period's prices below the initial price cap. Then, according to the regulatory rules, the second period's price cap is lower than the initial price cap. In the second period there is no strategic behaviour. The incumbent firm defines the quantities that maximise its profit under the constraint imposed by the second period's price cap, and that decision does not allow strictly positive profits to the entrant. Once again we conclude that it is the regulatory policy that confers credibility to the strategic behaviour adopted by the incumbent firm in the first period.

It is also important to notice that, as a consequence of the entry deterrence strategy, the price in market B (as well as the price in market A) decreases to $\frac{3}{2}f$. This value is above the price that would be necessary to deter entry if we were considering an individual price cap, as in section 3.2. In relation to the model with one market we conclude that the incumbent firm has to decrease the price to f (when the constraint is binding) to prevent entry. However, when the incumbent firm operates in two

markets and there is a price cap on the average price, to convince the entrant firm not to enter is enough to reduce both prices to $\frac{3}{2}f$ in the first period. This characteristic is due to the presence of the captive market's price in the average price subject to regulation. The consideration of the captive market's price in the average price increases the value of the price for which the incumbent payoff with entry deterrence is greater than the incumbent payoff with entry accommodation. Therefore, with average regulation, the incumbent firm can deter entry with a superior price in market B, compared to the one that would be necessary if market B were regulated with an individual cap. This result reveals the more aggressive behaviour of the incumbent firm in face of entry when it is subject to average price cap regulation than when it is subject to individual price cap regulation.

However, to evaluate the total effect for consumers of the entry deterrence strategy it is also necessary to consider that this strategy leads to a decrease in the price of the captive market.

3.4 The Effects on Consumer Surplus

3.4.1 Introduction

In the previous section we conclude that if the fixed entry cost is above a critical level the incumbent firm follows an anticompetitive strategy. With this strategy firm $\underline{i}$ reduces the prices in the first period in order to cause a decrease on the price cap of the second period. We prove that, under this lower price cap, the best option to firm $\underline{i}$ in the second period is to choose a price that does not allow a profitable entry.

In the present section we want to evaluate the effects of the entry deterrence strategy on consumer surplus. In particular, we want to know if the entry deterrence strategy has a negative impact on consumers welfare. If we consider the entry deterrence strategy when the price regulation only involves one market (as it was described

in section 3.2) it is easy to understand that this strategy has positive effects on consumer surplus: the entry deterrence strategy leads to a reduction of the price in the first period and this lower price will also be in force in the second period because of the regulatory policy.[15]

With two markets the consumers of market B benefit from the entry deterrence strategy because of the reduction of the price. However, as we indicated above the price decrease that avoids entry is not as strong as in the case with one market. Moreover, we also conclude that the entry deterrence strategy leads to the reduction of market's A price, which is positive for the consumers of this market.

To evaluate those effects we calculate the total consumer surplus (CS) as the sum of consumer surplus on both markets and periods, assuming a discount factor of one, and using the prices derived above.

3.4.2 The Entry Accommodation Case

The prices obtained when the incumbent firm follows an entry accommodation strategy and when we assume $\overline{p_1} < \frac{3}{8}$ are $p_1^A = p_1^B = \overline{p_1}$ for the first period, and $p_2^A = \frac{4}{3}\overline{p_1}$ and $p_1^B = \frac{2}{3}\overline{p_1}$ for the second period. Then, the value of the total consumer surplus is defined as follows:

$$CS^{Accom} = \frac{(1-\overline{p_1})^2}{2} + \frac{(1-\frac{4}{3}\overline{p_1})^2}{2} + \frac{(1-\overline{p_1})^2}{2} + \frac{(1-\frac{2}{3}\overline{p_1})^2}{2} = 2 - 4\overline{p_1} + \frac{19}{9}\overline{p_1}^2$$

3.4.3 The Entry Deterrence Case

The prices obtained when the incumbent firm follows an entry deterrence strategy and when we assume $\overline{p_1} < \frac{3}{8}$ are $p_1^A = p_1^B = p_2^A = p_2^B = \frac{3}{2}f$. Then, the value of the total consumer surplus is defined as follows:

$$CS^{Deter} = 4(\frac{(1-\frac{3}{2}f)^2}{2}) = \frac{1}{2}(-2+3f)^2$$

[15] A formal description of this result is presented in Appendix B3.1.

3.4.4 Comparison of the Results

From the comparison of the total consumer surplus that result from the two alternative strategies for firm i we reach the conclusion summarise in Proposition 3.3:

Proposition 3.3: Let $\overline{p_1} < \frac{3}{8}$ and $f^{**} = \frac{2}{3} - \frac{1}{9}\sqrt{36 - 72\overline{p_1} + 38\overline{p_1}^2}$. The consumer surplus is higher when firm i follows an entry deterrence strategy than when firm i follows an entry accommodation strategy if $f < f^{**}$.

Proof of Proposition 3.3: See Appendix B3.2.

If the fixed cost of entry f is very low then entry is attractive. Therefore, in order to deter entry, the incumbent firm has to define a very low price for the first period ($p_1^A = p_1^B = \frac{3}{2}f$), which is maintained in the second period ($p_2^A = p_2^B = \frac{3}{2}f$) by the regulatory rule. Hence, the consumer surplus with the entry deterrence strategy assume a relatively high value.

If, on the contrary, the fixed cost of entry is high, entry is not so attractive. Then, to deter entry it is not necessary to define a very low price. Hence, the entry deterrence strategy implies a relatively high price in both markets. From the consumers's perspective, if f is high it is better to have the entry accommodation strategy because then the second period's price in market B decreases to $\frac{2}{3}\overline{p_1}$ because of Stackelberg competition.

In the previous section we concluded that the incumbent firm chooses the entry deterrence strategy if $f > f^*$ with $f^* = \frac{1}{3} - \frac{1}{9}\sqrt{9 - 36\overline{p_1} + 42\overline{p_1}^2}$. As $f^{**} > f^*$ for every admissible values of $\overline{p_1}$, we conclude that for $f > f^{**}$ the incumbent firm chooses the entry deterrence strategy although from the consumers's perspective the entry accommodation strategy would be preferable. This is a quite different conclusion from the one reached in the model with only one market. This result is explained by the fact that, with average price cap regulation, the decrease in the price cap necessary to avoid entry is smaller than the one required when we are in the presence of an individual cap. To deter entry with individual price cap the

incumbent firm needs to decrease the price to f while with average price cap the decrease is to $\frac{3}{2}f$.

While in the model with only one market the effect of the entry deterrence strategy on consumer surplus is positive due to the price reduction that occurs in the first period, and that is sustained in the second period because of the regulatory policy, in the model with two markets the signal of the effect on consumer surplus depends on the value of f.

As it was described above the entry deterrence strategy leads to a reduction of the price cap. This does not necessarily imply a greater consumer surplus than the one obtained with the entry accommodation strategy. It is worthwhile to recall that if we were not studying the behaviour of the incumbent firm in the face of entry, the price cap reduction would lead to an increase of the consumer surplus as long as the demand functions for both markets were independent. This result was derived by Kang *et al.* (2000) who studied the effects on consumer surplus of a tighter price cap applied to a multiproduct monopolist firm. The authors did not consider the entry possibility and assumed that the price cap reduction was set by the regulator.

From the results described by Propositions 3.2 an 3.3, and considering the sensibility of the consumer surplus functions to the initial price cap ($\overline{p_1}$), we can extract some guidelines for the regulator's decision about $\overline{p_1}$.

Previously we concluded that when the fixed cost of entry is relatively low ($f < f^*$) the incumbent firm decides to accommodate entry because the entry deterrence strategy would require the definition of very low prices. Obviously, the consumers would be better off with the entry deterrence strategy. Starting from a situation where $f < f^*$ the consumer surplus can increase if the regulator sets a lower $\overline{p_1}$. This happens because the consumer surplus function when the incumbent firm chooses the entry accommodation strategy ($CS^{Accom} = 2 - 4\overline{p_1} + \frac{19}{9}\overline{p_1}^2$) is decreasing with $\overline{p_1}$ in the relevant range for $\overline{p_1}$.

However, the reduction of $\overline{p_1}$ not only leads to a direct increase of the consumer

surplus but also causes a reduction of f^*. With a lower f^* it is possible to reach a situation where $f > f^*$ for the same value for f. Therefore, as $f > f^*$, the incumbent firm chooses the entry deterrence strategy which leads to a higher consumer surplus. The limit for the reduction of $\overline{p_1}$ is the verification of Assumption 3.2. If $\overline{p_1}$ is so low that Assumption 3.2 is not verified, entry is blocked and we have two monopolies regulated by a tight price cap. This scenario is out of our study.

It is important to mention that after achieving a situation where $f > f^*$, and consequently the implementation of the entry deterrence strategy by firm i, it is not possibly to further increase the consumer surplus value by the modification of $\overline{p_1}$ (except if the regulator sets an initial price cap for which Assumption 3.2 is not verified). This result is explained because the consumer surplus function with entry deterrence ($CS^{Deter} = \frac{1}{2}(-2+3f)^2$) is not sensitive to the value of the initial price cap. What we observe is that $\overline{p_1}$ has an impact on the value of CS^{Deter} in relation to the value that the consumer surplus would have if firm i choosed the entry accommodation strategy. But the absolute value of CS^{Deter} is unchangeable under Assumption 3.2 and the condition $f > f^*$.

From Propositions 3.2 and 3.3 we know that if $f < f^{**}$ (and $f > f^*$) firm i chooses the entry deterrence strategy and this strategy is also the one that leads to higher consumer surplus. If, on the contrary, $f > f^{**}$, firm i chooses the entry deterrence strategy but the accommodation strategy would allow better results for consumers. However, the value of the consumer surplus is the same whether $f < f^{**}$ or $f > f^{**}$ as long as $f > f^*$.

Then, if f is higher than f^*, the regulator can not further increase the consumer surplus by using the value of the initial price cap. Therefore, we conclude that the consumer surplus has a maximum value when $f \geq f^*$. This is equivalent to say that the consumer surplus has a maximum value when $\overline{p_1} \leq \frac{3}{7} - \frac{3}{14}\sqrt{4+42f^2-28f}$.

The above conclusions are illustrated by the following example. Assuming $f = 0.15$ we compute the values of the relevant functions of the model considering several alternative values for the initial price cap $\overline{p_1}$. The results are presented in Table 3.1.

Table 3.1 - Simulation Results

f	$\overline{p_1}$	Π^{Accom}	Π^{Deter}	CS^{Accom}	CS^{Deter}	f^*	f^{**}	$\frac{2}{3}\overline{p_1}$
0,1500	0,3000	**0,7800**	0,6975	**0,9900**	1,2013	0,1770	0,1976	0,2000
0,1500	0,2500	**0,7083**	0,6975	**1,1319**	1,2013	0,1533	0,1651	0,1667
0,1500	0,2436	0,6975	0,6975	1,1509	1,2013	0,1500	0,1610	0,1624
0,1500	0,2320	0,6768	**0,6975**	1,1856	**1,2013**	0,1438	0,1534	0,1547
0,1500	0,2260	0,6656	**0,6975**	1,2038	**1,2013**	0,1406	0,1495	0,1507
0,1500	0,2240	-	-	-	-	-	-	0,1493

If the initial price cap has a high value, for example $\overline{p_1} = 0.3$, the incumbent firm chooses the entry accommodation strategy. If the regulator sets a lower $\overline{p_1}$, for example $\overline{p_1} = 0.25$, the incumbent firm also decides to accommodate entry but the consumer surplus is greater than with $\overline{p_1} = 0.3$.

However, the reduction of $\overline{p_1}$ also reduces the value of f^*. Therefore, if the regulator sets an even lower initial price cap, for example, $\overline{p_1} = 0.232$, the incumbent firm chooses the entry deterrence strategy and the consumer surplus is even higher.

Lower values for $\overline{p_1}$ do not further increase the consumer surplus. Then, the maximum consumer surplus is achieved as long as $\overline{p_1} \leq \frac{3}{7} - \frac{3}{14}\sqrt{4 + 42f^2 - 28f}$ which, in this example is equivalent to $\overline{p_1} \leq 0.2436$.

3.5 Conclusions

In this chapter we studied the way a multiproduct firm, regulated through a dynamic price cap, can develop a price strategy that uses the regulatory policy to deter entry. We considered a regulated firm that initially operates as a monopolist in two markets but, in the second period entry is possible in one of this markets. We conclude that if the fixed cost of entry is above a critical level then the regulated firm has the

incentive to follow an anticompetitive price policy which strategically blocks entry. The credibility of the entry deterrence strategy is guaranteed by the properties of the regulatory policy, in particular, by the fact that the price cap is defined as the observed average price of the previous period. Then, in the first period, the firm strategically defines the prices to influence the price cap of the next period. The entry deterrence strategy, that results as an outcome of the model leads, under some conditions, to the reduction of the price not only in the market where entry is possible but also in the captive market. However, the final effect of this strategy on total consumer surplus is not always positive. Therefore, we conclude that even with a price cap mechanism that does not allow the strategic manipulation of the price weights, the incumbent firm can have incentives to follow a strategy that might have negative effects to consumers and to the development of competition where it is possible.

Appendix A3

A3.1. Let $\overline{p_2} < \frac{1}{4} + \frac{f}{2}$. For $f > \frac{2}{3}\overline{p_2}$ the condition $f(1-2f)+(2\overline{p_2}-f)(1-2\overline{p_2}+f) > \frac{2}{3}\overline{p_2}\,(3-4\overline{p_2})$ is false.[16]

Let $\overline{p_2} \geq \frac{1}{4} + \frac{f}{2}$. Then $f(1-2f)+\frac{1}{4} > \frac{2}{3}\overline{p_2}\,(3-4\overline{p_2})$ implies $\overline{p_2} \leq \frac{3}{8} + \frac{1}{8}\sqrt{3}\,(-1+4f)$. However, this result for $\overline{p_2}$ is not compatible with the initial condition $\overline{p_2} \geq \frac{1}{4} + \frac{f}{2}$ when $f < \frac{1}{4}$. Then, it is not possible to find a value of $\overline{p_2}$ for which the second period's profit with the fighting strategy is greater than the second period's profit with entry accommodation for the admissible values of f.

A3.2. Let $p_1^A = p_1^B = \overline{p_1}$. Then $\overline{p_2} = \overline{p_1}$. If entry occurs and the incumbent firm decides to accommodate it, Stackelberg competition leads to $\pi_{2i} = \frac{2}{3}\overline{p_1}\,(3-4\overline{p_1})$ and $\pi_{2e} = \frac{4}{9}\overline{p_1}^2 - f^2$. Under Assumption 3.2 the entrant's profit is positive. If, on the contrary, the incumbent firm decides to fight entry, the quantity offered in market B would be $q_2^B = 1-2f$ and the price would be $p_2^B = f$ which leads to $\pi_{2e} = 0$ and $\pi_{2i} = f(1-2f) + (2\overline{p_1} - f)(1 - 2\overline{p_1} + f)$ if $\overline{p_1} < \frac{1}{4} + \frac{f}{2}$ or $\pi_{2i} = f(1-2f) + \frac{1}{4}$ if $\overline{p_1} \geq \frac{1}{4} + \frac{f}{2}$.

Let $\overline{p_1} < \frac{1}{4} + \frac{f}{2}$. Then $f(1-2f) + (2\overline{p_1} - f)(1 - 2\overline{p_1} + f) > \frac{2}{3}\overline{p_1}\,(3-4\overline{p_1})$ is always false, so it is false for $f < \frac{2}{3}\overline{p_1}$ (Assumption 3.2).

Let $\overline{p_1} \geq \frac{1}{4} + \frac{f}{2}$. Then $f(1-2f)+\frac{1}{4} > \frac{2}{3}\overline{p_1}\,(3-4\overline{p_1})$ implies $\overline{p_1} \leq \frac{3}{8} + \frac{1}{8}\sqrt{3}\,(-1+4f)$. However, this result for $\overline{p_1}$ is not compatible with the initial condition $\overline{p_1} \geq \frac{1}{4} + \frac{f}{2}$ when $f < \frac{1}{4}$. Then, under Assumption 3.2 and $\overline{p_2} = \overline{p_1}$, the incumbent's payoff is always greater with entry accommodation than with fighting entry.

A3.3. Proof of Proposition 3.2

Let $\overline{p_1} < \frac{3}{8}$. Then $\Pi^{Deter} - \Pi^{Accom} = 4(\frac{3}{2}f)(1 - \frac{3}{2}f) - 4\overline{p_1} + \frac{14}{3}(\overline{p_1})^2$. This is a concave second degree equation in f whose roots are $f_1 = \frac{1}{3} - \frac{1}{9}\sqrt{9 - 36\overline{p_1} + 42\overline{p_1}^2}$ and $f_2 = \frac{1}{3} + \frac{1}{9}\sqrt{9 - 36\overline{p_1} + 42\overline{p_1}^2}$. As $f_2 > \frac{2}{3}\overline{p_1}$, $f_1 < \frac{2}{3}\overline{p_1}$ and, by Assumption 3.2,

[16] In fact this condition is always false.

$f < \frac{2}{3}\overline{p_1}$, then the entry deterrence strategy allows a greater payoff than the entry accommodation strategy if $f > f_1$.

Appendix B3

B3.1. The Effect on Consumers Surplus of the Entry Deterrence Strategy in the Model With One Market

The consumer surplus (CS) is calculated as the sum of the consumer surplus in the first and second periods, assuming a discount factor of one, and using the prices derived before:

Prices with entry accommodation: $p_1 = \overline{p_1}$ and $p_2 = \begin{cases} \frac{1}{4} & \text{if } \overline{p_1} \geq \frac{1}{4} \\ \overline{p_1} & \text{if } \overline{p_1} < \frac{1}{4} \end{cases}$

Prices with entry deterrence: $p_1 = p_2 = f$

The Entry Accommodation Case When $\overline{p_1} \geq \frac{1}{4}$

$CS = \frac{(1-\overline{p_1})^2}{2} + \frac{(1-\frac{1}{4})^2}{2} = \frac{(1-\overline{p_1})^2}{2} + \frac{9}{32}$

The Entry Accommodation Case When $\overline{p_1} < \frac{1}{4}$

$CS = \frac{(1-\overline{p_1})^2}{2} + \frac{(1-\overline{p_1})^2}{2} = (1-\overline{p_1})^2$

The Entry Deterrence Case

$CS = \frac{(1-f)^2}{2} + \frac{(1-f)^2}{2} = (1-f)^2$

Comparing the Results

From the above definitions it is easier to demonstrate that the consumer surplus is greater when the incumbent firm chooses the entry deterrence strategy instead of the entry accommodation strategy, for both intervals of the initial price cap. This is due to the fact that the entry deterrence strategy requires a price decrease to

f in the first period, and this price reduction is maintain in the second period. Differently, with entry accommodation strategy, the price in the first period is equal to the initial price cap and, in the second period, the price is equal to the optimal duopoly price ($\frac{1}{4}$) if $\overline{p_1} \geq \frac{1}{4}$. Also, by Assumption 3.1, f is lower than $\overline{p_1}$ or $\frac{1}{4}$.

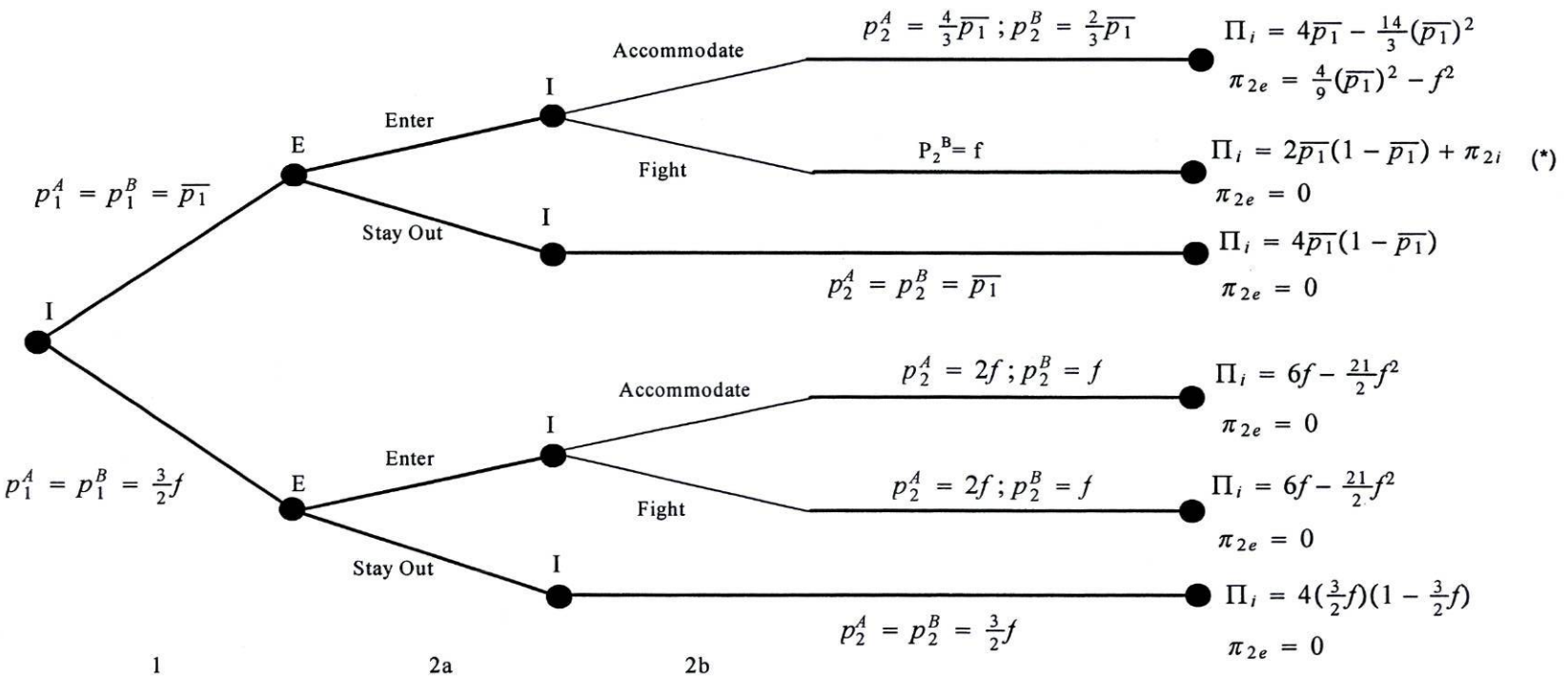
In section 3.2 we concluded that when $f > f^*$ the incumbent firm chooses the entry deterrence strategy and now we conclude that this is also the best decision from the consumers perspective.

B3.2. Proof of Proposition 3.3

Let $\overline{p_1} < \frac{3}{8}$. Then $CS^{Deter} - CS^{Accom} = \frac{1}{2}(-2+3f)^2 - 2 + 4\overline{p_1} - \frac{19}{9}\overline{p_1}^2$. This is a convex second degree equation in f whose roots are $f_1 = \frac{2}{3} - \frac{1}{9}\sqrt{36 - 72\overline{p_1} + 38\overline{p_1}^2}$ and $f_2 = \frac{2}{3} + \frac{1}{9}\sqrt{36 - 72\overline{p_1} + 38\overline{p_1}^2}$. As $f_2 > f$ for the admissible values of f then, $CS^{Deter} > CS^{Accom}$ implies $f < \frac{2}{3} - \frac{1}{9}\sqrt{36 - 72\overline{p_1} + 38\overline{p_1}^2}$.

Appendix C3

Figure 3.1: Extensive Representation of the Game Assuming $\overline{p_1} < \frac{3}{8}$



(*) The firm's i profit function for the second period and the second's period price in market A are characterised in Appendix A3.2.

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Chapter 4

Access Pricing - A Comparison Between Full Deregulation and Two Alternative Instruments of Access Price Regulation: Cost-Based and Retail-Minus

4.1 Introduction

The deregulation of network industries, such as telecommunications, electricity, gas or transportation, raises several questions about the conditions of access to the incumbent firm's network. In particular, when the incumbent firm is monopolist in the provision of an essential input (the network access) and is vertically integrated to the downstream market, the regulation of access price is a crucial question.[1] Without access price regulation the upstream monopolist might use its market power to foreclose the downstream rivals. In this context we consider the definition of foreclosure of Rey and Tirole (forthcoming): *"foreclosure refers to any dominant firm's practice that denies proper access to an essential input it produces to some users of this input, with the intent of extending monopoly power from one segment of the market (the bottleneck segment) to the other (the potentially competitive segment)."*

However, a tight access price regulation might decrease the incumbent firm's incentive to undertake the necessary investments to improve the network quality, which is indispensable for the development of the market.[2] Several other consequences from the definition of different levels of access prices may arise: if the access price is set "too low" inefficient entry might occur, if access price is set "too high" the entrants might have incentives to build inefficient facilities to bypass the incumbent's network[3] (Laffont and Tirole, 2000); if the level of entry costs in downstream market is high in comparison to the potential benefits of entry, the regulator may define a high access price (Valletti, 2003).

[1] For an extensive discussion and review of the literature on access regulation see Armstrong *et al.* (1996), Laffont and Tirole (2000) and Armstrong (2002).

[2] Gans (2001) specifically studies the incentives to undertake infrastructure investments by an upstream monopolist subject to access price regulation. The relationship between investment behaviour and regulation in the telecommunication sector (including the access regulation) is also extensively discussed in a recent set of papers collected at the *Symposium on Access Pricing Investment and Entry.* This set includes the following papers: Valletti (2003), Chang *et al.* (2003), Rood and te Velde (2003), Peitz (2003) and Cave and Vogelsang (2003).

[3] We say that it is possibly to bypass the incumbent's network when the entrants can obtain the key input elsewhere than from the incumbent firm.

The purpose of Chapter 4 is to compare two different instruments of access price regulation in what concerns the trade-off between two objectives of the regulatory authority: the objective of enhancing competition in the downstream market and the objective of promoting the investment in network quality.[4] The first instrument in discussion is cost-based regulation, under which the regulator defines the access price equal to the cost of providing the access. The second instrument is retail-minus regulation, under which the regulator defines the minimum value of the difference between the retail price and the access price.

Retail-minus regulation is a practical rule used by regulators aiming to protect the independent firms that compete with a vertically integrated firm. For example, Ofcom (Office of Telecommunications), the British regulator for the telecommunications sector, probably is going to impose retail-minus regulation to a wholesale service of British Telecom (BT) in the broadband internet access market.[5] Also, Anacom - Autoridade Nacional de Comunicações, the Portuguese regulator for the telecommunications sector, applied retail-minus regulation in the market of broadband internet access with ADSL technology.[6]

The idea behind the instruments of access price regulation referred (cost-based and retail-minus) is that the emergence of competition at the retail segment might be

[4]For simplicity, we do not include in our discussion the other consequences of the access price definition mentioned above, although in several contexts they might assume an important role in the definition of the access price.

[5]To offer broadband internet access to final consumers, the majority of UK Internet Service Providers (ISPs) depend upon suppliers of wholesale broadband access. BT is the predominant supplier of wholesale broadband access to IPSs, most of whom use the BT service called IPStream. The competitors of BT in the wholesale broadband access market do not bypass all the infrastructure of BT. In order to sell wholesale broadband access to the ISPs, they have to use some services from BT's network. Therefore, this operators are also clients of a BT product called Datastream. If the Datastream price is too close to the IPStream price, the BT's competitiors in the wholesale access market can not make sufficient margin, and therefore can not compete with BT in providing services to ISPs. Then, Ofcom probably is going to imposed a retail-minus regulation on the difference between IPStream and Datastream products of BT. This information was collected from the draft decision of Ofcom of 16.12.2003 about Regulation of Wholesale Broadband Access Market.

[6]See Anacom decision of 25.06.2003 about the "PT ADSL Network" product.

a precursor to competition at the wholesale segment, the ultimate goal of complete deregulation. Therefore, at an initial stage of the deregulation process, some assistance to entrants firms might be necessary to allow the emergence of competition at the retail level. This idea is clearly stated in the following quotation: *"Experience in the Netherlands and elsewhere shows that it is wrong to expect entrants immediately to emerge as fully fledged facilities-based competitors. To provide a credible retail service, they may in the early days need to resell the incumbent's retail products, and the wholesale discount to which they are entitled influences the viability of this form of competition. They will also clearly have to purchase many network components from the incumbent. A policy of high access prices in this phase of their activity may kill the entrant's business model stone dead."* (Cave and Vogelsang, 2003, p.722).

From the comparison of the two instruments described above we conclude that retail-minus regulation avoids foreclosure (as cost-based regulation does), but leads to better results in terms of the level of network quality investment and consumer surplus than the cost oriented regulation. Furthermore, although retail-minus regulation does not allow the investment level achieved under deregulation of access price, it leads to a higher consumer surplus as long as the difference between retail price and access price is carefully defined by the regulator.

We use a very simple analytical framework to highlight the properties of the regulatory instruments mentioned above. We assume an upstream monopoly, that we can think of as the historical incumbent firm. The monopolist firm sells network access, which is a vital input to downstream firms.[7] For simplicity, we assume a fixed coefficients technology: the production of one unit of the final service requires one unit of the input. The retail market is characterised as an unregulated duopoly market with an independent firm and a subsidiary firm of the upstream monopolist. We assume Stackelberg competition in the downstream market and we consider that the subsidiary firm has the leadership position. We also assume that the upstream monopolist might undertake investments to improve the network quality. High net-

[7]We abstract from bypass considerations by assuming that the incumbent is the only supplier of access and that access is essential for downstream production.

work quality is costly to provide but increases the value of the final product to consumers, which is represented by an increase in the retail demand function. This hypothesis is also assumed by Buehler *et al.* (2004) and Foros (2004). We assume that the quality of the input sold by the monopolist is the same whether it is sold to the independent firm or to the subsidiary firm. Thus, we are not studying the related question of sabotage.[8]

The associated literature to our model are the papers of Armstrong and Vickers (1998), Weisman (2002) and Foros (2004). Armstrong and Vickers (1998) compare the regulation of the access price with the regulation of the margin, assuming that the regulator's objective is to maximise total welfare defined as the unweighted sum of profits and consumer surplus. Under this assumption they characterise the optimal access price and the optimal margin, concluding that *"both welfare and entrant profit are higher with optimal access price regulation than with optimal margin regulation."* (Proposition 2 in Armstrong and Vickers, 1998, p.119). However, the Armstrong and Vickers's model differ in quite important features from our model. First, Armstrong and Vickers assume different cost functions in the downstream activity for the two firms, while we assume equal costs in the retail activity. Second, Armstrong and Vickers consider that margin regulation is equivalent to the application of the Efficient Component Pricing Rule with the retail price set at the monopoly level, while we assume that the retail price is defined by Stackelberg competition. Finally, we introduce in the model the incumbent firm's investment in network quality, which is not studied by Armstrong and Vickers.

In a quite different framework, Weisman (2002) compares two general access pricing rules: the marginal cost access pricing (what we call cost-based regulation) and the Efficient Component Pricing Rule (ECPR) assuming that, in both cases, the retail price is defined by Cournot competition. Weisman also considers that the vertically

[8]Sabotage exists when the upstream firm intentionally reduces the quality of the input when it is sold to independent firms. This strategy raises the downstream rivals' costs and benefits the subsidiary firm. For a study of sabotage see Weisman (1995, 1998), Economides (1998, 2000), Sibley and Weisman (1998), Reiffen (1998), Bergman (2000), Mandy (2000), Weisman and Kang (2001) and Beard *et al.* (2001).

integrated firm and the independent firms might have different marginal costs in the retail activity. Weisman conclude that if the vertically integrated firm is relatively efficient it prefers ECPR. As Armstrong and Vickers (1998), Weisman does not analyse the incumbent firm's investment in network. On the contrary, Foros (2004) considers the incumbent firm's network investment and its effects on retail demand. However, the purpose of Foros' model is to study the effects of the different ability to use network quality improvements by the downstream firms and not to compare different instruments of access regulation.

Our model was inspired by the market for broadband internet connectivity with ADSL technology, although it might be applied to other vertically integrated markets where the network access by an independent competitor in the retail market is a regulatory issue. There are several examples of this structure. One of those is found in the long distance telephone market in the United States. Each Bell Operating Company (BOC) is a near-monopoly supplier of the input (exchange access), whose price is regulated. Simultaneously, each BOC can compete (through a subsidiary firm) with other firms (AT&T, Sprint, MCI and others) in the downstream long distance service (Mandy, 2004). In railway and electricity industries similar situations can be found (Weisman, 2002).

Broadband internet access is characterised by the provision of services that are "always on", allow both voice and data services to be used simultaneously and provide data at speeds greater than a dial up connection.[9] It is generally accepted that broadband and narrowband internet access constitute different markets.[10] Today there are two major networks for broadband internet connectivity: the tele-

[9]This definition of broadband access is general accepted, althought there are not a rigid number for the speed that distinguish broadband from narrowband. For example, Ofcom and FCC (Federal Communications Commission) consider a transmission speeds greater than 256 kbps and 200 kbps, respectively, as broadband, while ITU (International Telecommunications Union) considers 1.5 to 2 Mbps (Kim *et al.*, 2003).

[10]Hausman *et al.* (2001) shows, from an econometric model applied to the United States, that the pricing of broadband access is not constrained by the pricing of narrowband dial-up internet. Also, several regulators (as Ofcom) consider that narrowband and broadband constitute separate markets.

phone network[11] and the cable network.[12] There are alternative technologies for the broadband access such as wireless, powerline, satellite and UMTS. However, these technologies are now in a development stage, although in the future they might compete with cable and DSL. Table A4.1 (in Appendix A4) presents information about the penetration rates of broadband internet access through DSL, cable modem and other platforms for OECD countries in June 2003. We conclude that the relative importance of DSL and cable networks is quite different across the OCDE countries. However, DSL is the dominant technology in most of the European countries, although there are some exceptions.

The broadband internet connectivity with ADSL technology implies that the firm that owns the telephone network, typically the historical incumbent firm, has to supply local access as an input to telecommunication operators in the retail market. In the Portuguese case, the historical operator Portugal Telecom Comunicações (PTC) has Significant Market Power (SMP) in the market of fixed telephone network (upstream market)[13] so it has the obligation, by European legislation, to sell the access to others operators.[14]

In several European markets the retail segment is an oligopoly where the independent firms compete with a firm that not only belongs to the same economic group as the upstream monopoly but also has a large market share. Table A4.2 (in Appendix A4) shows the historical operator's market shares in the retail market for broadband internet with DSL technology in several European countries in December 2003. Taking again the Portuguese market as an illustration, it is worthwhile to

[11]The technology used in telephone networks is the DSL (Digital Subscriber Lines). The most popular form of DSL is ADSL (Asymmetric DSL) in which the download transmission rates are higher than the upload rates (for details see, for example, Spulber and Yoo, 2003).

[12]MacKie-Mason (1999) quoted several authors that argue that cable and DSL will be the dominant technologies in broadband in the coming years. This opinion is also shared by Gillet *et al.* (2003), although in the future several wireless technologies (wi-fi, satellite, for example) and wireline technologies (powerline, for example) might compete with DSL and cable.

[13]The same happens with several others historical operators in European countries.

[14]Portugal Telecom offers the wholesale service "PT ADSL Network", which is the service of connectivity to PT fixed telephone service clients.

mention that there are nine firms that buy the access from PTC, and one of these firms, Telepac, belongs to the same economic group as PTC, the Portugal Telecom Group. Moreover, Telepac has a dominant position in the downstream market, as it is showed by the market share of 85%.

This gives support to our consideration of Stackelberg competition in the downstream segment, with the leadership of the subsidiary firm. Weisman (1995) also assumes Stackelberg competition in the downstream market and considers that the subsidiary firm (the subsidiary firm of the RBOC that enters in the interstate long distance market) is the Stackelberg leader. This assumption was strongly criticised by Beard *et al.* (2001), with the argument that it is unlikely that the RBOC subsidiary firm assumes a dominant position in the long distance market where it might compete with firms such AT&T, MCI or Sprint. However, as the values of Table A4.2 show, the industry structure of internet broadband access market in European countries is quite different from the long distance telecommunications market structure in the United States. Therefore, in this context, Stackelberg competition is a reasonable assumption.

Another crucial feature of our model is the investment in network quality undertaken by the upstream firm. We assume that the increase in the speed of communications is seen by consumers as an important improvement in the quality of the service, not only because they might have access to new services that require high speed (as interactive audio and video), but also because the conventional internet services (web-browsing and E-mail) acquire greater value (Hausman *et al.*, 2001; Foros, 2004). We assume that this improvement leads to more consumption by the actual consumers and to the attraction of new consumers for the market, which is represented by an increase in the retail market demand function. We also assume that the investment in the network is indispensable to increase the speed of communications and this requires investment in the network undertake by the upstream firm.

Our model emphasises the role of the investment undertake by the incumbent firm. We assume that this investment improves the quality of the incumbent firm's network and increases the demand size. However, in several network industries the

investments undertaken by the independent firms are also very significant to market development and thus the regulator's role on the promotion of these investments can not be ignore. In the broadband internet market some of the new operators in most of the European countries are building their own networks. The success of these investments will be decisive for the establishment of competition at the upstream segment of the market. However, the construction of infrastructure is a long run process during which the new operators also use the incumbent firm's network to expand more rapidly their business. This justifies our emphasis on the effects of the incumbent firm's investments on market demand.

Chapter 4 is organised as follows: section 4.2 describes the model, section 4.3 compares the results obtained for the three alternative ways of defining the access price, section 4.4 discusses the relationship between the Efficient Component Pricing Rule (ECPR) and retail-minus regulation and, finally, section 4.5 presents the conclusions of Chapter 4.

4.2 The Model

4.2.1 Introduction

Demand

We assume the following inverse demand function for the market of the final homogenous output: $p = 1 + \beta I - (q_1 + q_2)$, where p is the retail market price, q_1 and q_2 are the quantities offered by firm 1 (the vertically integrated firm) and firm 2 (the independent firm), respectively, and I represents the level of investment undertake by firm 1. The term βI ($\beta > 0$) does not change the slope of the demand function, but a modification of I changes the intersection point of the demand curve with the vertical axis, representing a modification on demand size. Therefore, we assume that an increase in the level of investment leads to an outward parallel shift of demand, which benefits both downstream firms.

Costs

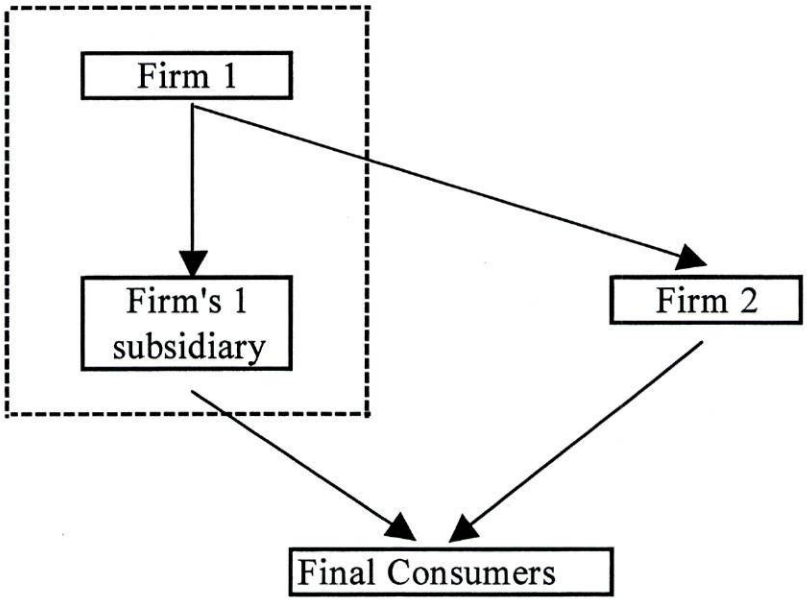
We consider that the cost of providing the access per user is constant and represented by c (with $c < 1$) and that the investment level does not have any impact on c. Also, we consider that the investment cost function is quadratic, with respect to investment in network quality and is given by $C_1(I) = \frac{\varphi I^2}{2}$, with $\varphi > 0$. The access price that the downstream firms have to pay to the upstream firm for the input is represented by w and we assume $w \geq c$. For simplicity, we consider that the cost of buying other inputs are equal for both downstream firms and normalised to zero. Therefore, the profit functions of firms 1 and 2 are given, respectively, by:

$$\pi_1 = (p - w)q_1 + (w - c)(q_2 + q_1) - \frac{\varphi I^2}{2} = (p - c)q_1 + (w - c)q_2 - \frac{\varphi I^2}{2}$$

$$\pi_2 = (p - w)q_2$$

Figure 4.1 illustrates the market structure previously described.

Figure 4.1 - Market Structure



Time of the game

The time of the game is the following:

- At stage 1 the upstream monopolist decides the investment level I.

- At stage 2 the upstream firm, or the regulator, chooses the access price w.

- At stage 3 the retail price and quantities are defined by Stackelberg competition between downstream firms. We assume uniform pricing.

Following Foros (2004) we consider that the access price is set after the investment decision takes place. The justification for this hypothesis relies mainly on the fact that the economic life of the investments in network quality usually is longer than the regulation contract used for access prices and that the regulator has limited commitment ability.

At stage 2 we consider three alternative scenarios for the definition of the access price w, characterised in the following way:

Scenario A: The access price is defined by the vertically integrated firm without the regulator's intervention.

Scenario B: There is cost-based regulation for the access price. Then, the regulatory authority defines $w = c$.

Scenario C: The regulatory authority applies retail-minus regulation. Therefore, the difference between the retail price p and the access price w can not be below $x\%$ of the retail price p, that is $p - w \geq x\%p$ with $x \in (0, 1)$. This instrument is called retail-minus x%.[15]

[15]For example, Anacom, by the decision of 25.06.2003, detemine for ADSL service with speed debit of 512 kbps/218kbps, that the monthly price of wholesale offer can not be higher than the lesser monthly retail price for this debit practiced by the subsidiary companies of PT Group deducted of 40%.

We consider a game with perfect information, thus each player anticipates what will happen in subsequent stages of the game. Hence, the resolution of the game will be done by backward induction.

4.2.2 Stage 3: Stackelberg Competition

The profit functions of firms 1 and 2 are given, respectively, by:

$$\pi_1 = (1 + \beta I - q_1 - q_2 - c)q_1 + (w - c)q_2 - \frac{\varphi I^2}{2}$$

$$\pi_2 = (1 + \beta I - q_1 - q_2 - w)q_2$$

From the first order condition of the profit maximisation problem for firm 2 we obtain the reaction function of firm 2, $q_2 = \frac{1+\beta I-w-q_1}{2}$.[16] Considering the reaction function of firm 2 in its profit function, firm 1 defines the optimal quantity from the first order condition of the profit maximisation problem. Then, we have the following equilibrium values of stage 3:

$$q_1 = \frac{1 + \beta I - c}{2} \; ; \; q_2 = \frac{1 + \beta I - 2w + c}{4} \; ; \; p = \frac{1 + \beta I + 2w + c}{4}$$

4.2.3 Stages 2 and 1: Scenario A - Deregulation

Stage 2: Definition of the Access Price

Under scenario A the vertically integrated firm chooses the access price w that maximises its profit function. From the first order condition we obtain: $w = \frac{1+\beta I+c}{2}$. Using this value in the results from stage 3 we have:

[16] The second order condition is fulfilled. In the rest of the Chapter, and for simplification, we will only mention the second order condition when it is necessary to impose some constraints to its verification.

$$q_1 = \frac{1+\beta I - c}{2} \; ; \; q_2 = 0 \; ; \; p = \frac{1+\beta I + c}{2}$$

We conclude that without access price regulation the vertically integrated firm sets an access price that forecloses the independent firm from the downstream market.[17] This is a well known result in the literature on vertical integration. In an unregulated environment, an integrated firm which controls an essential input has the incentive to foreclose the downstream rivals and extend its market power to the downstream segment of the market.[18]

Stage 1: Definition of the Investment Level

If the vertically integrated firm can choose the access price without restrictions then, from the previous result, we know that firm 2 will not produce. Hence, firm 1 will be a monopolist also in the downstream market. Therefore, under scenario A, the investment level is defined assuming a downstream monopoly. The downstream monopoly profit function is given by:

$$\pi_1 = (1 + \beta I - q_1 - c)q_1 - \frac{\varphi I^2}{2}$$

From the first order condition the optimal monopoly results are given by:

$$q_1 = \frac{1+\beta I - c}{2} \; ; \; p = \frac{1+\beta I + c}{2} \; ; \; \pi_1 = (\frac{1+\beta I + c}{2} - c)\frac{1+\beta I - c}{2} - \frac{\varphi I^2}{2}$$

[17] In order to keep the model as simple as possible we do not consider fixed costs. Otherwise, if the independent firm had to recover a fixed cost to survive, the result obtained before would be even stronger.

[18] See, for example, Rey and Tirole (forthcoming) for an extensive discussion of foreclosure in unregulated markets. However, the above result is deeply contested by the "Chicago critique", which argues that vertical integration has no anti-competitive effects. For a comparison of both perspectives ("foreclosure doctrine" and "Chicago critique") see, for example, Armstrong (2002).

The downstream monopolist chooses the investment level that maximise its profit function. From the first order condition we obtain $I^A = \frac{\beta(1-c)}{2\varphi-\beta^2}$. To guarantee the verification of the second order condition, and also that $I^A > 0$, we must assume that $2\varphi - \beta^2 > 0$.

Assumption 4.1: Let $2\varphi - \beta^2 > 0$.

Assumption 4.1 guarantee that φ is relatively high which means that the cost function of the investment is significantly convex. This assumption about parameter φ ensures that firm 1 *"will not make an infinite investment in quality improvement"* (Foros, 2004, p.11).

Inserting the value of I^A in the expressions for price and quantity we obtain the final results for scenario A:

$$q_1^A = \frac{\varphi(1-c)}{2\varphi-\beta^2} \; ; \; q_2^A = 0 \; ; \; p^A = \frac{\varphi(1+c)-\beta^2 c}{2\varphi-\beta^2}$$

The profit of firm 1 profit and the consumer surplus (CS) under scenario A are given, respectively, by:

$$\pi_1^A = \frac{\varphi(1-c)^2}{2(2\varphi-\beta^2)} \; ; \; CS^A = \frac{\varphi^2(1-c)^2}{2(2\varphi-\beta^2)^2}$$

4.2.4 Stages 2 and 1: Scenario B - Cost-Based Regulation

Stage 2: Definition of the Access Price

Under scenario B the regulatory authority defines $w = c$, suppressing the profit of firm 1 in the upstream market. The definition of scenario B is based on the conclusion that $w = c$ maximises social welfare under the assumption that $w \geq c$. Considering social welfare (W) measured by the unweight sum of consumer surplus and firms profits, and taking the Stackelberg competition results derived before, we

have:

$$W = \tfrac{1}{32}(3 + 3\beta I - c - 2w)^2 +$$

$$(\tfrac{1+\beta I+2w+c}{4} - c)\tfrac{1+\beta I-c}{2} +$$

$$(w - c)\tfrac{1+\beta I-2w+c}{4} - \tfrac{\varphi I^2}{2} + (\tfrac{1+\beta I+2w+c}{4} - w)\tfrac{1+\beta I-2w+c}{4}$$

This function has a maximum value for $w = \frac{3c-1-\beta I}{2}$. As $c < 1$ then $\frac{3c-1-\beta I}{2} < 0$. As, by assumption, the regulator does not set the access price below the marginal cost of providing the access, the access price that maximise the social welfare W measure is $w = c$. The intuitive explanation for this result is straightforward. As the downstream segment of the market has imperfect competition, the retail price is above the cost. Then, in order to correct this imperfection, the regulator would set a price below the cost of providing the access in the upstream segment. This result was derived by Armstrong *et al.* (1999, Chapter 5.2) with the assumption of Cournot competition.

Considering $w = c$ in the results of stage 3 we obtain:

$$q_1 = \frac{1 + \beta I - c}{2} \; ; \; q_2 = \frac{1 + \beta I - c}{4} \; ; \; p = \frac{1 + \beta I + 3c}{4}$$

$$\pi_1 = (\frac{1 + \beta I + 3c}{4} - c)(\frac{1 + \beta I - c}{2}) - \frac{\varphi I^2}{2}$$

Stage 1: Definition of the Investment Level

The investment level that maximises the profit of firm 1 is given by $I^B = \frac{\beta(1-c)}{4\varphi-\beta^2}$. To guarantee the verification of the second order condition of the maximisation problem, and also that $I^B > 0$, is necessary that $4\varphi - \beta^2 > 0$. This condition is true by Assumption 4.1, reminding that $\varphi > 0$. Considering the value of I^B previously found we have the following final results for scenario B:

$$q_1^B = \frac{2\varphi(1-c)}{4\varphi-\beta^2} \; ; \; q_2^B = \frac{\varphi(1-c)}{4\varphi-\beta^2} \; ; \; Q^B = \frac{3\varphi(1-c)}{4\varphi-\beta^2}$$

$$p^B = \frac{\varphi(1+3c)-\beta^2 c}{4\varphi-\beta^2} \; ; \; \pi_1^B = \frac{\varphi(1-c)^2}{2(4\varphi-\beta^2)} \; ; \; CS^B = \frac{9\varphi^2(1-c)^2}{2\left(4\varphi-\beta^2\right)^2}$$

4.2.5 Stages 2 and 1: Scenario C - Retail-Minus Regulation

Stage 2: Definition of the Access Price

Under scenario C we assume that firm 1 defines the access price under the condition $w \leq p(1-x)$ imposed by the regulatory authority and under the condition $w \geq c$. The problem faced by firm 1 is:

$$Maximise_w \quad \pi_1$$

$$subject\ to \quad w \leq p(1-x)$$

$$and \qquad c \leq w$$

The Lagrangian function $L(w, \lambda_1, \lambda_2)$ is defined as:

$$L(w,\lambda_1,\lambda_2) = (1+\beta I-q_1-q_2-c)q_1+(w-c)q_2-\frac{\varphi I^2}{2}-\lambda_1\left[w-p(1-x)\right]-\lambda_2(c-w)$$

where λ_1 and λ_2 are the Lagrange multipliers. The Kuhn-Tucker conditions can be described in the following way:

1. $\dfrac{\partial L(w,\lambda_1,\lambda_2)}{\partial w} \leq 0$ and $w \geq 0$ and $w\dfrac{\partial L(w,\lambda_1,\lambda_2)}{\partial w} = 0$

2. $\dfrac{\partial L(w,\lambda_1,\lambda_2)}{\partial \lambda_1} \geq 0$ and $\lambda_1 \geq 0$ and $\lambda_1\dfrac{\partial L(w,\lambda_1,\lambda_2)}{\partial \lambda_1} = 0$

3. $\dfrac{\partial L(w,\lambda_1,\lambda_2)}{\partial \lambda_2} \geq 0$ and $\lambda_2 \geq 0$ and $\lambda_2\dfrac{\partial L(w,\lambda_1,\lambda_2)}{\partial \lambda_2} = 0$

To solve the maximisation problem by the Kuhn-Tucker Theorem we must consider four different cases concerning the values of the Lagrange multipliers:

1st case: $\lambda_1 = 0$ and $\lambda_2 = 0$

2nd case: $\lambda_1 = 0$ and $\lambda_2 > 0$

3rd case: $\lambda_1 > 0$ and $\lambda_2 > 0$

4th case: $\lambda_1 > 0$ and $\lambda_2 = 0$

If $\lambda_1 = 0$ and $\lambda_2 = 0$ the constraints of the maximisation problem are not binding. Then, the solution of the problem under the first case is the solution of the unconstraint maximisation problem. We have already study this case when we consider the deregulation scenario.

If $\lambda_1 = 0$ and $\lambda_2 > 0$ the retail-minus constraint is not binding (that is, the solution of the maximisation problem would imply $w < p(1-x)$) but at the same time the second constraint is binding ($c = w$). Considering the features of the retail-minus regulation this case does not have economic interest because w already has the minimum possible value.

If $\lambda_1 > 0$ and $\lambda_2 > 0$ both constraints are binding simultaneously. This means that the solution of the maximisation problem would imply that the regulator set the value x such that the retail-minus regulation and the cost-based regulation lead to

the same value for w. Again, this does not have economic justification.

Therefore, only the fourth case is going to be analysed.

If $\lambda_1 > 0$ and $\lambda_1 \frac{\partial L(w,\lambda_1,\lambda_2)}{\partial \lambda_1} = 0$ then $\frac{\partial L(w,\lambda_1,\lambda_2)}{\partial \lambda_1} = 0$ which implies $w = p(1-x)$. Considering the result obtained from the Stackelberg competition at stage 3, $p = \frac{1+\beta I+2w+c}{4}$, we have the following expression for the access price:

$$w = \frac{(1-x)(1+\beta I+c)}{2(1+x)}$$

Inserting this value for w in the expressions obtained at stage 3 we have:

$$q_1 = \frac{1+\beta I-c}{2} \; ; \; q_2 = \frac{x(1+\beta I+c)}{2(1+x)} \; ; \; p = \frac{1+\beta I+c}{2(1+x)}$$

$$\pi_1 = \left[\frac{1+\beta I+c}{2(1+x)} - c\right]\frac{1+\beta I-c}{2} + \left[\frac{(1-x)(1+\beta I+c)}{2(1+x)} - c\right]\frac{x(1+\beta I+c)}{2(1+x)} - \frac{\varphi I^2}{2}$$

Under the fourth case we know that $\lambda_2 = 0$. This means that the solution of the maximisation problem described above requires that $c < w$. Then, $c < \frac{(1-x)(1+\beta I+c)}{2(1+x)}$ which is equivalent to $x < \frac{1+\beta I-c}{1+\beta I+3c}$.

Stage 1: Definition of the Investment Level

Considering the value $w = \frac{(1-x)(1+\beta I+c)}{2(1+x)}$ in the profit function of firm 1 we conclude that the investment level that maximises the profit function is given by $I^C = \beta\frac{(1+2x-x^2)-c(1+2x+3x^2)}{2\varphi(1+x)^2-\beta^2(1+2x-x^2)}$. The verification of the second order condition requires that $2\varphi(1+x)^2 - \beta^2(1+2x-x^2) > 0$. Under Assumption 4.1 this condition is verified. Considering the level of investment I^C, we have the following final results for scenario C:

$$w = \frac{(1-x^2)(\varphi + c\varphi - c\beta^2)}{2\varphi(1+x)^2 - \beta^2(1+2x-x^2)} \; ; \; p^C = \frac{(x+1)(\varphi + c\varphi - c\beta^2)}{2\varphi(1+x)^2 - \beta^2(1+2x-x^2)}$$

$$q_1^C = \frac{\varphi(1-c)(1+x)^2 - 2c\beta^2x^2}{2\varphi(1+x)^2 - \beta^2(1+2x-x^2)} \; ; \; q_2^C = \frac{(x+1)(\varphi + c\varphi - c\beta^2)x}{2\varphi(1+x)^2 - \beta^2(1+2x-x^2)}$$

$$Q^C = \frac{2\varphi x^2 + 3\varphi x + \varphi - \varphi xc - c\varphi - 3c\beta^2x^2 - c\beta^2x}{2\varphi(1+x)^2 - \beta^2(1+2x-x^2)}$$

$$CS^C = \frac{\left(\varphi + 3\varphi x + 2\varphi x^2 - c\beta^2x - 3c\beta^2x^2 - c\varphi x - c\varphi\right)^2}{2\left[2\varphi(1+x)^2 - \beta^2(1+2x-x^2)\right]^2}$$

These results are valid under the constraint $x < \frac{1+\beta I-c}{1+\beta I+3c}$. Let us assume that the critical value of x that results from this constraint is $\bar{x}$. Then, we conclude that the results of the retail-minus regulation are valid as long as $x < \bar{x}$.

4.3 Comparison of the Results

Considering that the regulator's main objectives concerning the access price policy are to enhance competition in the downstream market, to promote the investment in network quality and to improve consumer welfare, we compare scenarios A, B and C analysing three points: the existence of foreclosure, the investment level and the value of consumer surplus.

Table 4.1 summarises the results obtained in the previous section:

Table 4.1 - Results of Scenarios A, B and C

Scenario	π_2	I	CS
A	0	$\frac{\beta(1-c)}{2\varphi-\beta^2}$	$\frac{\varphi^2(1-c)^2}{2(2\varphi-\beta^2)^2}$
B	>0	$\frac{\beta(1-c)}{4\varphi-\beta^2}$	$\frac{9\varphi^2(1-c)^2}{2\left(4\varphi-\beta^2\right)^2}$
C	>0	$\beta\frac{(1+2x-x^2)-c(1+2x+3x^2)}{2\varphi(1+x)^2-\beta^2(1+2x-x^2)}$	$\frac{1}{2}\frac{\left(\varphi+3\varphi x+2\varphi x^2-c\beta^2x-3c\beta^2x^2-c\varphi x-c\varphi\right)^2}{\left[2\varphi(1+x)^2-\beta^2(1+2x-x^2)\right]^2}$

The analysis of the results of Table 4.1 is made under Assumption 4.2:

Assumption 4.2: Let $z < c\beta^4 < y$, with $z = \varphi\left[\beta^2(1+3c) - \varphi(2+2c)\right]$ and $y = \frac{\varphi}{3}\left[\beta^2(3+5c) - \varphi(2+2c)\right]$.

Assumption 4.2 guarantee that the values of x in discussion rely in the interval $(0,1)$.[19]

The comparison of the results of Table 4.1 is made through the analysis of each of the three points mentioned before: foreclosure, investment level and consumer surplus.

Foreclosure

In the previous section we have already concluded that if firm 1 chooses the access price without any restriction, it forecloses firm 2 from the market. On the contrary, cost-based regulation and retail-minus regulation protect the independent firm allowing it a positive profit. Note that the equilibrium quantity of firm 2 in scenario C, $q_2^C = \frac{(x+1)(\varphi+c\varphi-c\beta^2)x}{2\varphi(1+x)^2-\beta^2(1+2x-x^2)}$, is positive for all admissible values of x.[20]

[19] For details see Appendix B4.5.

[20] See proof in Appendix B4.1.

Investment Level

Observing Table 4.1 we immediately conclude that firm 1 has a greater incentive to undertake investments under unregulation of access price than under cost-based regulation.[21] This result is explained by the fact that under cost-based regulation, firm 1 only benefits from the investment through the activity of its subsidiary firm in the downstream market. On the contrary, with unregulation, firm 1 has positive profits in the upstream activity that are cumulative with the profits of its subsidiary in the downstream segment.

Comparing scenario C with scenario B we conclude that retail-minus regulation leads to higher investment level than cost-base regulation if x is lower than a critical value x_2. The value of x_2 depends on the model's parameters in the following way:[22]

$$x_2 = \frac{2\varphi(1-c) + 2\sqrt{\varphi^2(1-c)^2 + H\varphi(1-c)}}{2H} \quad \text{with} \quad H = 3\varphi - 2c\beta^2 + 5c\varphi.$$

Comparing scenario C with scenario A we conclude that retail-minus regulation leads to a lower investment level than deregulation for every admissible values of x.[23]

Therefore, in what concerns the investment level, retail-minus regulation can produce intermediate results between deregulation and cost-based regulation if the regulator carefully defines the value of x, that is, if x is not "too high".

As we have already mentioned, cost-based regulation is characterised by the definition of the access price equal to the marginal cost of providing access. Previously we demonstrated that this is a first best solution regarding access price under the assumption that w is equal or higher than c. However, in practice, cost-based regulation requires that the regulator defines how much the entrants should contribute

[21] Foros (2004) reaches this conclusion when he assumes that downstream firms have the same ability to differentiate the final product.

[22] See the proof in Appendix B4.2.

[23] See proof in Appendix B4.3.

to cover the fixed cost of providing the access. Then, the regulator usually defines a mark-up to cover this costs, or part of it. The concept of cost-based regulation in practice adopted by many telecommunication regulators (for example, in the United States, the United Kingdom and advocated by the European Commission since 1994) is the Long Run Incremental Cost (LRIC).[24]

The implementation of LRIC involves the quantification of the incremental cost of providing the access in a forward-looking perspective, that is, considering the replacement cost of the assets. This perspective is in contrast to the historic cost accounting. However, the precise quantification of the Long Run Incremental Cost raises many questions, namely concerning the allocation of commom costs and about the informational requirements to compute the appropriate replacement costs (Mason and Valletti, 2001). Hence, there is some discretion in the practical implementation of LRIC (Laffont and Tirole, 2000).

Moreover, even if the Long Run Incremental Cost is correctly quantificated, several other problems can be indicated. Hausman (1997, 2000) argues that the Federal Communications Commission's definition of LRIC does not cover all the the investment costs when there is rapid technological progress, as happens in the telecommunications sector. This occurs because, in Hausman's perspective, the concept of cost used by the FCC considers neither the irreversible nature of many of the telecommunication investments, nor the costs with unsuccessful services.

In the same line of argument as Hausman, also Cave and Prosperetti (2001) conclude that the regulatory approach to access price based in the Long Run Incremental Cost adopted by some European countries discourage investment in the fixed networks by the incumbent firms because they anticipate that they will be required to offer access at cost-based prices. Additionally, Farrell (1997) emphasises the poor performance in terms of dynamic efficiency of cost-base regulation because firms do not have incentive to innovate if they know that they will be required to offer the access to their rivals at cost-based prices.

[24]For a detailed description of the concept of Long Run Incremental Cost see, for example, Valletti and Estache (1999), Laffont and Tirole (2000) and Cave and Vogelsang (2003).

The above mentioned concerns about cost-based regulation are also present in the argumentation of Ofcom defending the retail-minus regulation for the broadband internet access market: *"The Director believes that, since these are still immature markets, setting cost-based charges would be a risky exercise which may lead to charges that do not provide the correct signal to entrants. In immature markets there is a high degree of uncertainty with regards to costs, and issues such as the timing of cost recovery and the appropriate rate of return on the capital employed are more complicated than in established markets. The downsides of setting incorrect charges, particularly if they are set too low, are significant. It would deter investment in broadband access technologies by the existing operators, ie., BT and cable companies who are still rolling out their networks (...) This, would, in the long term, affect the development of competition. Accordingly, the Director considers that regulating charges on a LRIC+ basis would be premature and potentially harmful to investment decisions and that, given the specific nature of the markets, retail-minus appears to be the most appropriate pricing rule."* (Oftel, 2003).

The results of our model are consistent with Ofcom's perspective.

Consumer Surplus

Comparing the consumer surplus of scenarios A and B we conclude that if $\varphi < \beta^2$ deregulation leads to higher consumer surplus than cost-based regulation. That is, if the investment cost function is increasing and convex, but not excessively convex, consumers prefer the deregulation hypothesis. This result is explained by the high level of investment of scenario A that leads to a significant increase in demand. If, on the contrary, $\varphi > \beta^2$ consumers prefer cost-based regulation. This result is explained by the fact that, even without regulation, the investment level is not too high because of the strongly increasing costs of the investment and, therefore, from the consumers's point of view, it is better to have a duopoly rather than a monopoly in the downstream market.

Let us assume $\varphi < \beta^2$.

Comparing scenario C with scenario B we conclude that retail-minus regulation leads to higher consumer surplus than cost-based regulation if x is lower than a critical value $\bar{x}_2$. The value of $\bar{x}_2$ depends on the model's parameters in the following way:[25]

$$\bar{x}_2 = \frac{1}{2A}\left(-B - \sqrt{B^2 - 4AC}\right)$$

with

$$A = \varphi\left[\varphi(6c+2) - \beta^2(5+9c)\right] + 3c\beta^4$$

$$B = 8\varphi^2 c + 3\varphi\beta^2 - 9\varphi c\beta^2 + c\beta^4$$

$$C = -2\varphi c\beta^2 - 2\varphi^2 + 2\varphi\beta^2 + 2c\varphi^2$$

Comparing scenario C with scenario A we conclude that retail-minus regulation leads to higher consumer surplus than deregulation if $x < x_3$. The value of x_3 depends on the model's parameters in the following way:[26]

$$x_3 = \frac{2\varphi^2 - 3\varphi c\beta^2 - \varphi\beta^2 + 2\varphi^2 c + c\beta^4}{-(2\varphi^2 - 5c\beta^2\varphi - 3\varphi\beta^2 + 3c\beta^4 + 2c\varphi^2)}$$

Therefore, we conclude that, from the consumers's perspective, retail-minus regulation allows better results than the other alternatives in place provided that the regulator sets a value for x that is not higher than x_3.

The above conclusions are summarised in Propositions 4.1 and 4.2:

Proposition 4.1: Under Assumption 4.2 and when $\varphi < \beta^2$, the retail-minus regulation shows better results than cost-based regulation (leads to higher investment level and to higher consumer surplus), if the regulatory authority carefully defines the value of x, that is, if $x < min\{\bar{x}, x_2, \bar{x}_2\}$.

[25] See the proof in Appendix B4.4.

[26] See the proof in Appendix B4.5.

Proposition 4.2: Under Assumption 4.2 and when $\varphi < \beta^2$, the retail-minus regulation shows better results than unregulation of the access price, in terms of foreclosure and consumer surplus, if the regulator carefully defines x, that is, if $x < min\{\bar{x}, x_3\}$.

Table 4.2 summarises the conclusions described above assuming that $x < min\{\bar{x}, x_2, \bar{x}_2\}$ and $x < min\{\bar{x}, x_3\}$:

Table 4.2 - Comparison of the Results

Scenario	Foreclose	I	CS
A	Yes	+++	++
B	No	+	+
C	No	++	+++

We conclude that retail-minus regulation can be a good choice for the regulatory authority: it protects the independent firm position in downstream market and does not damage consumer surplus. The main drawback is the impact on the incentives to invest in the network, although the performance of retail-minus regulation is better than the cost-based regulation.

Because of the highly non-linear nature of the critical values for x ($\bar{x}$, x_2, $\bar{x}_2$ and x_3) we were not able to prove analytically that $\bar{x} < x_2$ or that $\bar{x} < \bar{x}_2$. However, for some values of the parameters that obey to all of the model's assumptions, we conclude that these conditions are verified. This allows us to conclude that retail-minus regulation leads to higher investment level and higher consumer surplus than cost-base regulation for the values consider. Concerning the critical value x_3 we conclude that both conditions $\bar{x} < x_3$ and $\bar{x} > x_3$ are true depending on the particular values consider for the model's parameters. To illustrate these conclusions we present some of the simulation results in Table 4.3.

Table 4.3 - Simulation Results

c	β	φ	$\bar{x}$	x_2	$\bar{x}_2$	x_3
0.1	0.5	0.2	0.776	0.872	0.943	0.429
0.2	0.5	0.15	0.667	0.786	0.839	0.111
0.5	0.6	0.2	0.409	0.527	0.590	0.059
0.9	0.5	0.2	0.063	0.158	0.491	0.429
0.5	0.7	0.2	0.546	0.601	0.613	0.111
0.2	0.5	0.18	0.635	0.767	0.860	0.282
0.1	0.45	0.2	0.760	0.862	0.995	0.952

With the purpose of getting some economic insight about the critical values of x we analyse their sensibility to the model's parameters. This analyses was made with the consideration of some possible values for two of the model's parameters and observing how the critical value of x varies with changes on the third parameter.

In what concerns the critical value $\bar{x}$ we conclude that its sensibility to the parameters has the expected signal. Then, $\bar{x}$ is decreasing with c and φ. These parameters represent the features of the cost functions, the marginal cost function and the investment cost function, respectively. Higher values of c or φ lead to high costs for firm 1. With higher costs the margin between the retail price and the access price must be lower. Therefore, the maximum possible value for x is decreasing with c and φ. Additionally, $\bar{x}$ is increasing with β. This parameter represent the sensibility of the demand size to the investment level. For higher values of β the demand size is higher and therefore the margin between the retail price and the access price can also be higher.

In what concerns the critical value x_3 we conclude that its sensibility to β and φ has the expected signal. Then, x_3 is decreasing with β and increasing with φ. These relationships are explained by the fact that the effect of the deregulation scenario on consumer surplus is made through the impact of the investment on

the demand function. For high values of β this effect is more intense and thus the consumer surplus with the deregulation scenario is relatively high. Then, the consumer surplus with retail-minus regulation can only be higher than the consumer surplus with deregulation for quite low values of x. Additionally, if φ is high, even under the deregulation scenario, the level of the investment is not high. Therefore, the effect of the investment on the consumer surplus is not very strong and then it is easier to find situations for which the consumer surplus with retail-minus is higher than the consumer surplus with deregulation. Finally, we conclude that x_3 is not sensitive to the parameter c.[27] This result is also explained by the fact that the effect of the deregulation scenario on consumer surplus is made through the demand function and thus it is independent of the marginal cost. The deregulation scenario implies a greater consumer surplus than the retail-minus regulation when x is relatively high and this value of x does not depend on the marginal cost, but only on the parameters that have impact on the demand function.

It is worthwhile to mention that all the above conclusions do not change if we consider Cournot competition instead of Stackelberg competition. In particular, this means that with Cournot competition the conclusions summarise in Table 4.2 are the same although, as it is expected, the equilibrium values of the relevant variables (prices, quantities, investment and consumer surplus) and of the critical values of x, are different from the ones obtained with Stackelberg competition.

4.4 ECPR and Retail-Minus

The Efficient Component Pricing Rule (ECPR) is one of the instruments of access price regulation most extensively discussed. It was advanced by Willig and Baumol[28] who argue that ECPR improves welfare because new entrants do not affect the incumbent firm's revenues, and entry only occurs if the entrants have lower

[27] This result is immediatly confirmed by the value of the first derivative of x_3: $\frac{\partial x_3}{\partial c} = 0$.

[28] See Baumol and Sidak (1994) for a detailed description of ECPR.

costs than the incumbent firm. However, ECPR was also strongly criticised[29] especially with the argument that it protects the incumbent firm's profits, even if they are the monopoly profits. With only a few exceptions, ECPR has never been applied by regulators (Mason and Valletti, 2001).[30] One widely quoted example of practical utilisation of ECPR occurred in 1994 when the New Zealand Telecom (the incumbent telecommunication operator) defended the implementation of ECPR for the definition of the access price that its rival firm, Clear Communication, should paid by the network access. However, after a deep discussion, this proposal was not accepted.[31]

ECPR states that the access price should be equal to the direct incremental cost of providing the access plus the incumbent firm's lost profit in the retail market caused by providing the access (that is, the opportunity cost of providing the access).

Using the notation of the previous section, the ECPR can be represented by $w = c + \sigma [p - (c + s)]$, where s is the marginal cost of the incumbent firm in the downstream activity[32] and σ, the displacement ratio, represents how many units of retail service are lost by the incumbent firm by supplying one unit of access to its rivals in the downstream market. This definition of ECPR follows Armstrong *et al.* (1996).

The original definition of ECPR by Willig and Baumol uses the concept of average incremental cost instead of marginal cost. The consideration of marginal cost has implicitly the idea that if fixed costs exist they are covered by alternative instruments (for example subsidies). To clarify this distinction in the discussion of network competition, Laffont *et al.* (1988) define the concepts of marginal-cost ECPR and average-cost ECPR. The former definition does not include any fixed cost while the latter includes those costs.

Vickers (1997) distinguishes ECPR from margin regulation. Under margin regula-

[29] See, for example, Economides and White (1995).

[30] See, for example, Spulber and Yoo (2003, p.974), for a description of the reasons why the Federal Communications Commission did not apply ECPR to the access to local telephone netwoks.

[31] For details see, for example, Laffont *et al.* (1988).

[32] For simplicity, in the previous sections we assumed $s = 0$.

tion the access price is equal to the incumbent firm's retail price minus the incumbent's marginal cost in the retail activity: $w = c + [p - (c + s)]$. Therefore, ECPR coincides with margin regulation $(p - w)$ when the displacement ration is one[33] and *"in the absence of fixed cost recovery problem."* (Vickers, 1997, p.23).

In the original definition of ECPR it is assumed that the retail price is exogenously defined as a result of a "perfect contestable market" or by regulation.[34] This means that the access price has no effect on allocative efficiency. Also, it means that the critique that ECPR protects monopoly profits is not so convincing because ECPR assumes that the retail price is optimally defined. Under the assumption referred to, ECPR is an instrument of price access regulation, that can be represented as $w = p - s$ (assuming $\sigma = 1$) or, equivalently, as $p - w = s$, with p and s being defined exogenously.

However, recently several authors have studied the results of ECPR when the retail price is endogenously defined. In this case the ECPR can be interpreted as regulation of the margin $p-w$, and, contrary to the original definition, it has effects on allocative efficiency. For instance, Armstrong and Vickers (1998) compare the regulation of the access price (w) with the regulation of the margin $(p - w)$. With this purpose they characterised the optimal access price and the optimal margin, that is, the ones that maximise social welfare. Armstrong and Vickers conclude that, for linear demand and costs, the optimal access price is the marginal cost of providing the access (what we previously called cost-base regulation: $w = c$) and the optimal margin is given by ECPR assuming that the retail price is set at monopoly level. From the comparison of the two instruments referred, Armstrong and Vickers conclude that the optimal access price regulation leads to higher social welfare and higher entrant's profit than the optimal margin regulation.

In a different framework, Weisman (2002) also compares cost-based regulation, where $w = c$ (which Weisman calls marginal cost access pricing), and ECPR, where

[33]The displacement ratio is 1 if a fixed coefficients tecnhology, an homogenous product and no bypass of the incumbents infrastructure are assumed.

[34]See, for example, Noam (2002) for a discussion of these hypothesis.

$w = p - s$. Weisman considers that the retail price is defined by Cournot competition between the vertically integrated firm and n independent firms. The main conclusion of Weisman is that the vertically integrated firm *"earns either monopoly or competitive profits in equilibrium under ECPR depending upon its relative efficiency downstream."*

Both papers mentioned above assume that the firms have different costs in the downstream activity. However, from Weisman's (2002) model we conclude that, if the incumbent firm and the independent firms have equal costs in the downstream activity, under ECPR the incumbent firm foreclosures the independent firm. This conclusion results from the definition of ECPR: the independent firm will only produce if it is more efficient than the vertically integrated firm. Then, under the assumption of equal costs, the ECPR instrument leads to the same results as no regulation of the access price. In both cases the incumbent firm remains a monopolist.

In the model described in this Chapter we assume equal costs of downstream activity for both firms. Therefore, the ECPR instrument leads to the results of scenario A. We have already demonstrated that the retail-minus regulation allows a higher consumer surplus than the deregulation case as long as the value of x is not "too high", and avoids foreclosure, because we assume a strictly positive value for x. We also demonstrate that retail-minus regulation leads to a lower level of investment than the deregulation case.

From this analyses we conclude that retail-minus can be different from ECPR. ECPR sets the margin $p - w$ equal to the incumbent costs in the downstream segment, while retail-minus regulation sets the margin $p - w$ at $x\%p$. Depending on the value of x, this can be higher than the downstream costs. Although the relationship between ECPR and retail-minus regulation deserves a deep analysis, we think that one reason for the recent use of retail-minus regulation by regulators[35] might be explained by

[35] Valletti (2003) refers that *"ECPR has not found applications in fixed telephone at time when the incumbent's prices were regulated (...) while it is now proposed, under a different name - "Retail-Minus" - in mobile telephone where final prices are unregulated (...)."*

the unregulation of the retail prices. In this case the retail-minus regulation is in fact a kind of regulation of the margin (because the retail price is also endogenous) that leads to attractive levels for consumer surplus compared to the ones reached with unregulated access price or cost-based regulation.

4.5 Conclusions

When the regulatory authority has multiple objectives regarding the access price regulation (Laffont and Tirole, 2000) and only one instrument to apply, there is a trade off between the possible outcomes of the regulatory policy. From the model described in previous sections we conclude that if the regulator carefully defines the margin between retail and access prices, with retail-minus regulation it is possible to achieve a better result than either with deregulation or cost-based regulation, in terms of protection of downstream competition and consumer surplus.

Retail-minus regulation allows a greater flexibility in access price definition than cost-based regulation. Under the former the access price definition is influenced not only by the costs but also by demand characteristics and oligopoly interaction that occurs in the retail market. Additionally, the incumbent firm has a higher incentive to invest in network improvements which has positive consequences on market development.

We conclude that the retail-minus allows the development of competition in downstream market and, if the regulator carefully defines this instrument, the damage on the incentives of the incumbent firm to invest might be limited. Although we have not considered in our model the incentives to invest by new firms, we are convincing that if the access price is not too low the new firms may have incentive to invest in their own facilities, which in the future might allow the development of competition in the upstream segment and then regulation will be dispensable. Therefore, retail-minus has a good performance as a transitory instrument to full deregulation of the market.

Appendix A4

Table A4.1

Broadband access in OECD countries per 100 inhabitants, June 2003

	DSL	%	Cable Moden	%	Other Platforms	%	Total
Australia	1,48	55,8	1,11	41,9	0,07	2,6	2,65
Austria	2,76	39,5	4,22	60,5	0	0,0	6,98
Belgium	6,25	60,4	3,82	36,9	0,27	2,6	10,34
Canada	6,09	45,9	7,18	54,1	0	0,0	13,27
Czech Republic	0,06	21,4	0,21	75,0	0	0,0	0,28
Denmark	7,29	65,6	3,17	28,5	0,65	5,9	11,11
Finland	5,39	81,5	1,21	18,3	0,01	0,2	6,61
France	3,56	86,2	0,57	13,8	0	0,0	4,13
Germany	4,68	96,7	0,06	1,2	0,1	2,1	4,84
Hungary	0,56	60,2	0,36	38,7	0	0,0	0,93
Iceland	10,66	95,0	0	0,0	0,56	5,0	11,22
Ireland	0,19	46,3	0,08	19,5	0,14	34,1	0,41
Italy	2,5	88,0	0	0,0	0,34	12,0	2,84
Japan	6,49	75,5	1,75	20,3	0,36	4,2	8,6
Korea	14,36	62,0	8,45	36,5	0,37	1,6	23,17
Luxembourg	2,02	87,1	0,24	10,3	0,06	2,6	2,32
Mexico	0,12	42,9	0,15	53,6	0,001	0,4	0,28
Netherlands	3,82	41,5	5,38	58,5	0,001	0,0	9,2
New Zealand	1,87	90,3	0,06	2,9	0,14	6,8	2,07
Norway	4,08	75,7	1,17	21,7	0,14	2,6	5,39
Poland	0,09	42,9	0,12	57,1	0	0,0	0,21
Portugal	1,12	30,1	2,61	70,2	0	0,0	3,72
Slovak Republic	0	0,0	0,01	100,0	0	0,0	0,01
Spain	3,24	76,4	1	23,6	0	0,0	4,24
Sweden	5,44	59,4	1,96	21,4	1,76	19,2	9,16
Switzerland	4,7	51,5	4,43	48,5	0	0,0	9,13
Turkey	0,01	16,7	0,05	83,3	0	0,0	0,06
United Kingdom	1,78	49,0	1,82	50,1	0,02	0,6	3,63
United States	2,68	32,5	4,84	58,7	0,74	9,0	8,25
OECD	3,37	55,6	2,4	39,6	0,29	4,8	6,06
EU	3,31	72,7	1,1	24,2	0,14	3,1	4,55

Source: OECD (Organisation for Economic Co-operation and Development)

Table A4.2

ADSL share of the incumbent firms in December 2003

Country	Incumbent firm	ADSL share (in %) of the incumbent firm
Austria	Austria Telekom	80
Belgium	Belgacom	86
Denmark	Teledanmark	92
Finland	Tele Sonera	93
France	France Telecom	57
Germany	Deutshe Telekom	100
Greece	OTE	47
Ireland	Eircom	81
Italy	Telecom Italia	85
Netherlands	KPN Telecom	100
Portugal	Portugal Telecom	85
Spain	Telefonica	79
Sweden	Telia Sonera	75
United Kingdom	British Telecom	50

Source:ECTA (European Competitive Telecommunications Association)

Appendix B4

B4.1. Under Assumption 4.1 we know that $2\varphi(1+x)^2 - \beta^2(1+2x-x^2) > 0$ for all $x \in (0,1)$. Then, $q_2^C > 0$ if $\varphi + c\varphi - c\beta^2 > 0$ or, equivalent, if $\varphi > \frac{2c}{1+c}\frac{\beta^2}{2}$. As $\frac{2c}{1+c} < 1$ for $c \in (0,1)$ and, by Assumption 4.1, we know that $\varphi > \frac{\beta^2}{2}$, then $\varphi > \frac{2c}{1+c}\frac{\beta^2}{2}$ is true.

B4.2. The condition $I^C > I^B$ is equivalent to $-2\frac{-2cx^2\beta^2+3x^2\varphi+5cx^2\varphi-2x\varphi+2cx\varphi-\varphi+c\varphi}{(2\varphi(1+x)^2-\beta^2(1+2x-x^2))(4\varphi-\beta^2)}$ > 0. As the denominator is positive, it is necessary to guarantee that $-2cx^2\beta^2 + 3x^2\varphi + 5cx^2\varphi - 2x\varphi + 2cx\varphi - \varphi + c\varphi < 0$. This condition is equivalent to $(3\varphi - 2c\beta^2 + 5c\varphi)x^2 + (2c\varphi - 2\varphi)x + (c\varphi - \varphi) < 0$.

Let $H = 3\varphi - 2c\beta^2 + 5c\varphi$. From Assumption 4.1 we have $H > 0$. Notice that $H > 0$ is equivalent to $\varphi > \frac{4c}{3+5c}\frac{\beta^2}{2}$ and, as $\frac{4c}{3+5c} < 1$ for $c < 1$ and $\varphi > \frac{\beta^2}{2}$ (by Assumption 4.1), we conclude that $\varphi > \frac{4c}{3+5c}\frac{\beta^2}{2}$ is true.

Then $Hx^2 + (2c\varphi - 2\varphi)x + (c\varphi - \varphi)$ is a convex second degree equation in x whose roots are:

$x_1 = \frac{2\varphi(1-c)-2\sqrt{\varphi^2(1-c)^2+H\varphi(1-c)}}{2H}$ and $x_2 = \frac{2\varphi(1-c)+2\sqrt{\varphi^2(1-c)^2+H\varphi(1-c)}}{2H}$. As $\varphi^2(1-c)^2 + H\varphi(1-c) > 0$, then x_1 and x_2 are real roots.

As $x_1 < 0$ and $x_2 > 0$ we conclude that $I^C > I^B$ if $x < x_2$.

B4.3. $I^C > I^A$ is equivalent to $\frac{\left[(1+2x-x^2)-c(1+2x+3x^2)\right](2\varphi-\beta^2)-(1-c)\left[2\varphi(1+x)^2-\beta^2(1+2x-x^2)\right]}{\left[(2\varphi(1+x)^2-\beta^2(1+2x-x^2)\right](2\varphi-\beta^2)} > 0$.

As the denominator is positive we have $I^C > I^A$ if the numerator is also positive. The numerator can be written as $4x^2(-\varphi - c\varphi + c\beta^2)$. However, $-\varphi - c\varphi + c\beta^2 < 0$, because $\frac{c}{1+c} < \frac{1}{2}$ and $\varphi > \frac{\beta^2}{2}$. Then, $I^C < I^A$ for all admissible x.

B4.4. As the demand function is linear the consumer surplus is define as $CS = \frac{Q^2}{2}$. Then $CS^C > CS^B$ if $Q^C > Q^B$. From section 4.2 we know that

$Q^B = \frac{3\varphi(1-c)}{4\varphi-\beta^2}$ and $Q^C = \frac{2\varphi x^2+3\varphi x+\varphi-\varphi xc-c\varphi-3c\beta^2x^2-c\beta^2x}{2\varphi(1+x)^2-\beta^2(1+2x-x^2)}$. Then $Q^C > Q^B$ is equivalent to

$$\frac{(2\varphi x^2+3\varphi x+\varphi-\varphi xc-c\varphi-3c\beta^2x^2-c\beta^2x)(4\varphi-\beta^2)-3\varphi(1-c)\left[(2\varphi(1+x)^2-\beta^2(1+2x-x^2)\right]}{\left[(2\varphi(1+x)^2-\beta^2(1+2x-x^2)\right](4\varphi-\beta^2)} > 0$$

As the denominator is positive, we need to identify the values of x for which the numerator is also positive. The expression in the numerator can be written as:

$\left[\varphi\left[\varphi(6c+2)-\beta^2(5+9c)\right]+3c\beta^4\right]x^2 + (8\varphi^2c+3\varphi\beta^2-9\varphi c\beta^2+c\beta^4)x + (-2\varphi c\beta^2 - 2\varphi^2+2\varphi\beta^2+2c\varphi^2)$.

Let

$A = \varphi\left[\varphi(6c+2)-\beta^2(5+9c)\right]+3c\beta^4$

$B = 8\varphi^2c+3\varphi\beta^2-9\varphi c\beta^2+c\beta^4$

$C = -2\varphi c\beta^2 - 2\varphi^2+2\varphi\beta^2+2c\varphi^2$

Hence, the numerator can be represented as $Ax^2 + Bx + C$.

Let us assume that $A < 0$ and $B > 0$.[36] We can write $C = 2\varphi(1-c)(\beta^2 - \varphi)$. As we are assuming $\varphi < \beta^2$ and $c \in (0,1)$ then $C > 0$. Then the numerator is a concave second degree equation in x with roots $\bar{x}_1$ and $\bar{x}_2$. We also know that:

i) $B^2 - 4AC > 0$ because $A < 0$ and $C > 0$. Thus, $\bar{x}_1$ and $\bar{x}_2$ are real roots;

ii) $\bar{x}_1 = \frac{1}{2A}\left(-B + \sqrt{B^2 - 4AC}\right)$. As $A < 0$, $B > 0$ and $C > 0$ then $\bar{x}_1 < 0$.

iii) $\bar{x}_2 = \frac{1}{2A}\left(-B - \sqrt{B^2 - 4AC}\right)$. As $A < 0$, $B > 0$ and $C > 0$ then $\bar{x}_2 > 0$.

Therefore, $Q^C > Q^B$ if $x < \bar{x}_2$.

B4.5. We know that if $Q^C > Q^A$ then $CS^C > CS^A$, because we are considering a linear demand function. $Q^C > Q^A$ can be written as

$$\frac{(2\varphi x^2+3\varphi x+\varphi-\varphi xc-c\varphi-3c\beta^2x^2-c\beta^2x)(2\varphi-\beta^2)-\varphi(1-c)\left[(2\varphi(1+x)^2-\beta^2(1+2x-x^2)\right]}{\left[2\varphi(1+x)^2-\beta^2(1+2x-x^2)\right](2\varphi-\beta^2)} > 0.$$

Under Assumption 4.1 the denominator is positive. Then we will search for the values of x for which the numerator is also positive. Solving for x we have:

$x < \frac{2\varphi^2-3\varphi c\beta^2-\varphi\beta^2+2\varphi^2c+c\beta^4}{-(2\varphi^2-5c\beta^2\varphi-3\varphi\beta^2+3c\beta^4+2c\varphi^2)}$. Let $x_3 = \frac{2\varphi^2-3\varphi c\beta^2-\varphi\beta^2+2\varphi^2c+c\beta^4}{-(2\varphi^2-5c\beta^2\varphi-3\varphi\beta^2+3c\beta^4+2c\varphi^2)}$.

It is important to guarantee that x_3 is positive. Let $N = 2\varphi^2 - 3\varphi c\beta^2 - \varphi\beta^2 + 2\varphi^2 c + c\beta^4$ and $D = 2\varphi^2 - 5c\beta^2\varphi - 3\varphi\beta^2 + 3c\beta^4 + 2c\varphi^2$. Then, we have $x_3 = \frac{N}{-D}$. x_3 is positive either if $N > 0$ and $D < 0$ or if $N < 0$ and $D > 0$. Analysing the expressions of N and D we conclude that $N > 0$ and $D < 0$ if $z < c\beta^4 < y$ with $z = -\varphi(\varphi(2+2c) - \beta^2(1+3c))$ and $y = \frac{\varphi}{3}(\beta^2(3+5c) - \varphi(2+2c))$.

Notice that we can write N as

$N = \varphi\left[(\varphi(2+2c) - \beta^2(1+3c)\right] + c\beta^4$. Hence, we conclude that $N > 0$ if $c\beta^4 > -\varphi\left[(\varphi(2+2c) - \beta^2(1+3c)\right]$; and we can write D as

$D = \varphi(\varphi(2+2c) - \beta^2(3+5c)) + 3c\beta^4$. Then we conclude that $D < 0$ if $c\beta^4 < -\frac{\varphi}{3}(\varphi(2+2c) - \beta^2(3+5c))$, because $\varphi < \beta^2$ and $\frac{3+5c}{2+2c} > 1$.

[36] In Appendix B4.5 we prove that, under Assumption 4.2, $A < 0$ and $B > 0$.

It is also important to note that, as $\varphi > \frac{\beta^2}{2}$ and $\frac{c}{1+c} < \frac{1}{2}$, the condition

$-\varphi\left[\varphi(2+2c)-\beta^2(1+3c)\right] < -\frac{\varphi}{3}\left[\varphi(2+2c)-\beta^2(3+5c)\right]$ is true; and that, as $\frac{2+4c}{4c} > 1$, the condition $-\frac{\varphi}{3}\left[\varphi(6c+2)-\beta^2(5+9c)\right] > -\frac{\varphi}{3}\left[\varphi(2+2c)-\beta^2(3+5c)\right]$ is true.

Finally, note that, by Assumption 4.1 and knowing that $\frac{c}{1+c} < \frac{1}{2}$, we can not have $N < 0$ and $D > 0$.

Now we can demonstrate that, under Assumption 4.2 we have $A < 0$ and $B > 0$, with $A = \varphi(\varphi(6c+2)-\beta^2(5+9c)) + 3c\beta^4$ and $B = 8\varphi^2 c + 3\varphi\beta^2 - 9\varphi c\beta^2 + c\beta^4$.

We know that $A < 0$ is equivalent to $c\beta^4 < -\frac{\varphi}{3}(\varphi(6c+2)-\beta^2(5+9c))$, and this condition is verified because $-\frac{\varphi}{3}(\varphi(6c+2)-\beta^2(5+9c)) > -\frac{\varphi}{3}(\varphi(2+2c)-\beta^2(3+5c))$ is true.

We know that $B > 0$ is equivalent to $c\beta^4 > -8\varphi^2 c - 3\varphi\beta^2 + 9\varphi c\beta^2$ and this condition is verified because $z > -8\varphi^2 c - 3\varphi\beta^2 + 9\varphi c\beta^2$ is true.

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