Université de Toulouse 1 - Sciences Sociales

Midi-Pyrénées Sciences Economiques

THESE

Pour le Doctorat en Sciences Economiques

Essays on Regulation of Regional Gas Markets

Presenté et soutenue le 30 Semptembre 2005

par

Juan Daniel OVIEDO ARANGO

Sous la direction de

Farid GASMI

Membres du Jury

M. Helmuth CREMER, Professeur, Université Toulouse 1

M. Philippe DE DONDER, Chargé de recherche au CNRS, Université Toulouse 1

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les opinions particulières du candidat.

Contents

Abstract

The European gas industry has been experiencing substantial changes due to both the liberalization process started in the mid nineties and the increasing dependency on gas imports from few countries outside of the EU. Given the high degree of concentration, the issue of the impact of transport capacity on market structure and market power bears particular importance. The general goal of this dissertation is to address this strategic question using simple regulatory models and numerical simulations. It is composed of a general introduction and three self-contained chapters.

The first chapter analyzes some policies implemented by a social planner seeking to control regional monopoly power in the natural gas industry when, because of liberalization, the planner sees the set of available control instruments progressively reduced. The analysis allows us to assess the extent to which transfers, transport capacity, and price are substitutes or complements when fighting market power. We focus on the role of transport capacity and characterize the cases where loss of control instruments results in “over” or “under” sizing of the transport network. The analysis yields some insights on the social planner’s incentives to invest in infrastructure with the objective of integrating separated markets.

The second chapter extends the model of the regulator-firm relationship to account for information problems. Assuming an industry configuration in which a monopoly market and a competitive market can be linked by a pipeline, we first derive normative policies corresponding to different sets of available regulatory instruments. By focusing on the capacity variable, we then examine the extent to which information and incentive problems affect pipeline capacity. Finally, we explore the (capacity) effects of the regulator’s ability to commit to investments in the transport network.

The third chapter develops a (complete information) model with an upstream firm providing transport capacity at a regulated price to a marketer competing in output with an incumbent in a downstream gas commodity market. The equilibrium outcome of the firms’ interaction in the downstream market is explicitly taken into account by the regulator when setting the transport charge. We consider various forms of competition in this market and derive the corresponding optimal transport charge policies. We then run simulations that allow us to perform a comparative welfare analysis of these transport capacity policies based on different assumptions about the competitiveness of the gas commodity market.

Resumé

L'industrie gazière européenne a connu des changements importants à la suite du processus de libéralisation entamé au milieu des années quatre-vingt-dix dans un contexte de dépendance accrue d'importations provenant d'un petit nombre de pays hors Union Européenne. Ainsi, étant donnée la forte concentration qui caractérise la filière gazière européenne, la question de l'impact de la capacité du réseau de transport sur la structure de marché et l'exercice du pouvoir de marché par les acteurs de cette filière revêt un caractère particulièrement important pour l'UE. L'objectif général des travaux constituant cette thèse est d'analyser cette question stratégique en nous appuyant sur des modèles issus de la nouvelle économie de la régulation et sur des simulations numériques de ces modèles. Elle comprend une introduction et trois chapitres autonomes.

Le premier chapitre consiste en une analyse de politiques mises en œuvre par un planificateur social pour contrôler le pouvoir de monopole régional dans l'industrie du gaz naturel lorsque, en raison d'une libéralisation progressive des marchés, le planificateur voit l'ensemble des instruments de contrôle qui sont à sa disposition se réduire. L'étude permet d'examiner dans quelle mesure les transferts, la capacité du réseau de transport et la tarification du gaz, sont des substituts ou des compléments dans la mission de contrôle du pouvoir de marché par le planificateur social. En prêtant une attention particulière à la capacité du réseau de transport, nous sommes en mesure de caractériser les conditions sous lesquelles la perte progressive d'instruments de contrôle conduit à un "sur dimensionnement" ou un "sous dimensionnement" du réseau. L'analyse fournit ainsi un éclairage quant aux incitations du planificateur à investir dans les infrastructure de transport dans un but d'intégrer des marchés séparés.

Le second chapitre est une extension du modèle de la relation régulateur-firme qui tient compte explicitement des problèmes d'information. En supposant une configuration industrielle simple dans laquelle deux marchés distincts, un marché de monopole et un marché concurrentiel, peuvent être connectés via un gazoduc, nous dérivons dans un premier temps des politiques normatives correspondant à différents ensembles d'instruments de régulation. En nous concentrant sur la capacité du réseau de transport, nous examinons dans un deuxième temps l'impact des contraintes informationnelles et d'incitation sur le dimensionnement du réseau. Enfin, nous explorons le rôle de la capacité du régulateur à s'engager sur les investissements en infrastructure de transport.

Le troisième chapitre développe un modèle en information complète dans lequel une firme en amont fournit à un prix régulé de la capacité de transport à un négociant qui concurrence sur un marché de gaz naturel en aval un opérateur historique. L'équilibre sur le marché-aval est explicitement pris en compte par le régulateur lorsqu'il fixe le prix de la capacité. Nous considérons différentes formes de concurrence sur ce marché et nous caractérisons les politiques optimales de tarification de la capacité qui y sont associées. A l'aide de simulations, nous menons une analyse comparative de ces politiques basées sur différentes hypothèses concernant le degré de concurrence sur le marché de la molécule, afin d'évaluer leur performance relative en terme de bien-être économique.

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Now that this dissertation, which stands for a crucial step forward in my academic and personal life, has taken shape, here comes the opportunity to express my gratitude to all people that directly or indirectly shed some light on this work.

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As my advisor Farid Gasmi keeps saying: "...and the adventure must go on."

Introduction

The last two decades have witnessed a marked interest around the world for the introduction of competition in the natural gas industry. In the European Union, the gas market has experienced since the second half of the nineties a wide and complex liberalization process.[1] The European Commission (EC), under the terms of the 2003 EC gas directive, has committed to the establishment of a single market throughout Europe scheduled to be fully open by July 2007.[2] Although a large number of gas consumers in Europe are now able to choose their suppliers and many steps have been taken towards the harmonization of national legislation as a result of the EU directives, barriers to competition still remain. These primarily relate to market structure, national attitudes towards liberalization, access to gas supplies, and access to key infrastructure facilities.[3]

Natural gas plays an important role in the European energy economy. Various factors such as the high population density, the extensive urbanization, and the local availability of gas production have contributed to the development of intensive gas use within western Europe. These factors are reinforced by the fact that natural gas has a large potential for being the most preferred input-choice for power generation in the European Union since it is a "clean" fuel with higher efficiency levels that those of its close competitors such as coal and fuel oil. However, in most European countries, gas production is expected to significatively decline over

1. See Cremer et al. (2003) for an overview of these reforms.

2. Currently, all European Union Member States, unless specifically exempt from the liberalization requirements, have a similar level of market opening. Indeed, industrial gas consumers have been able to choose their suppliers since July 2004.

3. Overall, by the end of 2004, at least 56% of gas consumed in Europe was supplied to end-users who were legally able to choose their suppliers.

the next decade as existing gas fields are reaching maturity and new discoveries are generally small. Thus, the European gas market will most probably become increasingly dependent on imports from outside the region.[4]

Norway is Europe's only major gas exporter supplying around 14% of European gas consumption. Russia supplies more than 60% of the gas imported into Europe and is expected to remain its largest external supplier for decades. Algeria supplies more than 25% of the gas imported into Europe by pipeline to southern Europe and as LNG to several countries including France, Belgium, Greece, and Portugal. The need for supply diversification is strong and European gas importers are willing to diversify their sources and LNG provides a way to do this. LNG imports currently represent 11% of total imports into the region and this figure is expected to steadily grow in the future.

Recently developed demand and supply projections for Europe, even when based on moderate expectations of future demand for natural gas, have shown the existence of a substantial gap between demand and the potential supply from outside Europe. The extensions and new gas connections that need to be put in place in order to meet demand in 2020 mainly involve new pipelines from Russia, Algeria and the Caspian sea Area, and new LNG terminals to receive LNG from Egypt and the Middle East.[5]

Given the above discussed features of demand and supply, the European gas system raises interesting "investment" questions that may not be found in the US. This is due to the fact that the market is likely to remain dominated by a few large producers in the long run. Thus, the issue of the impact of transport capacity on market structure and market power certainly deserves some attention. This topic has been documented in both the institutional/empirical and the theoretical literature on energy.

In the electricity sector, competitive strategies in deregulated markets have become a very active area of research. Most of the published literature (see, e.g.,

4. Almost all countries in Europe are net importers of gas and many, including major users such as France and Spain, are almost totally dependent on gas imports. Moreover, Europe is expected to be the largest world market for imported natural gas between 2000 and 2020 (Cayrade, 2004).

5. A rough estimate of the bill for these infrastructure projects lies between 150 and 200 billion US dollars. See Sagen and Aune (2004) for more details.

Green and Newbery, 1992, Von der Fehr and Harbord, 1993, Borenstein and Bushnell, 1999, Rudkevich et al., 1999, and Green, 1999) examines strategic behavior in a static setting. Concerning imperfect competition in generation, many authors have proposed models in which generators take advantage of transmission constraints to exert local market power (Oren, 1997, Cardell et al. 1997, Borenstein et al., 2000, and Nasser, 1998). These studies have either abstracted from the details of transmission or used a variant of a standard transportation model to describe the geographic differences among markets. The choice of possible strategies follows the common Cournot quantity approach. A general finding is that the role of the transmission segment goes beyond that of simply bringing power from competitive sources.

More relevant to the European power market, Smeers and Wei (1999) propose an oligopoly model where both power generators and consumers are spatially dispersed. The generators compete à la Cournot in a context where transmission prices are regulated, i.e., they take their rivals' output and the prices for transmission services as fixed when deciding about profit-maximizing output. The transmission firm takes the quantities of transmission services demanded by the generators as fixed when it determines the transmission prices according to certain regulatory rules. In this framework, they analyze the impact of the market power retained by the generators after the restructuring of the electricity industry. They also assess the effect of pricing of transmission services on the generation segment and the investment in transmission assets. A similar issue was analyzed in Smeers and Wei (1997) where they consider two-stage models for the electricity industry where the second stage (the energy market) and the first stage (investment) behaviors obey different competition paradigms.

From a regulatory perspective, Nasser (1998) describes how generation and transmission of power have been unbundled to foster the introduction of competition in the electricity industry. The author identifies the importance of designing institutions that lead to "optimal" network expansion. He describes alternative arrangements that have been proposed which can be classified as follows: planning by a government entity, regulation of the network operator, and decentralization of investment decisions supported by pricing of congestion of the network.[6] He shows that the socially optimal network expansion is such that the marginal cost of capacity equals its social marginal value. This value is given in terms of the congestion reduction brought about by a marginal increase of capacity.

Léautier (2000) highlights the importance of the optimal design of regulatory contracts for the operators of power transmission networks in the United States. He examines the regulation of a for-profit transmission company in charge of bringing competitive power to wholesale power markets. Such contract should ensure financial viability of the transmission activity, promote adequate usage of the service, induce productive efficiency, and encourage optimal expansion of the network. This last feature is considered by the author as critical for the development of efficient wholesale power markets.[7]

Similarly, Léautier (2001) identifies two important effects of transmission expansion. First, part of market demand will be met by cheap power instead of expensive local power, the so called substitution effect. Second, competition among power generators is increased, the so called strategic effect. The author finds that while the substitution effect is always welfare improving, the welfare impact of the strategic effect is not unambiguous, i.e., it might be the case that consumers pay a lower price but generators earn lower profits.

In the natural gas sector, for the case of the US gas industry and mainly on the empirical front, a large stream of the literature has examined the impact of interconnecting sub-networks on the degree of market integration and competition (see, e.g., Doane and Spulber, 1994, and De Vany and Walls, 1994).[8] Some of the earlier efforts at characterizing various aspects of the European natural gas market include Tzoannos (1977) and Haurie et al. (1987). Mathiesen et al. (1987) screen the European market with respect to three scenarios, namely, perfect competition,

6. Brazil has opted for the first solution, the United Kingdom for the second, and Argentina for the third.

7. From Léautier (2000), insufficient transmission capacity creates four costs: higher than optimal congestion, higher than optimal power losses, lower than optimal reliability, and imperfect competition in generation.

8. For a review of the literature related to the impact of third-party access to pipelines in the natural gas industry see Cremer et al. (2003) and Cremer and Laffont (2002).

Cournot, and collusion of the producers. Other applications of the Cournot-type competitive framework have since been developed for the purpose of analyzing the European gas market. A three-level Stackelberg game has been developed by Grais and Zheng (1996) to study the transport of natural gas from Russia to Western Europe.

The potential impact of the possible introduction of open access in the European gas system was also studied by means of a Cournot framework in Golombek et al. (1995). The authors explore the impact of open access on market power exerted by natural gas producers through the development of marketers. Using a numerical model where producers behave in a Cournot fashion and face a competitive fringe of marketers, they show that this competitive effect is indeed significant. In a more elaborated model, Golombek et al. (1998) study the impact on the imperfectly competitive supply side of the natural gas industry of policies that introduce competition in the demand side. They show that these pro-competitive demand measures will generate incentives to break up national gas producers into several independent domestic producers.

De Wolf and Smeers (1997) adopt a Stackelberg game perspective for their work on the European natural gas market. Breton and Zaccour (2001) concentrate on analyzing a duopoly of producers under a security constraint but in a somewhat abstract form. More recently, Boots et al. (2004) model a successive oligopoly applied to the European natural gas market. In this numerical model, Cournot producers are also Stackelberg leaders with respect to traders, who may be Cournot oligopolists or price takers. They obtain that successive oligopoly yields higher prices and lower consumer welfare than an oligopoly with only one level. Moreover, due to the high concentration of traders, prices are distorted more by market power in trading than in production. Finally, they show that when traders increase in number, prices approach competitive levels.[9]

Even though the literature shows the abundance of models supposed to represent the European natural gas market, these models are meant to be short-term models where there is no place for capacity expansion decisions. This constitutes

9. Egging and Gabriel (2005) extend the model of Boots et al. (2004) by considering the role of storage and transmission both assumed to be perfectly competitive.

a critical handicap when it comes to analyzing the "normative" implications of capacity expansion and its impact on market structure. For the purpose of our work, the closest approach to ours is that followed by Cremer and Laffont (2002) who examine the possibility of building "excess" capacity in order to mitigate local market power. They obtain results that are not unambiguous although their main focus is on cases where excess capacity arises.

The work reported in this dissertation builds on the results obtained in Cremer and Laffont (2002) and generalizes their framework by enlarging the set of instruments that can be used to control regional market power. The question of interest is then what types of policies, including imports, are to be implemented by network operators concerned by the exercise of market power by incumbent local monopolies. The first chapter of this dissertation considers a sample of such policies and analyzes their impact on the natural gas transport network. The basic theoretical setting used to analyze this issue consists of a local market dominated by a single firm linked to a competitive market by a transport line. Gas produced in the competitive market at some relatively low marginal cost can be imported to the regional market through the transport line.

The capacity of this line is under the control of the network owner/operator whose objectives are assumed to coincide with those of a social planner. Within this basic framework, capacity control can be motivated in two ways. First, it can act as a remedy to any possible productive inefficiency due to the incumbent monopolist's use of a low efficiency technology by allowing for access to a more efficient source of natural gas. Second, by the very fact that the building of capacity allows to import cheaper gas into the regional market, competitive pressure can be put on the local firm in order to mitigate the exercise of its market power and hence to alleviate the allocative inefficiency it entails.

In addition to capacity, the analysis introduces the possibility for the social planner to set price and use transfers between consumers and the firm. However, price control and transfers are both intended to exclusively deal with the allocative inefficiency associated with the exercise of market power. Our main goal then is to study the degree to which transport capacity and the two alternative control instruments substitute or complement each other as instruments to maximize social welfare in this second-best environment. We examine this substitutability relationship both for a fixed and a variable set of control instruments available to the network operator.

A necessary first step in our investigation is to assume complete information. With no information problems, one would expect capacity to be a substitute to the other control instruments used by the social welfare maximizing network operator, that is, the absence of one of them would imply that capacity is more intensively used. To investigate this conjecture, we define three control schemes that differ in the set of instruments available to the social planner. We start from a situation where the social planner has three control instruments, namely, transfers, price (or equivalently output), and capacity, and then restrain the available instruments to price and capacity only, and finally to capacity only.[10]

Comparing the levels achieved by the endogenous variables in the three control schemes, we show that this conjecture does not hold in general. This type of analysis allows us to investigate the incentives of a social planner to develop transport infrastructure in order to fight market power. In our framework, we find that the incentives of the social planner to build infrastructure capacity depend on the available control instruments, how relatively inefficient the regional firm is, whether there is indeed a fixed cost of this firm to be financed, the cost structure of the capacity building activity, and how costly raising public funds through taxation is.

In the first chapter of the dissertation, we analyze the interaction among control instruments under the admittedly strong assumption of complete information. A natural extension is then to introduce incomplete information, and this is undertaken in the second chapter of the dissertation. There are various ways to incorporate information incompleteness in our framework. In this chapter, we introduce adverse selection by assuming that the local monopoly privately knows its

10. When capacity is the only available instrument to the social planner, we are in a framework similar to that of a mixed oligopoly model with a Stackelbeg leadership given to the social planner. See Merill and Schneider (1966), Cremer et al. (1989 and 1991), and De Fraja and Delbono (1989) for models of this type. More particularly, De Fraja and Delbono (1989) show that the presence of a publicly-owned welfare maximizing enterprise can be seen as a direct regulatory instrument to maximize social welfare if the market is not competitive enough.

marginal cost and that the regulator has only some beliefs on it described by a probability that it takes on either a low or a high value.

We then investigate how asymmetric information affects capacity planning for a given control scheme. In this incomplete information framework, the appropriate benchmark is a scheme in which the network operator sets the levels of the regulatory instruments in a sequential way under uncertainty. More specifically, we assume that the network operator first chooses the transport capacity of the network and then sets the remaining control variables, i.e., price and transfers (if he is allowed to do so), with the additional assumption that when deciding on the network capacity, the operator is uncertain about the level of the firm's marginal cost (and hence he maximizes expected social welfare where the expectation is taken with respect to the distribution of the firm's marginal cost). The optimal level of capacity achieved under this benchmark control scheme is then compared to that obtained under a regulatory scheme with asymmetric information. The key feature of this regime that differentiates it from the benchmark is that, at the time of setting price and transfers (if available), the regulator must offer an *incentive compatible* contract to the firm.

In the case where the network operator controls capacity, price, and transfers, we obtain that asymmetric information leads to a size of the transport network that is unambiguously larger or equal to that under the benchmark. When transfers are not available, it turns out that the impact of information incompleteness on capacity planning is not unambiguous and we identify the region of the parameters of the model in which asymmetric information calls for "excess" or "less" capacity. When the network operator sets capacity only, since we assume that the local monopoly maximizes profits, the firm's incentive compatibility constraint is trivially satisfied, and then capacity is unaffected by asymmetric information in this scenario. In this case, we explore the effect on capacity of the regulator's ability to commit to investments in the transport network.

In the first two chapters of the dissertation, we analyze the role of transport capacity as an instrument available to the regulator to mitigate the effect of gas suppliers' market power. In the third chapter we take a step further and study the case where, because of an advanced liberalization process, the regulator looses the possibility of itself building transport capacity. Since the natural gas industry combines activities with natural monopoly characteristics (pipeline transport and distribution) with those that are potentially competitive (production and commodity supply), it is natural to see a combination of regulation of price and non-price behavior coexisting with competition.[11]

More specifically, we study the case where transport capacity is provided by a vertically separated private firm (upstream) and used in the commodity gas market by a trading agent, the marketer (downstream), which competes in quantities with an incumbent firm. However, since pipeline transportation and distribution have natural monopoly characteristics, regulation of price and non-price behavior is required. In this first exercise, we focus on the impact of the regulation of the upstream transport charge on the competitive performance of the downstream gas commodity market.[12]

We assume that a perfectly informed regulator sets the transport charge taking as given competition in output between an incumbent and the marketer in a downstream gas commodity market. The outcome of the downstream firms' interaction is synthesized by generic equilibrium output responses to changes in the transport charge. We then apply this general setting to specific forms of market conduct with a varying degree of competition, namely, no competition, Stackelberg competition, Cournot competition, and competition exercised by a fringe of gas traders. Once we have studied the impact of price regulation on the alternative downstream equilibria considered, we proceed to perform a comparative analysis of the optimal transport charge policies with the objective of assessing their relative welfare performance by means of simulations. While the simulations confirm the general wisdom that more competition is preferred to less from the consumers and the social welfare points of view, they also show some less expected results about the ordering of key policy variables, such as the capacity of pipelines and its price, across different competitive scenarios that reveal some redistribution conflicts.

11. The UK industry is a good illustration of this coexistence (see Waddams Price,1997).

12. See Smeers and Wei (1999) for a similar exercise performed in the electricity industry. The timing of events we use is the one assumed by these authors, but we follow a simplified approach that allows us to perform some ex-post welfare analysis.

The work undertaken in this dissertation has brought to surface a whole set of open questions to be investigated in the near future. The results obtained so far in our simple industry configuration have shown that transport capacity plays a major role in the shaping of the industry. Indeed, it affects its horizontal structure, its regional developments, and its degree of vertical integration. Adequate regulation is crucial for the networks to follow an “optimal” expansion path and to be financially viable, and for the capacity building activity to be efficient.[13] Concerning the latter, an immediate extension of the model considered in the third chapter consists in introducing in the regulator-transporter relationship the assumption that the transporter is privately informed about some cost parameter. One would expect this asymmetry of information to have an important impact on the capacity pricing schedules and hence on the functioning of the downstream market. Our model can also be used to analyze the role of temporary initiatives such as *gas-release* measures. Under gas release programs, the incumbent in the downstream gas commodity market is mandated to release a share of its supply, i.e., long-term contracts, to its competitors. In effect, these measures are short-term substitutes to investments in capacity and hence could foster effective competition in the short run.

13. An example that shows how an excessive regulation could hinder the development of gas infrastructure was recently given by the Federal Energy Regulatory Commission (FERC) in the US. The obligation of open access to newly constructed LNG-receiving terminals had to be relaxed, as major companies argued that they could not justify building new LNG terminals if they could not also control the shipments through the plants.

Chapter 1

Controlling regional monopolies in the natural gas industry

1.1 Introduction

Following the US and the UK that reformed their natural gas industries in the late 70s and the 80s respectively, the EU has launched in the late 90s structural policies for enhancing gas-to-gas competition with the objective of complete liberalization of the market by 2007. More recently, EU Member States have been heavily investing in the development of their pipeline networks and Liquefied Natural Gas (LNG) liners. Such investments can be seen as driven by the need to anticipate growth of demand and import dependency. Indeed, gas penetration in energy consumption across activities in Europe has increased from less than 10% in the 70s to a current level of about 25% with an external dependency around 50%.[1] Still, some observers have come to wonder whether such large-scale investments in capacity expansion are all that needed (see, e.g., Junola, 2003).

Since bringing the benefits of competition to consumers is a stated goal of the EU gas directive adopted in 1998 and amended in 2003, and given the high concentration of both commodity supply and transport in the EU region, it makes sense to investigate the role of network investments in the liberalization process.

1. Algeria, Norway, and Russia are the main suppliers for Europe.

An issue that is particularly important in the European context is the nature of policies that should accompany this liberalization process and their effectiveness in mitigating the economic distortions that would result from the working of a competition that is going to be at best imperfect, at least in the foreseeable future. This chapter considers a sample of fiscal-, pricing-, and investment-type policies in the polar case where a social planner is concerned with the exercise of market power by a regional monopoly in the commodity gas market. We analyze the degree to which these alternative policies are substitutes to each other as instruments to lessen the effect of market power with a particular emphasis on the role of network transport capacity.[2]

The impact of transport capacity on market structure and market power in energy has drawn the attention of both empirical and theoretical economists. For the case of the US gas industry, a large empirical literature has examined the impact of investments in sub-network interconnection on the degree of market integration and the level of competition (Doane and Spulber, 1994, and De Vany and Walls, 1994). From a more theoretical perspective, in electricity, one line of literature has directly examined the impact of transmission capacity on local market power (Borenstein et al., 2000, Léautier, 2001) reaching the conclusion that transmission link expansion is effective for promoting competition. Building on a framework developed in Cremer et al. (2003), Cremer and Laffont (2002) argue that countering local market power in the natural gas industry might necessitate building "excess" transport capacity. The purpose of this chapter is to further investigate the relationship between network size and regional market power.

At this initial stage of the investigation, our analysis assumes away information problems.[3] We consider a social planner who has complete information on demand and technology and the objective of controlling an incumbent monopoly in a regional commodity gas market potentially by means of three instruments: transfers between consumers and the firm, pricing of the gas commodity, and investment

2. It is worth mentioning here that the issue of fighting market power due to geographic isolation and the role of communications/transport means should not be unique to gas markets and more generally to network industries.

3. In Gasmi et al. (2003) we have used a similar approach as here to study the control of regional market power under the assumption that there is no productive inefficiency.

in capacity of the transport network. We initially assume that the social planner indeed disposes of these three instruments of control. Then, we restrict the set of available instruments by successively removing transfers and price from this set. As this set of control instruments gets reduced, one expects the social planner to intensively rely on the remaining instruments to fight monopoly power. Hence, fulfilling this objective without the ability to use transfers and to control price can be expected to require a strictly higher level of transport capacity. Testing this conjecture is the main motivation for this research and this leads us to analyze the optimal policies under the alternative control regimes and compare the levels of capacity they prescribe. We find that these comparisons are not unambiguous and we produce a characterization of the conditions under which control of regional monopoly power requires "over"- ("under") - sizing the transport network. This close examination of optimal dimensioning of networks yields some insights on the social planner's incentives to invest in infrastructure in increasingly liberalized markets.

The plan of the chapter is as follows. The next section describes the model of the industry configuration we consider and its basic theoretical ingredients. Sections 1.3, 1.4, and 1.5 characterize the optimal policies under three control regimes, respectively, one that lets the social planner have the largest set of instruments, namely, transfers, price, and capacity, one in which transfers are not allowed, and one in which the social planner controls only the capacity of the transport network. The optimal policies are illustrated using some specific functional forms for the demand and cost functions. Section 1.6 focuses on the capacity variable and provides a systematic comparison of the optimal levels achieved under each of the three control regimes. This section also presents the results of some simulations that allow us to perform comparisons of capacity levels in cases where closed-form solutions couldn't be obtained. We summarize our main findings, discuss some of their policy implications, and give some directions for further research in the conclusion. Formal proofs and background material for the simulation results presented in section 1.6 are given in the appendix.

1.2 Industry configuration

Consider a regional natural gas commodity market, market M, supplied by a single incumbent firm, firm m, producing with a technology $C_m(q_m) = \theta q_m + F_m$, where q_m is output, θ is marginal cost, and F_m is fixed cost.[4] Gas is also supplied at marginal cost c in a competitive market, market C_p, which is geographically distinct from market M but could be linked to it if a pipeline of capacity K is built at cost $C(K)$, where $C(\cdot)$ is increasing convex, $C'(0) = 0$, and $C''(0) > 0$. See Figure 1.1. We assume that the regional monopoly's marginal cost is at least as large as that at which gas is produced in market C_p, i.e., $\theta \geq c$. Gas produced under competitive conditions in this market C_p and imported into the regional market M should counter the exercise of monopoly power by the firm in its "local" commodity gas market.

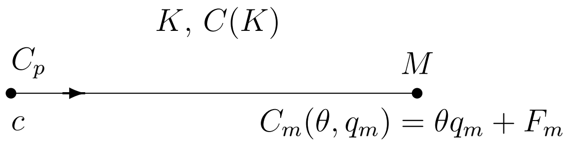

Figure 1.1: Industry configuration

Our analysis rests, indeed, on the presumption that the very reason for a social planner to support a policy of building a transport line that links these two markets is to allow imports of gas from market C_p into market M that would bring consumers in this market the benefits of competition. Letting $Q_M(\cdot)$ represent these consumers' demand function which is assumed to be downward-slopping and concave, if a quantity of gas corresponding to full capacity of the pipeline K is shipped from the competitive market into the regional market, the firm remains a monopoly on the residual demand $Q_M(p_M) - K$, where p_M is price.

We assume that the social planner knows the demand and cost functions $Q_M(\cdot)$ and $C_m(\cdot)$ and proceed to characterize the prescriptions of policies that he may use to restrain the firm from exerting its monopoly power in the regional market M, most importantly the policy of interconnecting this market and the competitive

4. We assume that the fixed cost F_m is bounded and later provide a technical justification for this assumption. Even though shutting down the firm is sometimes prescribed by the optimal policies considered in this chapter, the financing of this fixed cost is always accounted for.

market C_p. This public intervention is implemented under a second-best framework in which public funds are raised through distortionary taxes at social cost of $\lambda > 0$. We observe that since in the industry configuration considered here all demand takes place in the regional market, any pricing policy that is implemented in this market wouldn't affect welfare in the competitive market where price is at the first-best level (marginal cost c). Hence, without loss of generality, we do not incorporate welfare in this competitive market into the analysis.[5]

We start from a situation where the social planner has the ability to control the regional monopoly by means of three instruments, namely, (possibly two-way) transfers between consumers and the firm, price, transport capacity of the network, and hence monopoly output. We then restrict the set of available control instruments. We first consider the case where the social planner may not use transfers when he sets the price and capacity levels. Then, we examine the situation where in addition to the fact that transfers are not allowed, the social planner can only affect the gas commodity price in the regional market through transport capacity and the firm exerts its residual monopoly power.

1.3 Controlling the regional monopoly with transfers, price, and transport capacity

In this section, we assume that the social planner may use public funds to make transfers between consumers and the firm. These funds are raised through taxation that generates welfare losses and hence, a monetary transfer to the firm T costs society $(1+\lambda)T$ where λ is the cost of public funds. Let $S(\cdot)$ represent gross surplus of consumers in market M. Total supply of gas $Q_M(p_M)$ in this market, composed of K units imported from the competitive market and q_m units produced locally

5. Another factor that is also neglected in the analysis without affecting its main qualitative results is the marginal cost of transport. Alternatively, if marginal cost of transport is constant it can be included in the constant c, i.e., we may write $c = c_p + c_t$ where c_p is now the marginal cost of production in the competitive market and c_t is the marginal cost of transport.

by the firm, brings taxpayers an aggregate (net) welfare V given by

$$\begin{aligned} V = \; & \{S(Q_M(p_M)) - p_M Q_M(p_M)\} \\ & + \{(1+\lambda)\left[(p_M - c)K - C(K)\right]\} - \{(1+\lambda)T\} \end{aligned} \tag{1.1}$$

This taxpayers' welfare comprises the net surplus of consumers in the regional market M, the social valuation of profits generated by the K units of gas imported from the competitive market, and the social cost of the transfer T made to the firm. The latter's welfare is measured by its utility U that sums its profits from sales and the transfer it receives:

$$U = \{(p_M - \theta)\left[Q_M(p_M) - K\right] - F_m\} + T \tag{1.2}$$

When controlling the regional monopoly, the social planner has to account for the participation constraint of the firm and the constraint of nonnegativity of its output:[6]

$$U \geq 0 \tag{1.3}$$

$$q_m = Q_M(p_M) - K \geq 0 \tag{1.4}$$

The utilitarian social welfare function W is the sum of taxpayers' welfare V and firm's utility U. Substituting for V from (1.1) and for T from (1.2) yields social welfare

$$\begin{aligned} W = \; & \{S(Q_M(p_M)) + \lambda p_M Q_M(p_M) \\ & - (1+\lambda)\left[\theta(Q_M(p_M) - K) + cK + C(K) + F_m\right]\} - \lambda U \end{aligned} \tag{1.5}$$

as the social valuation of total production minus its social cost, minus the social opportunity cost of the firm's utility. From this expression of social welfare we see that reducing the monopoly's utility is socially desirable for this utility includes a transfer of public funds collected through distortive taxation (see (1.2)). Similarly,

6. The output nonnegativity constraint needs to be taken into account here because transfers T (here unconstrained in sign and magnitude) can be used to finance any fixed cost that wouldn't be recovered through revenues from gas.

we see from (1.5) that the social valuation of total production explicitly includes the fiscal value of the revenues that it generates $\lambda p_M Q_M(p_M)$.[7]

With transfers, monopoly output, and capacity as instruments of control, the social planner's program consists in maximizing social welfare W given by (1.5) with respect to p_M, K, and U, under the firm's participation and output non-negativity constraints, respectively (1.3) and (1.4).[8] Letting ϕ and ν denote the Lagrange multipliers associated with these two constraints respectively, and using the fact that $\frac{\partial S(Q_M)}{\partial Q_M} = p_M$, the following first-order conditions obtain:[9]

$$\lambda Q_M + (1+\lambda)(p_M - \theta) Q'_M + \nu Q'_M = 0 \tag{1.6}$$

$$(1+\lambda)\left[(\theta - c) - C'(K)\right] - \nu = 0 \tag{1.7}$$

$$-(\lambda - \phi) = 0 \tag{1.8}$$

$$\phi U = 0 \tag{1.9}$$

$$\nu\left[Q_M - K\right] = 0 \tag{1.10}$$

From (1.8) and (1.9), we immediately see that the participation constraint is binding, i.e., $U = 0$ and, indeed, transfers allow the social planner to totally extract (finance) the firm's profit (deficit). Letting $\varepsilon(Q_M)$ designate the price-elasticity of demand in market M, the first-order conditions (1.6)-(1.10) allow us to state the following proposition:

Proposition 1.1 *When price (or equivalently output) and capacity are both controlled by the social planner, and the latter can use public funds to make transfers between consumers and the firm, optimal price and capacity are characterized as follows, according to whether or not there is a marginal-cost gap between the regional and competitive markets.*

The no-cost-gap case: When $\theta - c = 0$, no capacity is built ($K = 0$), regional

7. Indeed, these revenues allow the government to rely less on public funds raised through taxation at a deadweight loss.

8. Note that as long as the social planner controls monopoly output and transport capacity, he totally controls price in market M.

9. To minimize notation, the arguments of some of the demand and cost functions will be dropped in the presentation.

demand is entirely met by the local monopoly ($q_m = Q_M$, $\nu = 0$), and the optimal price satisfies:

$$\frac{p_M - \theta}{p_M} \left(= \frac{p_M - c}{p_M}\right) = \frac{\lambda}{1+\lambda} \frac{1}{\varepsilon(Q_M)} \tag{1.11}$$

The cost-gap case: *When $\theta - c > 0$, one of two following policies (K, p_M, ν) arises:*

(i) The policy $(0 < K < Q_M, p_M > \theta, \nu = 0)$ in which the local monopoly meets part of the market demand and the optimal price and capacity satisfy

$$\frac{p_M - \theta}{p_M} \left(= \frac{p_M - (c + C'(K))}{p_M}\right) = \frac{\lambda}{1+\lambda} \frac{1}{\varepsilon(Q_M)} \tag{1.12}$$

$$(1+\lambda)C'(K) = (1+\lambda)(\theta - c) \tag{1.13}$$

(ii) The policy $(K = Q_M, p_M > c, \nu > 0)$ in which the local monopoly is shut down and market demand is entirely met through imports. The markup of the import activity is given by

$$\frac{p_M - (c + C'(Q_M))}{p_M} = \frac{\lambda}{1+\lambda} \frac{1}{\varepsilon(Q_M)} \tag{1.14}$$

Under policy (i), the condition $0 < (\theta - c) < C'(Q_M)$ holds, i.e., the firm's marginal cost, θ, is smaller than the marginal cost of imports when the latter meet the entire market demand, $c + C'(Q_M)$. Under policy (ii) the reverse is true.

Note that, thanks to the availability of transfers, the policies described in Proposition 1.1 are not responsive to the value of the fixed cost, F_m. From equations (1.11), (1.12), and (1.14) we see that pricing obeys a Ramsey principle according to which the price markup is inversely proportional to the price-elasticity of demand in the regional market.[10] When $\nu = 0$, i.e., when the local monopoly is active, it is indeed optimal to let it apply a markup (see (1.11) and (1.12)) since

10. Note that here the coefficient of proportionality is a function of λ and hence, in contrast to the standard Ramsey formulas, is exogenous.

public funds are costly and the social planner can use transfers to capture this markup. As to capacity, it is set such that the social marginal cost of imports, $(1+\lambda)[c+C'(K)]$, is equal to the social marginal cost of local production, $(1+\lambda)\theta$, a relationship that can be seen from (1.13). When $\nu > 0$, i.e., when the firm is shut down, its fixed cost is financed through transfers and there is still a markup but now the relevant marginal cost is that of imported gas (see (1.14)).

To get the reader familiar with the resolution approach we adopt in the rest of the analysis, let us implement it in the context of the control scheme of reference considered in this section. To study the solution to the system of first-order conditions (1.6)-(1.10), we proceed in two steps. First, we consider the unconstrained maximization program (maximization of (1.5)) in the capacity-price (K-p_M) space, and then we introduce the firm's output nonnegativity constraint (1.4).[11]

An unconstrained welfare maximizing capacity-price pair satisfies the following first-order conditions[12]

$$\lambda Q_M + (1+\lambda)\left(p_M - \theta\right) Q'_M = 0 \tag{1.15}$$

$$(1+\lambda)\left[(\theta - c) - C'(K)\right] = 0 \tag{1.16}$$

For the social welfare function (1.5), $sign[\frac{\partial^2 W}{\partial K \partial p_M}] = 0$, which says that the social marginal valuation of capacity remains unaffected by changes in the regional market price.[13] Hence, in the K-p_M space, the first-order condition with respect to price (1.15) can be represented by a line parallel to the K-axis at the price level $p_M = \theta - \frac{\lambda}{(1+\lambda)} \frac{Q_M}{Q'_M}$.[14] Similarly, the first-order condition with respect to capacity (1.16) is a line parallel to the p_M-axis at the capacity level K such that

11. Since $U = 0$, we can ignore the firm's participation constraint (1.3).

12. The welfare function given in (1.5) will be strictly concave if, for any capacity-price pair, the condition $(1+\lambda)C''(K)\left[(1+2\lambda)Q'_M + (1+\lambda)(p_M-\theta)Q''_M\right] < 0$ holds. As we assume both $C''(K) > 0$ for any $K \geq 0$ and a concave downward-sloping demand schedule, provided $(p_M - \theta) \geq 0$, the former condition is always satisfied. Thus, the optimal price and capacity levels are not only local but also global interior welfare maximizers.

13. For a general convex firm's cost function, $sign[\frac{\partial^2 W}{\partial K \partial p_M}] = sign[(1+\lambda)C''_m Q'_M]$ which is either negative or zero.

14. Strict concavity of the social welfare function (1.5) insures that this differential equation defines a unique line for nonnegative prices.

$(\theta - c) = C'(K)$, i.e., at $K = C'^{-1}((\theta - c))$.[15] The unique solution to the system constituted of the two equations (1.15) and (1.16) corresponds then to the intersection of these two lines.

Next, the *nonnegativity set* defined by the constraint (1.4) has a boundary which is decreasing and concave with slope $\frac{1}{Q'_M}$ in the K-p_M space. If the capacity-price pair that solves (1.15) and (1.16) yields $q_m > 0$, and this will be the case if and only if

$$K = C'^{-1}((\theta - c)) < Q_M(p_M)\big|_{p_M = \theta - \frac{\lambda Q_M}{(1+\lambda)Q'_M}}, \tag{1.17}$$

then this pair will also be the solution of the constrained program of the social planner. In this case, total demand in market M cannot be met exclusively by imports K at the prevailing price. Otherwise, the solution to the constrained maximization program will be at the tangency point of a welfare level curve and the boundary of the nonnegativity set characterized by:[16]

$$-\frac{(1+\lambda)\left[(\theta - c) - C'(Q_M)\right]}{\lambda Q_M + (1+\lambda)(p_M - \theta)\, Q'_M} = \frac{1}{Q'_M} \tag{1.18}$$

To illustrate the resolution of this three-instrument control scheme, let us consider the case where demand is linear and the technology of capacity building is quadratic. More specifically, let

$$Q_M(p_M) = \gamma - p_M, \quad C(K) = \frac{\omega}{2}K^2; \quad \gamma, \omega > 0, \quad \gamma > c \tag{1.19}$$

With these functional forms, the first-order condition with respect to price (1.15) is a horizontal line crossing the p_M-axis at $p_M = \theta + \frac{\lambda}{(1+2\lambda)}(\gamma - \theta)$, whereas that with respect to capacity (1.16) is a vertical line crossing the K-axis at $K = \frac{(\theta - c)}{\omega}$. See Figures 1.2a and 1.2b. The shaded areas correspond to the set defined by the local monopoly output nonnegativity constraint (1.4), which here is the set of (K, p_M) pairs such that $K + p_M \le \gamma$.

15. Note that since C' is increasing convex, its inverse exists.

16. Given our demand and capacity building cost assumptions, second-order conditions are always satisfied.

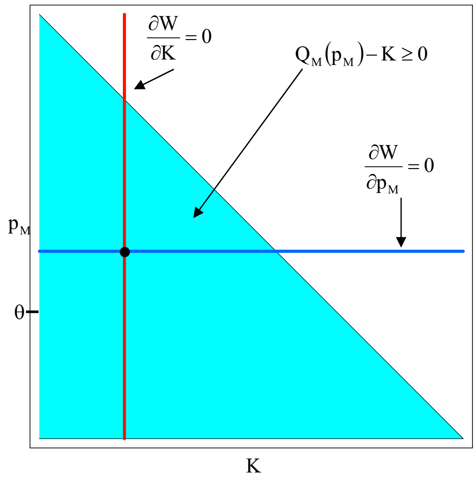

Figure 1.2a: Interior solution

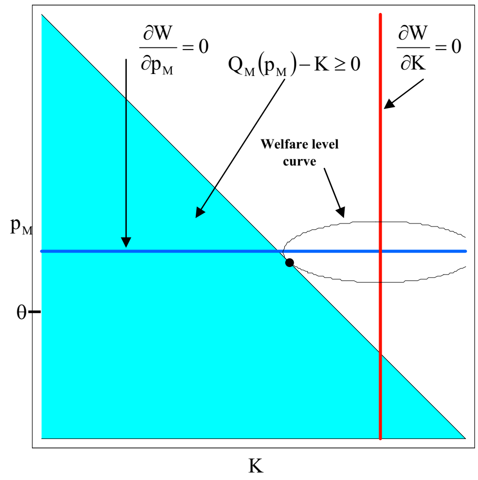

Figure 1.2b: Boundary solution

When (1.17) holds, we obtain the interior solution to (1.6)-(1.10) as the intersection of the two lines shown in Figure 2a. More specifically, when

$$0 \leq (\theta - c) < \left[\frac{\omega(1+\lambda)}{(1+2\lambda)+\omega(1+\lambda)}\right](\gamma - c) \tag{1.20}$$

the (interior) solution is

$$K = \frac{(\theta - c)}{\omega} \tag{1.21}$$

$$p_M = \theta + \left[\frac{\lambda}{1+2\lambda}\right](\gamma - \theta) \tag{1.22}$$

When $\theta - c = 0$, this solution with θ replaced by c corresponds to that described in the no-cost-gap case of Proposition 1.1. When $\theta - c > 0$, it corresponds to policy (i) of the cost-gap case in the proposition. When (1.17) does not hold, the boundary solution at the tangency point shown in Figure 2b is obtained. More specifically, when

$$\left[\frac{\omega(1+\lambda)}{(1+2\lambda)+\omega(1+\lambda)}\right](\gamma - c) \leq (\theta - c) < (\gamma - c) \tag{1.23}$$

this boundary solution is

$$K = \left[\frac{1+\lambda}{(1+2\lambda)+\omega(1+\lambda)} \right] (\gamma - c) \tag{1.24}$$

$$p_M = c + \left[\frac{\lambda+\omega(1+\lambda)}{(1+2\lambda)+\omega(1+\lambda)} \right] (\gamma - c) \tag{1.25}$$

This solution corresponds to policy (ii) of the no-cost-gap case described in Proposition 1.1.

1.4 Controlling the regional monopoly with price and capacity only

In this section, we assume that the social planner can still set the transport capacity and the firm's output level, and hence fully controls price in market M, but transfers between consumers and the firm are no longer permitted. Social welfare W is now expressed as

$$\begin{aligned} W = \ & \{S(Q_M(p_M)) - p_M Q_M(p_M)\} \\ & +\{(1+\lambda)\left[(p_M - c)K - C(K)\right]\} \\ & +\{(p_M - \theta)\left[Q_M(p_M) - K\right] - F_m\} \end{aligned} \tag{1.26}$$

that is, as the sum of the net consumer surplus, the social value of the profits generated by the K units imported from the competitive market, and the profits of the firm that now cannot be transferred to consumers. Gathering terms, we obtain

$$\begin{aligned} W = \ & S(Q_M(p_M)) + \lambda p_M K \\ & - \left[\theta(Q_M(p_M) - K) + F_m\right] - (1+\lambda)\left[cK + C(K)\right] \end{aligned} \tag{1.27}$$

Cross-examining (1.5) and (1.27), we see that as now transfers are not allowed, the social planner assigns a fiscal value $\lambda p_M K$ only to the revenues generated by the K units shipped from the competitive market C_p into the regional market M.

The social planner maximizes social welfare given by (1.27) with respect to price and capacity, under the participation constraint (nonnegativity of profits) that now does not include transfers, and the firm's output nonnegativity constraint

$$\Pi_m = (p_M - \theta)\left[Q_M(p_M) - K\right] - F_m \geq 0 \tag{1.28}$$

$$q_m = Q_M(p_M) - K \geq 0 \tag{1.29}$$

Given that transfers are not allowed, it makes sense for us to consider only the policies with $p_M \geq \theta$ when the firm is active. When there is a strictly positive fixed cost, i.e., $F_m > 0$, the firm will always be active. When there is no fixed cost, i.e., $F_m = 0$, cases where the firm is shut down may (and actually do) arise. In such cases, because the social planner does not face the concern of financing a fixed cost, the relevant constraint is (1.29). In order then to rule out irrelevant solutions with a negative margin ($p_M < \theta$), we assume that when $F_m = 0$, the marginal cost gap is not too high, so that[17]

$$0 \leq (\theta - c) \leq C'(Q_M) - \frac{\lambda}{1+\lambda}\frac{Q_M}{Q'_M} \tag{1.30}$$

Hence, from now on, we focus on the set defined by the participation constraint (1.28) hereafter referred to as the *participation set*.

Letting ϕ denote the Lagrange multiplier associated with the participation constraint, the system of first-order conditions that characterize the optimal policy is

$$\lambda K + (p_M - \theta)\, Q'_M + \phi\left[(p_M - \theta)\, Q'_M + (Q_M - K)\right] = 0 \tag{1.31}$$

$$(1+\lambda)\left[(\theta - c) - C'(K)\right] + (\lambda - \phi)\,(p_M - \theta) = 0 \tag{1.32}$$

$$\phi\left[(p_M - \theta)\,(Q_M - K) - F_m\right] = 0 \tag{1.33}$$

$$(p_M - \theta)\,(Q_M - K) - F_m \geq 0 \tag{1.34}$$

To rule out the possibility of having $K < 0$ when $F_m > 0$ we assume that the fixed

17. This constraint on the value of the marginal cost gap is not needed as long as the fixed cost is arbitrarily far away from zero.

cost is bounded so that

$$F_m \leq -\frac{\lambda Q_M^2 + \left[(1+\lambda)(\theta - c)Q'_M + \sqrt{G}\right] Q_M}{2(1+\lambda)Q'_M} \tag{1.35}$$

where $G \equiv [\lambda Q_M + (1+\lambda)(\theta - c)Q'_M]^2 - 4(1+\lambda)^2(\theta - c)Q_M Q'_M$.[18]

For the purpose of analyzing the solution to (1.31)-(1.34) in the K-p_M space, we first consider the unconstrained maximization program and then introduce the participation set. An unconstrained welfare maximizer capacity-price pair satisfies the following first-order conditions:

$$\lambda K + (p_M - \theta)\, Q'_M = 0 \tag{1.36}$$

$$(1+\lambda)\,[(\theta - c) - C'(K)] + \lambda(p_M - \theta) = 0 \tag{1.37}$$

Second-order conditions for such an unconstrained local social welfare maximizer are synthesized by

$$\frac{\lambda Q'_M}{\lambda K Q''_M - {Q'_M}^2} < \frac{(1+\lambda)C''(K)}{\lambda} \tag{1.38}$$

18. This upper-bound is obtained as follows. When $F_m > 0$, we look for the conditions characterizing a policy of the type $(0, p_M > \theta, \phi > 0)$. Substituting for $K = 0$ in the system of first-order conditions (1.31)-(1.33), we see that such a policy is defined by

$$\phi = \lambda + \frac{(1+\lambda)(\theta - c)Q_M}{F_m} \quad \text{and} \quad \phi Q_M + \frac{(1+\phi)F_m Q'_M}{Q_M} = 0.$$

Solving for F_m, yields the right-hand side term of the inequality (1.35). It is easy to see that any F_m smaller than this term will indeed yield $K > 0$. Moreover, it can be shown that (1.35) implies $F_m \leq -\frac{Q_M^2}{Q'_M}$, which is a condition that insures that the participation set be nonempty for nonnegative values of K. The latter condition is derived as follows. For the participation set to be nonempty for $K \geq 0$ it suffices that the largest K that makes the participation constraint binding be nonnegative. Such a K is found by solving the following program:

$$\begin{aligned} \max_{p_M, K} \quad & K \\ s.t. \quad & (p_M - \theta)\,[Q_M(p_M) - K] - F_m = 0 \\ & K \geq 0 \end{aligned}$$

It is then easy to show that such a capacity level satisfies $\frac{Q'_M F_m + (Q_M - K)^2}{F_m} \leq 0$. Now, if this inequality holds for $K = 0$, it will clearly hold for any $K > 0$.

Observe that, for the welfare function (1.27), $sign[\frac{\partial^2 W}{\partial K \partial p_M}\ (= \lambda)] > 0$.[19] Hence, under this control scheme without transfers, the social marginal valuation of capacity increases with the regional market price.

In the K-p_M space, provided that $Q_M''' \leq 0$ and $C'''(K) \geq 0$, the first-order condition with respect to price of the unconstrained program (1.36) can be represented by an increasing concave function, with slope $\frac{\lambda Q_M'}{\lambda K Q_M'' - {Q_M'}^2}$, which crosses the p_M-axis at $p_M = \theta$. Similarly, the first-order condition with respect to capacity (1.37) can be represented by an increasing convex function, with slope $\frac{(1+\lambda)C''(K)}{\lambda}$, which crosses the p_M-axis at $p_M = \theta - \frac{(1+\lambda)(\theta-c)}{\lambda} \leq \theta$. These two functions representing (1.36) and (1.37) cross at most twice for any K and at most once for $K > 0$.

Two situations might arise according to the value of the cost gap. With no cost gap ($\theta - c = 0$), (1.36) and (1.37) cross at $(0, c)$. This point is an unconstrained welfare maximizer if $\lambda^2 + (1+\lambda)C''(0)Q_M' < 0$. If $\lambda^2 + (1+\lambda)C''(0)Q_M' > 0$, an unconstrained welfare maximizer with $K > 0$ (located at a second crossing point) may exist if $Q_M' \left[C''(K) - \frac{C'(K)}{K}\right] - \frac{\lambda K}{Q_M'} Q_M'' C''(K) < 0$.[20]

With a cost gap ($\theta - c > 0$) and at $K = 0$, the increasing concave function representing (1.36) implies a strictly larger level of price than the one implied by the increasing convex function representing (1.37). Therefore, such functions are expected either to cross only once or not at all. It is straightforward to show that in the case they cross only once, the crossing point, which is a solution to (1.36)-(1.37), satisfies the second-order conditions (1.38) for the unconstrained welfare maximization program.

The participation set is a convex set in the K-p_M space when both $q_m \geq 0$ and

19. For a general convex cost function of the regional monopoly, $sign[\frac{\partial^2 W}{\partial K \partial p_M}] = sign[\lambda + C_m'' Q_M'] \gtreqless 0$. Therefore, in general the effect of an increase in the regional market price p_M on the social marginal valuation of capacity depends on the relative magnitude of λ. This shows the simplification that the specific cost function $C_m(\theta, q_m) = \theta q_m + F_m$ allows to achieve.

20. In particular, this second crossing point does not exist when (1.36) and (1.37) are represented by linear functions in the K-p_M space.

$p_M \geq \theta$. Its boundary has a slope m_{Π_m} given by

$$m_{\Pi_m} = \frac{p_M - \theta}{(Q_M - K) + (p_M - \theta)Q'_M} = \frac{F_m}{Q'_M F_m + (Q_M - K)^2} \tag{1.39}$$

for $F_m \geq 0$.[21] If the capacity-price pair that satisfies (1.36)-(1.38) belongs to the participation set, it will also be a solution to the constrained welfare maximization program. Otherwise, the constrained welfare maximizer is at a tangency point between a welfare level curve and the boundary of the participation set, characterized by:[22]

$$m_{\Pi_m}\Big|_{F_m \geq 0} = -\frac{(1+\lambda)\left[(\theta - c) - C'(K)\right] + \lambda(p_M - \theta)}{\lambda K + (p_M - \theta)\, Q'_M} \tag{1.40}$$

where $m_{\Pi_m}\Big|_{F_m=0} = \frac{1}{Q'_M}$ and $m_{\Pi_m}\Big|_{F_m>0} = \frac{F_m}{Q'_M F_m + (Q_M - K)^2}$, from (1.39).

The next proposition characterizes the alternative optimal pricing and transport capacity policies associated with this control scheme.

Proposition 1.2 *When price (or equivalently output) and capacity are both controlled by the social planner but the latter cannot use public funds to make transfers between consumers and the firm, the optimal price and capacity are characterized as follows.*

The no-cost-gap-no-fixed-cost case: When $(\theta - c) = 0$ and $F_m = 0$, there are two exclusive candidate optimal policies (K, p_M, ϕ):

(i) The policy $(K = 0, p_M = \theta = c, \phi = 0)$ which consists in building no capacity,

21. Note that when $K = Q_M$ and F_m goes to zero, by the L'hôpital rule, the second expression of m_{Π_m} in (1.39) goes to $\frac{1}{Q'_M}$.

22. The second-order conditions for this boundary solution are synthesized as

$$\begin{aligned}&\left[(1+\lambda)(Q_M - (1+\lambda)K)^2 C''(K)\right] Q'''_M \\ &- \left[\phi(Q_M - K) + \lambda K\right]\left[(2\phi^2 + 3\phi - 2\lambda)(Q_M - K) + \lambda(1+2\lambda)K\right] {Q'_M}^2 \\ &+ \left[\phi(Q_M - K) + \lambda K\right]^3 Q''_M \leq 0\end{aligned}$$

It is easy to see that this condition is satisfied whenever $F_m = 0$, as in this case the boundary solution yields $K = Q_M$.

setting price in the local market at marginal cost, and thus making the local monopoly just break even.

(ii) The policy $(0 < K \leq Q_M, p_M > \theta = c, \phi \geq 0)$ *which prescribes building capacity and setting price above marginal cost. This policy takes one of the two following forms:*

(a) The policy $(0 < K < Q_M, p_M > \theta = c, \phi = 0)$ *in which the local monopoly meets part of the market demand and makes positive profits. The markup of this monopoly takes the form*

$$\frac{p_M - \theta}{p_M} \left(= \frac{p_M - c}{p_M} \right) = \frac{\lambda K}{Q_M} \frac{1}{\varepsilon(Q_M)} \tag{1.41}$$

The import activity earns a markup given by

$$\frac{p_M - (c + C'(K))}{p_M} = \frac{\lambda}{1+\lambda} \frac{K}{Q_M} \frac{1}{\varepsilon(Q_M)} \quad , \tag{1.42}$$

and capacity obeys

$$(1+\lambda)C'(K) = -\lambda^2 \frac{K}{Q'_M} \tag{1.43}$$

(b) The policy $(K = Q_M, p_M > \theta = c, 0 < \phi < \lambda)$ *in which the local monopoly is shut down and the whole market demand is met through imports sold with a markup given by*

$$\frac{p_M - (c + C'(Q_M))}{p_M} = \frac{\lambda}{1+\lambda} \frac{1}{\varepsilon(Q_M)} \tag{1.44}$$

When λ *is low enough or the capacity building cost function is highly convex, so that the condition* $(1+\lambda)Q'_M C''(0) + \lambda^2 < 0$ *holds, policy (i) is the optimal policy. When this condition does not hold, e.g., for* λ *high enough, two situations might arise. When demand concavity and capacity cost convexity are such that* $Q'_M \left[C''(K) - \frac{C'(K)}{K} \right] - \frac{\lambda K}{Q'_M} Q''_M C''(K) < 0$*, policy (ii-a) is optimal and the social marginal cost of imports when they exclusively cover market demand,* $(1+\lambda)[c + C'(Q_M)]$*, net of the marginal fiscal revenue of imported gas,* λp_M*, is greater than* *the marginal cost of the firm, θ (in this case $\theta = c$). This condition is summarized by $C'(Q_M) + \frac{\lambda^2}{1+\lambda}\frac{Q_M}{Q'_M} > 0$. Optimality of policy (ii-b) calls for the reverse of at least one of these conditions.*

The no-cost-gap-with-fixed-cost case: *When $(\theta - c) = 0$ and $F_m > 0$, there are two exclusive candidate optimal policies (K, p_M, ϕ):*

(i) The policy $(K = 0, p_M > \theta = c, \phi = \lambda)$ which consists in building no capacity and letting the local monopoly earn a markup that makes it just break even:

$$\frac{p_M - \theta}{p_M} \left(= \frac{p_M - c}{p_M}\right) = \frac{\phi}{1+\phi}\frac{1}{\varepsilon(Q_M)} \left(= \frac{\lambda}{1+\lambda}\frac{1}{\varepsilon(Q_M)}\right) \tag{1.45}$$

(ii) The policy $(0 < K < Q_M, p_M > \theta = c, \phi \geq 0)$ which prescribes building capacity and setting price above marginal cost. This policy takes one of the two following forms:

(a) The policy $(0 < K < Q_M, p_M > \theta = c, \phi = 0)$, characterized by (1.41)-(1.43), in which the local monopoly meets part of the market demand and makes positive profits.

(b) The policy $(0 < K < Q_M, p_M > \theta = c, 0 < \phi < \lambda)$, in which the local monopoly makes a markup

$$\frac{p_M - \theta}{p_M} \left(= \frac{p_M - c}{p_M}\right) = \left[\frac{\lambda K + \phi(Q_M - K)}{(1+\phi)Q_M}\right]\frac{1}{\varepsilon(Q_M)}, \tag{1.46}$$

to just break even, the import activity earns a markup

$$\frac{p_M - (c + C'(K))}{p_M} = \left[\frac{\lambda K + \phi(Q_M - K)}{(1+\lambda)Q_M}\right]\frac{1}{\varepsilon(Q_M)}, \tag{1.47}$$

and capacity satisfies

$$(1+\lambda)C'(K) = \frac{J}{(Q_M - K)}, \tag{1.48}$$

where $J \equiv m_{\Pi_m} \times [\lambda Q_M(Q_M - K) + (1+\lambda)Q'_M F_m] > 0$, where m_{Π_m} is given by (1.39).

Under policy (i) the fixed cost F_m is equal to the highest variable profit level the regional monopoly can earn, $(p_M - \theta)Q_M$ $(= (p_M - c)Q_M)$, i.e., $F_m = -\frac{\lambda}{1+\lambda}\frac{Q_M^2}{Q_M'}$. When the fixed cost is not that large, i.e., when $F_m < -\frac{\lambda}{1+\lambda}\frac{Q_M^2}{Q_M'}$, only policies of type (ii) may arise. Provided that $Q_M'\left[C''(K) - \frac{C'(K)}{K}\right] - \frac{\lambda K}{Q_M'}Q_M''C''(K) < 0$, under policy (ii-a) the marginal cost of the regional monopoly, θ $(= c)$, is equal to the "net" social marginal cost of imports, $(1+\lambda)[c + C'(K)] - \lambda p_M$, and the firm's variable profits are larger than the fixed cost, i.e., $F_m < -\lambda K\frac{(Q_M - K)}{Q_M'}$. Under policy (ii-b) at least one of these conditions is reversed.

The with-cost-gap-no-fixed-cost case: *When $(\theta - c) > 0$ and $F_m = 0$, there are two exclusive candidate optimal policies (K, p_M, ϕ):*

(i) The policy $(0 < K < Q_M, p_M > \theta, \phi = 0)$ in which the local monopoly meets part of the market demand and makes positive profits. The pricing rule for this policy is described by (1.41) and (1.42), and the capacity building rule by

$$(1+\lambda)C'(K) = (1+\lambda)(\theta - c) - \lambda^2\frac{K}{Q_M'} \tag{1.49}$$

(ii) The policy $(K = Q_M, p_M \geq \theta, \phi > 0)$ in which the local monopoly is shut down and hence the whole market demand is met through imports. The pricing rule for this policy is given by (1.44).

If $Q_M'\left[C''(K) - \frac{C'(K)}{K}\right] - \frac{\lambda K}{Q_M'}Q_M''C''(K) < 0$, optimality of policy (i) is consistent with the condition $(\theta - c) < C'(Q_M) + \frac{\lambda^2}{1+\lambda}\frac{Q_M}{Q_M'}$. Under policy (ii) at least one of these two conditions is violated. The interpretation of these conditions is similar to that of the conditions obtained in the no-cost-gap-no-fixed-cost case.

The with-cost-gap-with-fixed-cost case: *When $(\theta - c) > 0$ and $F_m > 0$, there are two exclusive candidate optimal policies (K, p_M, ϕ):*

(i) The policy $(K = 0, p_M > \theta, \phi > \lambda)$ which consists in building no capacity and letting the local monopoly earn a markup that makes it just break even:

$$\frac{p_M - \theta}{p_M} = \frac{\phi}{1+\phi}\frac{1}{\varepsilon(Q_M)} \tag{1.50}$$

(ii) The policy $(0 < K < Q_M, p_M > \theta, \phi \geq 0)$ *which prescribes building capacity and setting price above marginal cost. This policy takes one of the two following forms:*

(a) The policy $(0 < K < Q_M, p_M > \theta, \phi = 0)$*, characterized by (1.41), (1.42), and (1.49).*

(b) The policy $(0 < K < Q_M, p_M > \theta, \phi > 0)$ *in which the pricing rule is characterized by (1.46) and (1.47), and the capacity building rule by*

$$(1+\lambda)C'(K) \quad = (1+\lambda)(\theta - c) + \frac{J}{(Q_M - K)} \ , \tag{1.51}$$

where J *is defined as in the policy (ii-b) of the no-cost-gap-with-fixed-cost case.*

Under policy (i) the fixed cost satisfies condition (1.35) with equality. Whenever (1.35) is satisfied with strict inequality only policies of type (ii) may arise. Policy (ii-a) corresponds to the case where $Q'_M \left[C''(K) - \frac{C'(K)}{K}\right] - \frac{\lambda K}{Q'_M} Q''_M C''(K) < 0$ *and* $F_m < -\lambda K \frac{(Q_M - K)}{Q'_M}$*. Policy (ii-b) corresponds to the case where either of these inequalities is reversed. These conditions have the same interpretation as those obtained in the case of no cost gap and positive fixed cost.*

From Proposition 1.2, we see that when the solution of the constrained welfare maximization program allows the monopoly to earn positive profits (see the cases with $\phi = 0$), the markup it makes is inversely related to the elasticity of demand and increases with the share of imports in the total consumption of gas in the regional market. The reason for this latter result is that the social marginal valuation of capacity increases with price. As to the markup made on imports, it is increasing with the share of these imports in total demand but it is less sensitive to it than the firm's markup. From the capacity building rule, we see that at the optimum the social cost of the marginal unit of gas shipped from the competitive market just $(1+\lambda)[c + C'(K)]$ net of the fiscal revenue of this imported gas unit, λp_M, equals the social cost of having this unit produced by the local monopoly, $\theta \geq c$.

When it is optimal to let the local monopoly active and just break even ($q_m > 0$ and $\phi > 0$), the markup made by the monopoly is again inversely related to the regional market demand elasticity. However, the proportionality term is the ratio of the fiscal valuation of the revenues from imports, $\lambda p_M K$, plus the valuation the planner assigns to the fact that revenues made by the firm help to relax the participation constraint, $\phi p_M q_m$, to the social valuation of the aggregate revenues in the regional market in the case where these revenues were exclusively generated by the firm, $(1+\phi)p_M Q_M$. The markup from imports has a similar structure but the denominator of the proportionality term is the social valuation of aggregate revenues in the case where total demand is met by imports, $(1+\lambda)p_M Q_M$.[23]

Under these zero-profit cases, optimal capacity makes the "net" social cost of the marginal unit of gas shipped from the competitive market, $(1+\lambda)[c + C'(K)] - \lambda p_M$, just equals the social cost of having this unit produced by the local monopoly, θ, net of the value the planner assigns to the contribution of this unit to the relaxation of the firm's participation constraint, $\phi(p_M - \theta)$. Indeed, these profits can no longer be collected by the planner as he now lacks the instrument that would allow him to do so.

The extreme case in which no capacity is built ($K = 0$) arises when either there is no fixed cost or it is too high. The behavior of price and capacity depends on whether or not $\phi = 0$ and its characterization is as described in the preceding paragraphs. The case where the local monopoly is shut down ($q_m = 0$ and $\phi > 0$), exclusively arises when there is no fixed cost. In this case, the relevant markup is the one made by the import activity and is identical to that derived for the scheme that allows the social planner to use transfers (see (1.14)).

Let us again examine the solution that obtains with the specific functional forms (1.19). In this case, the function representing the first-order condition of the unconstrained program (1.36) is a line of slope λ, while that representing (1.37) is a line of slope $\frac{\omega(1+\lambda)}{\lambda}$. From the second-order condition (1.38), the crossing point between these two lines is an unconstrained welfare maximizer if $\frac{\omega(1+\lambda)}{\lambda} > \lambda$, and this is so irrespective of the value of the fixed cost F_m.

23. This interpretation is obtained after multiplying the right-hand side expressions of (1.46) and (1.47) by $\frac{p_M}{p_M}$.

Let us now examine the participation set for the relevant region where $p_M \geq \theta$. In the no-fixed-cost case, $F_m = 0$, the boundary of this set is flat whenever $(p_M - \theta) = 0$ and will have a slope equal to -1 when $(p_M - \theta) > 0$, with $K = Q_M$ on this negatively-slopped portion of the boundary. Figures 1.3a and 1.3b illustrate these features. The shaded regions correspond to the participation set defined by (1.28). The upward-slopping lines represent the first-order conditions (1.36) and (1.37).

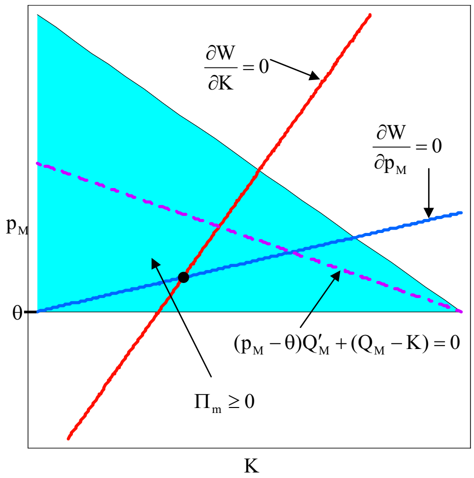

Figure 1.3a: Interior solution with $\omega(1+\lambda) - \lambda^2 > 0$

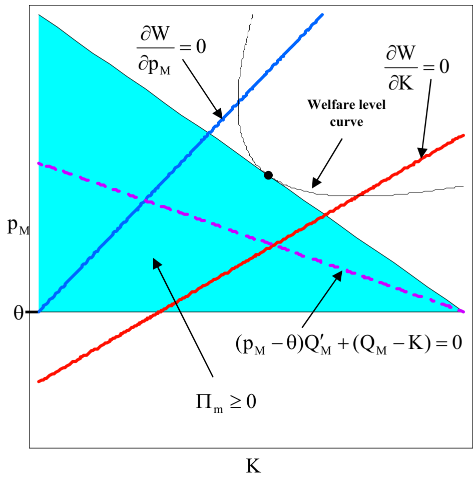

Figure 1.3b: Boundary solution with $\omega(1+\lambda) - \lambda^2 < 0$

Figure 1.3a sketches the case where the solution to the unconstrained program is also that of the constrained program. This solution, given by

$$K = \left[\frac{1+\lambda}{\omega(1+\lambda) - \lambda^2}\right](\theta - c) \tag{1.52}$$

$$p_M = c + \left[\frac{\lambda + \omega(1+\lambda)}{\omega(1+\lambda) - \lambda^2}\right](\theta - c)\ , \tag{1.53}$$

arises when both conditions

$$\omega(1+\lambda) - \lambda^2 > 0 \tag{1.54}$$

$$0 \leq (\theta - c) < \left[\frac{\omega(1+\lambda) - \lambda^2}{(1+2\lambda) + \omega(1+\lambda)}\right](\gamma - c) \tag{1.55}$$

hold. When $\theta - c = 0$, this solution corresponds to policy (i) of the no-cost-gap-no-fixed-cost case of Proposition 1.2. When $\theta - c > 0$, it represents policy (i) of the with-cost-gap-no-fixed-cost case stated in the proposition. Figure 1.3b represents the boundary solution characterized by (1.40). This solution is given by

$$K = \left[\frac{1+\lambda}{(1+2\lambda)+\omega(1+\lambda)}\right](\gamma - c) \tag{1.56}$$

$$p_M = c + \left[\frac{\lambda+\omega(1+\lambda)}{(1+2\lambda)+\omega(1+\lambda)}\right](\gamma - c)\ , \tag{1.57}$$

and arises when (1.54) and (1.55) do not hold, i.e., when[24]

$$\left[\frac{\omega(1+\lambda)-\lambda^2}{(1+2\lambda)+\omega(1+\lambda)}\right](\gamma - c) \leq (\theta - c) \leq \left[\frac{\lambda+\omega(1+\lambda)}{(1+2\lambda)+\omega(1+\lambda)}\right](\gamma - c) \tag{1.58}$$

When $\theta - c = 0$, this solution corresponds to policy (ii-b) of the case with no cost gap and no fixed cost in Proposition 1.2. When $\theta - c > 0$, it illustrates policy (ii) of the case with cost gap and no fixed cost in the proposition.

When turning to the case where $F_m > 0$, no closed-form solutions are obtained. Indeed, our analysis gets complicated by the fact that the shape of the participation set is sensitive to the size of the fixed cost. To understand the nature of this difficulty, it is useful to go back a moment to the case with no fixed cost and focus on the region defined by the first-order condition with respect to price (1.31). In both Figures 1.3a and 1.3b, the downward-slopping dashed line represents the (K, p_M) pairs such that $[(p_M - \theta)\, Q'_M + (Q_M - K)] = 0$. Given the geometric characterization of the first-order condition with respect to price of the unconstrained program (1.36), see Figures 1.3a and 1.3b, and provided that ϕ is nonnegative, it follows that the (K, p_M) pairs which satisfy (1.31) belong to the shaded regions in Figures 1.4a and 1.4b. For alternative values of the cost-gap $\theta - c$, we see from (1.32) that the solution of the constrained program lies on the bold segments shown in these figures.

24. Given that $(\theta - c)$ lies on the interval defined by (1.30), this condition is always satisfied when the reverse of inequality (1.54) holds, namely, when $\omega(1+\lambda) - \lambda^2 < 0$.

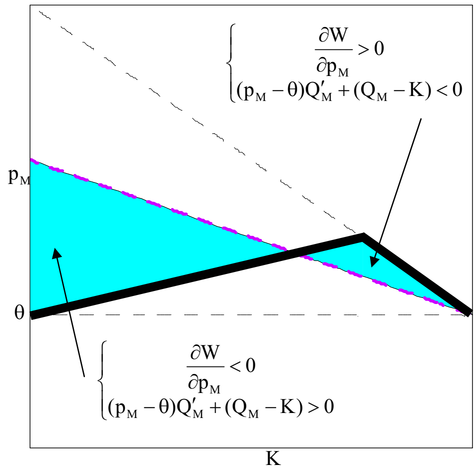

Figure 1.4a: Locus of solutions with $\omega(1+\lambda) - \lambda^2 > 0$

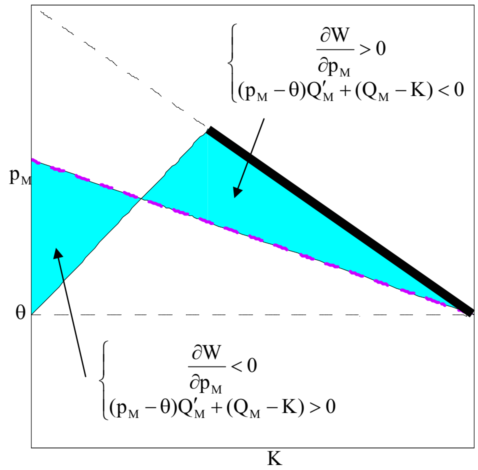

Figure 1.4b: Locus of solutions with $\omega(1+\lambda) - \lambda^2 < 0$

Now, when we proceed to generalize this argument to the case where $F_m > 0$, the bold segments representing the solution to the constrained program in Figures 1.4a and 1.4b become curves, and more importantly, their shapes are sensitive to the size of the fixed cost. Figures 1.5a and 1.5b show these bold curves for two different values of F_m with those on the upper parts corresponding to a lower fixed cost than those on the lower parts. Cross-examining Figures 1.4a-1.4b and 1.5a-1.5b, we see that when there is no fixed cost, solutions with $\phi > 0$ only happen in the negatively sloped portion of the boundary of the participation set, while with fixed cost a solution with $\phi > 0$ may lie on either the positively or negatively sloped portion of the boundary of the participation set. This "indeterminacy" of the solution convinces us of the usefulness of simulations for studying the behavior of the endogenous variables of this scheme, namely, p_M, K, and ϕ. The results of such simulations are shown in the appendix.

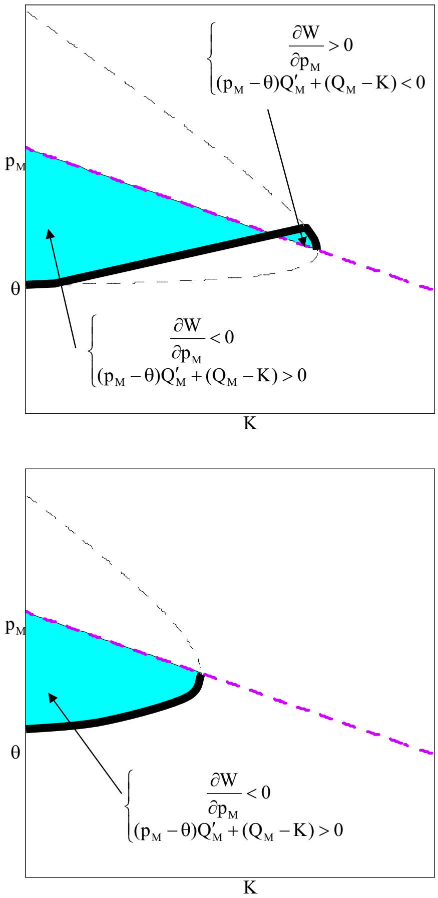

Figure 1.5a: Locus of solutions with $\omega(1+\lambda) - \lambda^2 > 0$, $F_m > 0$

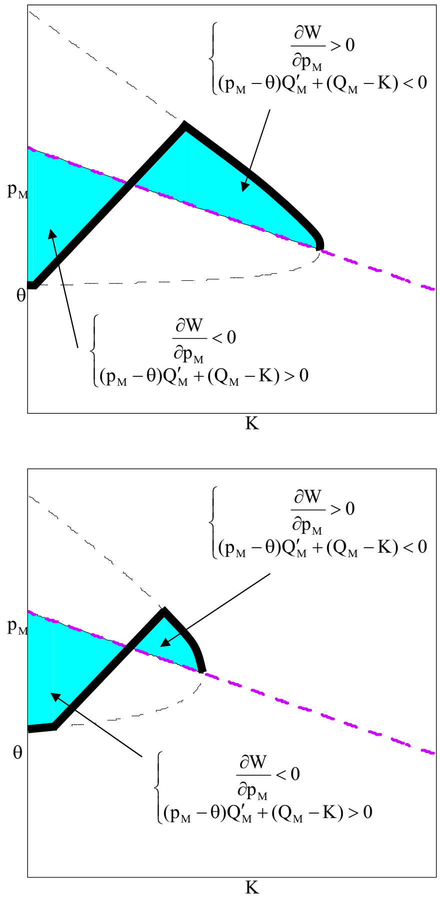

Figure 1.5b: Locus of solutions with $\omega(1+\lambda) - \lambda^2 < 0$, $F_m > 0$

1.5 Controlling the regional monopoly with transport capacity only

We now assume that the social planner lacks an additional instrument of control, namely, setting the monopoly's level of output, and hence he can only partially affect price in market M. Transport capacity is therefore the only instrument left to him to counter the exercise of local market power by the firm in this market.

In practice though, we model this case as if the social planner continues to set the price level, but now this price has to fall within a profit-maximizing-constrained set of values. Let us be more specific.

For a given volume of gas K imported from the competitive market, the firm remains a monopoly in its local commodity gas market on the residual demand $Q_M(p_M) - K$. Given this demand, the firm sets price so as to maximize its profit Π_m given by

$$\Pi_m = (p_M - \theta)\left[Q_M(p_M) - K\right] - F_m \tag{1.59}$$

The first-order condition of this profit-maximization problem is

$$(p_M - \theta)Q'_M + Q_M - K = 0 \tag{1.60}$$

while the second-order condition that ensures that we are indeed at a maximum is $\Omega \equiv (p_M - \theta)Q''_M + 2Q'_M < 0$.

Given that transfers are not allowed, the form of the social welfare function for this control scheme is analogous to the one described in the previous section which we restate here:

$$\begin{aligned} W = \; & S(Q_M(p_M)) + \lambda p_M K \\ & -\theta(Q_M(p_M) - K) - (1+\lambda)\left[cK + C(K)\right] - F_m \end{aligned} \tag{1.61}$$

The program of the social planner consists in maximizing social welfare given by (1.61) with respect to p_M and K, under the regional monopoly participation constraint, $\Pi_m \geq 0$, where Π_m is given by (1.59), its output nonnegativity constraint, $q_m \geq 0$, and its profit-maximization constraint (1.60).[25] As in the previous section, let us focus on policies with $p_M \geq \theta$ in which case the firm's output nonnegativity constraint can be ignored.[26] Letting ϕ and η designate the Lagrange multipliers associated with the firm's participation and profit-maximization constraints,

25. Strictly speaking, the second-order condition of the firm's profit-maximization program should also be taken as a constraint. The standard way to deal with this issue, is to check ex post that this second-order condition is satisfied by the solution of the program.

26. Indeed, $(p_M - \theta) \geq 0$ and (1.60) imply $q_m \geq 0$. Note that in this case there is no need for a constraint on the size of the marginal cost gap.

respectively, we obtain the following first-order conditions:[27]

$$\lambda K + (p_M - \theta)\, Q'_M - \eta\Omega = 0 \tag{1.62}$$

$$(\lambda - \phi)\,(p_M - \theta) + (1+\lambda)\,[(\theta - c) - C'(K)] + \eta = 0 \tag{1.63}$$

$$\phi\,[(p_M - \theta)(Q_M - K) - F_m] = 0 \tag{1.64}$$

$$(p_M - \theta)(Q_M - K) - F_m \geq 0 \tag{1.65}$$

$$(p_M - \theta)Q'_M + Q_M - K = 0 \tag{1.66}$$

Turning to the study of the solution to the system (1.62)-(1.66) in the K-p_M space, observe that since social welfare under this control scheme is the same as that in the previous section, so is the analysis of the unconstrained maximization program. When constraints are introduced in the maximization program, however, an additional one arises here, namely, the profit-maximization constraint (1.60). Such a constraint is represented in the K-p_M space by a decreasing concave function with slope $-\frac{Q'_M}{(Q_M-K)Q''_M - 2{Q'_M}^2}$ and intercept point strictly in the interior of the participation set. Furthermore, this function crosses the boundary of the participation set at a point where the latter is infinitely sloped.[28]

Equation (1.62), (1.63), and (1.66) define a tangency point between a welfare level curve and the function that represents the profit-maximization constraint. Hence, such a point satisfies

$$-\frac{Q'_M}{(Q_M - K)Q''_M - 2{Q'_M}^2} = \frac{(1+\lambda)\,[(\theta - c) - C'(K)]\,Q'_M - \lambda(Q_M - K)}{[Q_M - (1+\lambda)K]Q'_M} \tag{1.67}$$

27. The Lagrange multiplier associated with the profit-maximization constraint (1.60), η, is interpreted as the social marginal cost of letting the regional monopoly maximize profits. Indeed, $\eta > 0$ implies that a reduction in the optimal price markup made by the firm, results in a higher level of welfare. However, note that from the cross-partial derivative of the welfare function (1.61), $\frac{\partial^2 W}{\partial p_M \partial K} = \lambda$, a reduction in the price markup leads to a decrease in the optimal capacity level. In particular, when $\eta > 0$ a reduction in import capacity is welfare improving.

28. The reader can check that such a crossing point is characterized by the condition

$$\frac{F_m}{(Q_M(p_M) - K)} = -\frac{(Q_M(p_M) - K)}{Q'_M}$$

Solving for F_m and substituting into the expression of the slope of the boundary of the participation set (1.39) yields the slope of this set at the crossing point.

If such a tangency point satisfies the firm's participation constraint (1.65) with a strict inequality, it is an interior solution.[29] Note from (1.67) that $K = 0$ cannot be a tangency point, and hence not an interior solution. If such a tangency point violates (1.65), the solution to (1.62)-(1.66) lies at the intersection of the function representing the profit-maximization constraint and the boundary of the participation set where, recall, the latter is infinitely sloped.[30] The following proposition summarizes the optimal policies.

Proposition 1.3 *When capacity is the only instrument controlled by the social planner, it is always built and the optimal price and capacity building rules are characterized as follows.*

The no-cost-gap-no-fixed-cost case: When $(\theta - c) = 0$ and $F_m = 0$ there is a unique policy $(0 < K < Q_M, p_M > \theta = c, \phi = 0, \eta \neq 0)$ at which the local monopoly meets part of the market demand and makes positive profits. The markup of this monopoly takes the form

$$\frac{p_M - \theta}{p_M} \left(= \frac{p_M - c}{p_M} \right) = \left[\frac{\lambda K - \eta \Omega}{Q_M} \right] \frac{1}{\varepsilon(Q_M)} = \left[\frac{Q_M - K}{Q_M} \right] \frac{1}{\varepsilon(Q_M)} \tag{1.68}$$

The import activity earns a markup given by

$$\frac{p_M - (c + C'(K))}{p_M} = \left[\frac{\lambda K - \eta(\Omega - Q'_M)}{(1+\lambda) Q_M} \right] \frac{1}{\varepsilon(Q_M)} \quad , \tag{1.69}$$

and capacity obeys

$$(1+\lambda) C'(K) = -\frac{\lambda(Q_M - K)}{Q_M{}'} - \frac{Q_M - (1+\lambda) K}{\Omega} \tag{1.70}$$

where $\Omega \equiv (p_M - \theta) Q''_M + 2Q'_M$.

29. Second-order conditions are synthesized as:

$$-\Omega^2 (1+\lambda) C''(K) + 2\lambda\Omega - \left[\frac{(Q_M - K)(Q''_M - \eta Q'''_M)}{Q'_M} \right] + [Q'_M - 3\eta Q''_M] < 0$$

Note that for a downward-sloping linear demand, the former condition holds for any value of η.

30. In this case, second-order conditions are always satisfied. It is worthwhile noting that (1.35) and (1.67) imply that transport capacity is always built under this scheme. This point will be further discussed in the next section.

The no-cost-gap-with-fixed-cost case: *When* $(\theta - c) = 0$ *and* $F_m > 0$*, there are two exclusive candidate optimal policies* (K, p_M, ϕ, η)*:*

(i) The policy $(0 < K < Q_M, p_M > \theta = c, \phi = 0, \eta \neq 0)$*, characterized by (1.68)-(1.70), in which the local monopoly meets part of the market demand and makes positive profits.*

(ii) The policy $(0 < K < Q_M, p_M > \theta = c, \phi > 0, \eta \neq 0)$ *under which the markup of the monopoly satisfies the following average cost pricing condition*

$$\frac{p_M - \theta}{p_M} \left(= \frac{p_M - c}{p_M} \right) = \left[\frac{Q_M - K}{Q_M} \right] \frac{1}{\varepsilon(Q_M)} = \frac{\sqrt{-Q_M{}' F_m}}{Q_M} \frac{1}{\varepsilon(Q_M)} \tag{1.71}$$

The markup of the import activity is

$$\frac{p_M - (c + C'(K))}{p_M} = \left[\frac{(1+\phi)[\lambda K - \eta \Omega] + \eta Q'_M}{(1+\lambda) Q_M} \right] \frac{1}{\varepsilon(Q_M)} \quad , \tag{1.72}$$

and capacity is given by

$$K = Q_M - \sqrt{-Q_M{}' F_m} \tag{1.73}$$

Under policy (i) the marginal cost of the local monopoly θ $(= c)$ *plus the shadow cost of the firm's profit maximization constraint,* η*, equals the "net" social marginal cost of imports,* $(1+\lambda)[c + C'(K)] - \lambda p_M$*, and the resulting firm's variable profits are larger than the fixed cost, i.e.,* $F_m < -\frac{(Q_M - K)^2}{Q'_M}$*. Under policy (ii) this condition holds with equality, i.e.,* $F_m = -\frac{(Q_M - K)^2}{Q'_M}$*.*

The with-cost-gap-no-fixed-cost case: *When* $(\theta - c) > 0$ *and* $F_m = 0$*, one of the two following policies* (K, p_M, ϕ, η) *emerges according to the size of the marginal cost gap:*

(i) The policy $(0 < K < Q_M, p_M > \theta, \phi = 0, \eta \neq 0)$ *in which the local monopoly meets part of the market demand and makes positive profits. The monopoly and import activity markups are given by (1.68) and (1.69), whereas optimal*

capacity under this policy satisfies

$$(1+\lambda)C'(K) = (1+\lambda)(\theta - c) - \frac{\lambda(Q_M - K)}{{Q_M}'} - \frac{Q_M - (1+\lambda)K}{\Omega} \quad (1.74)$$

where Ω *is as defined above.*

(ii) The policy $(K = Q_M, p_M = \theta, \phi > 0, \eta < 0)$ *in which the local monopoly is shut down, the whole market demand is met through imports, and the markup for the import activity is defined as follows*

$$\frac{p_M - (c + C'(Q_M))}{p_M} = \frac{\eta Q'_M}{(1+\lambda)Q_M} \frac{1}{\varepsilon(Q_M)} \quad (1.75)$$

Under policy (i) the "net" social marginal cost of imports when they exclusively cover market demand, $(1+\lambda)[c+C'(Q_M)] - \lambda p_M$*, is greater than the marginal cost of the firm* θ *plus the shadow cost of the firm's profit maximization constraint,* η*, i.e.* $0 < (\theta - c) < C'(Q_M) - \frac{1}{2}\frac{\lambda}{1+\lambda}\frac{Q_M}{Q'_M}$*. Under policy (ii) the reverse of this latter condition is true.*

The with-cost-gap-with-fixed-cost case: *When* $(\theta - c) > 0$ *and* $F_m > 0$*, there are two exclusive candidate optimal policies* (K, p_M, ϕ, η)*:*

(i) The policy $(0 < K < Q_M, p_M > \theta, \phi = 0, \eta \neq 0)$*, characterized by (1.68), (1.69), and (1.74), in which the local monopoly meets part of the market demand and makes positive profits.*

(ii) The policy $(0 < K < Q_M, p_M > \theta, \phi > 0, \eta \neq 0)$*, characterized by the average cost pricing rule (1.71), and the capacity building rule given by (1.73).*

Under policies (i) and (ii), $F_m < -\frac{(Q_M-K)^2}{Q'_M}$ *and* $F_m = -\frac{(Q_M-K)^2}{Q'_M}$ *respectively. The interpretation of these conditions is similar to the case with no cost gap and positive fixed cost.*

Proposition 1.3 shows that when the solution allows for positive profits by the firm ($\phi = 0$), the latter earns a markup which is proportional to the share of its output in the aggregate demand and inversely related to the elasticity of demand. The size of this monopoly's markup is larger (smaller) than that under the control scheme where the social planner had total control over pricing, described in section 1.4, if the shadow cost of the firm's profit maximization constraint η is positive (negative). Optimal capacity is determined by balancing the net social cost of having an extra unit imported from the competitive market, $(1+\lambda)[c+C'(K)]-\lambda p_M$, against the cost of having that unit produced locally by the monopoly, $\theta \geq c$, plus the social cost of complying with the profit-maximization constraint, η.

When this control scheme yields no profits for the local monopoly at the optimum ($\phi > 0$), the firm's markup is inversely related to the elasticity of demand but increases with the size of the fixed cost. Since in this particular case capacity is used by the social planner as a residual instrument to make the firm just break even, it is decreasing in F_m (see (1.73)). However, the firm may be forced to shut down ($q_m = 0$ and $\phi > 0$) when there is no fixed cost and the marginal cost gap $(\theta - c)$ is strictly positive. In such a case, the markup of the import activity is strictly positive and increases with the absolute value of the shadow cost of the profit maximization constraint.

Let us illustrate the solution under this control scheme using the functional forms (1.19). In this case, the set defined by the firm's profit maximization constraint (1.60) is a line of slope $-\frac{1}{2}$ that crosses the boundary of the participation set at the point where the latter is infinitely sloped, as shown in Figures 1.8a and 1.8b. The shaded regions correspond to the participation set defined by (1.59). The upward-slopping lines represent the price and capacity first-order conditions of the unconstrained program, respectively, (1.36) and (1.37). The downward-slopping dashed line is the set of (K, p_M) pairs which satisfy the profit-maximization constraint of the local monopoly (1.60).

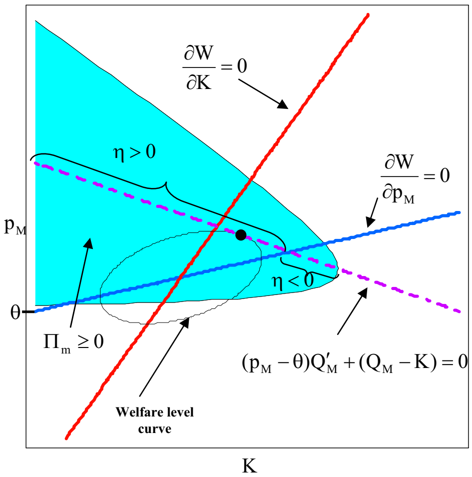

Figure 1.6a: Interior solution

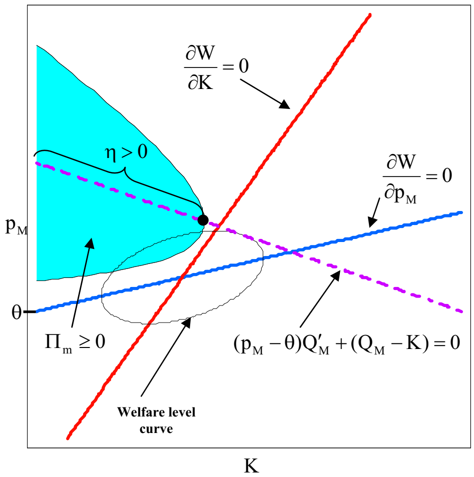

Figure 1.6b: Boundary solution

Figure 1.6a sketches the case in which the solution lies in the interior of the participation set. This interior solution is

$$K = \frac{(1+2\lambda)(\gamma-c)+(3+2\lambda)(\theta-c)}{1+4\lambda+4\omega(1+\lambda)} \tag{1.76}$$

$$p_M = \theta + \frac{[\lambda+2\omega(1+\lambda)]\,(\gamma-c)-(\theta-c)\,[2+3\lambda+2\omega(1+\lambda)]}{1+4\lambda+4\omega(1+\lambda)}\ , \tag{1.77}$$

and emerges when the condition

$$0 \leq (\theta-c) < \frac{(\gamma-c)\,[\lambda+2\omega(1+\lambda)]-\sqrt{F_m}\,[1+4\lambda+4\omega(1+\lambda)]}{2+3\lambda+2\omega(1+\lambda)} \tag{1.78}$$

holds. When $\theta - c = 0$ and $F_m = 0$. This is the unique solution described in the no-cost-gap-no-fixed cost case of Proposition 1.3. When $\theta - c = 0$ and $F_m > 0$, and when $\theta - c > 0$ and $F_m \geq 0$, it represents policies of type (i) in the proposition. When condition (1.78) does not hold, the solution is on the boundary of the participation set. Figure 1.6b shows such a boundary solution given by

$$K = \gamma - \theta - 2\sqrt{F_m} \tag{1.79}$$

$$p_M = \theta + \sqrt{F_m} \tag{1.80}$$

This solution represents the policies of type (ii) in Proposition 1.3.

1.6 Role of control instruments

In the last three sections, we have characterized optimal policies obtained under three control regimes that are differentiated by the set of control instruments available to the social planner. More specifically, we have considered the benchmark case in which the social planner can use transfers, capacity, and price to mitigate regional market power. Then, we have studied the more realistic cases in which first, transfers are not allowed, second, neither transfers nor price control are possible. The purpose of this section is to study in a systematic way the consequences in terms of network capacity of restrictions in the set of control instruments that should normally follow an increasingly liberalized industry.

For clarity of exposition, we refer to the schemes described in section 1.3 (control of price and capacity with transfers), 1.4 (control of price and capacity without transfers), and 1.5 (control of capacity only) as schemes A, B, and C respectively. We study the evolution of network capacity as the planner possesses fewer and fewer instruments to maximize social welfare. Letting K^A, K^B, K^C, and p_M^A, p_M^B, p_M^C designate the optimal levels of network capacity and price achieved under the respective control schemes, we proceed by pairwise comparisons in order to identify the impact of each individual instrument on transport capacity. These comparisons allow us to assess the extent to which the various instruments are substitute or complements in combating regional market power.[31]

1.6.1 Absence of transfers

When analyzing the impact of a loss of the ability to use transfers between consumers and the firm, the relevant comparison is between schemes A and B. We

31. Each pairwise comparison is illustrated by using specific functional forms and particular parameter values. This empirical analysis is based on simulations with respect to two parameters that play an important role, namely, the marginal cost gap and the fixed cost. The background material for these simulations is presented in the appendix.

express the first-order conditions of the constrained welfare maximization programs under these schemes, (1.6), (1.7), and (1.31), (1.32) as follows:

$$\frac{\partial W^A}{\partial p_M} + \nu^A Q'_M = 0 \tag{1.81}$$

$$\frac{\partial W^A}{\partial K} - \nu^A = 0 \tag{1.82}$$

$$\frac{\partial W^B}{\partial p_M} + \phi^B \frac{\partial \Pi_m}{\partial p_M} = 0 \tag{1.83}$$

$$\frac{\partial W^B}{\partial K} - \phi^B (p_M - \theta) = 0 \tag{1.84}$$

Examining the left-hand sides of (1.15), (1.16), and (1.36), (1.37), we see that

$$\frac{\partial W^B}{\partial p_M} = \frac{\partial W^A}{\partial p_M} - \lambda \frac{\partial \Pi_m}{\partial p_M} \tag{1.85}$$

$$\frac{\partial W^B}{\partial K} = \frac{\partial W^A}{\partial K} + \lambda (p_M - \theta) \tag{1.86}$$

A casual look at (1.81)-(1.86) suggests that the (endogenous) shadow cost of the constraint of nonnegativity of the firm's output, ν^A, the (endogenous) shadow cost of its participation constraint, ϕ^B, and the (exogenous) social cost of public funds, λ, are going to influence the relative optimal levels of transport capacity. The following proposition formalizes this relationship.

Proposition 1.4 *Absence of transfers as a control instrument has the following consequences. When the shadow cost of the participation constraint under scheme B, ϕ^B, is smaller than the social cost of public funds, λ, i.e., $(\lambda - \phi^B) \geq 0$, society suffers a net marginal cost from letting the firm make positive profits under this scheme and "excess" capacity (in the large sense) is needed, i.e., $K^B \geq K^A$. If society enjoys marginal gains from letting the firm make positive profits, i.e., $(\lambda - \phi^B) < 0$, there is a need for a strict reduction of transport capacity, i.e., $K^B < K^A$. In the particular case where there is no fixed cost, K^B is unambiguously greater than or equal to K^A.*

As an illustration of this proposition, Figures 1.7a and 1.7b exhibit the sign of the capacity differential, $(K^B - K^A)$, and that of ν^A and ϕ^B, in terms of the marginal cost gap, $(\theta - c)$, and the fixed cost, F_m, assuming the functional forms (1.19) and under the parameter values $(\lambda, \omega, \gamma, c) \in \{(\frac{1}{3}, \frac{1}{2}, 10, 2), (\frac{1}{3}, \frac{1}{15}, 10, 2)\}$.[32]

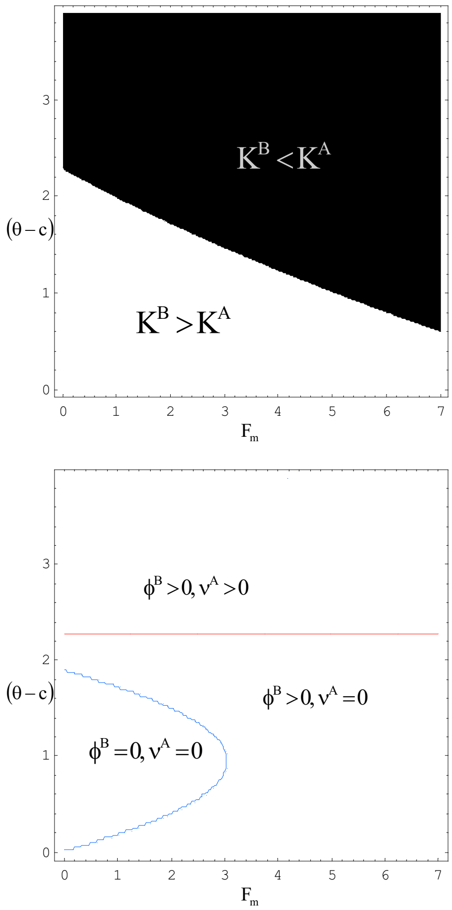

Figure 1.7a: $(K^B - K^A)$, ν^A, and ϕ^B with $\omega(1+\lambda) - \lambda^2 > 0$

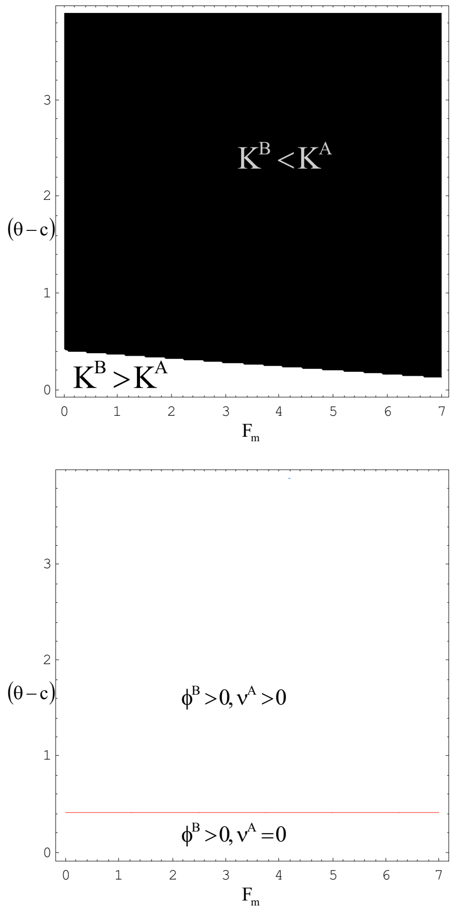

Figure 1.7b: $(K^B - K^A)$, ν^A, and ϕ^B with $\omega(1+\lambda) - \lambda^2 < 0$

Cross-examining the upper and lower parts of Figures 1.7a and 1.7b, we see that whenever the solution under scheme B is interior ($\phi^B = 0$), so is the solution under A ($\nu^A = 0$), and $K^B \geq K^A$. Moreover, when the solution under A yields $q_m = 0$ ($\nu^A > 0$), the solution under B has the firm just break even ($\phi^B > 0$), and $K^B < K^A$. Note that, as stated in the proposition, these figures show that the

32. These two sets of parameter values allow us to examine both the case where the polynomial $\omega(1+\lambda) - \lambda^2$ is positive and negative.

sign of the capacity differential $(K^B - K^A)$ is the same as that of $(\lambda - \phi^B)$.

1.6.2 Lack of price control

Suppose now that the social planner initially has two control instruments, price and capacity, and then looses the ability to set price. In order to analyze the impact of such a reduction in the set of control instruments, the relevant comparison is between schemes B and C. Since the welfare functions of these two schemes are identical and scheme C has an additional constraint (the firm's profit-maximization constraint), let us express its first-order conditions (1.62), (1.63), and (1.66) as

$$\frac{\partial W^B}{\partial p_M} - \eta^C \Omega = 0 \tag{1.87}$$

$$\frac{\partial W^B}{\partial K} - \phi^C (p_M - \theta) + \eta^C = 0 \tag{1.88}$$

$$\frac{\partial \Pi_m}{\partial p_M} = 0 \tag{1.89}$$

These first-order conditions give us reasons to expect that the shadow costs of the participation constraint under B and C, ϕ^B and ϕ^C, and that of the profit-maximization constraint under C, η^C, are going to be influential in the determination of the relative size of transport capacity. This can be seen in the next proposition.

Proposition 1.5 *When price and capacity are controlled by the social planner and the latter looses price control, the impact on network capacity is as follows. When the social marginal cost of letting the firm maximize profits is positive, i.e., when $\eta^C > 0$, the lose of price control by the social planner entails "excess" capacity, i.e., $K^C > K^B$. When it is beneficial to allow the firm to maximize profits, i.e., when $\eta^C < 0$, the ranking between K^C and K^B is undetermined. However, when there is neither a marginal cost gap ($\theta = c$) nor a fixed cost ($F_m = 0$), $\eta^C > 0 \Rightarrow K^C > K^B$ and $\eta^C < 0 \Rightarrow K^C < K^B$.*

Figures 1.8a and 1.8b show the sign of the capacity differential, $(K^C - K^B)$, and that of ϕ^B, ϕ^C, and η^C in terms of the marginal cost gap, $(\theta - c)$, and the fixed cost, F_m, assuming the functional forms given by (1.19) and under the parameter values used in the previous subsection.

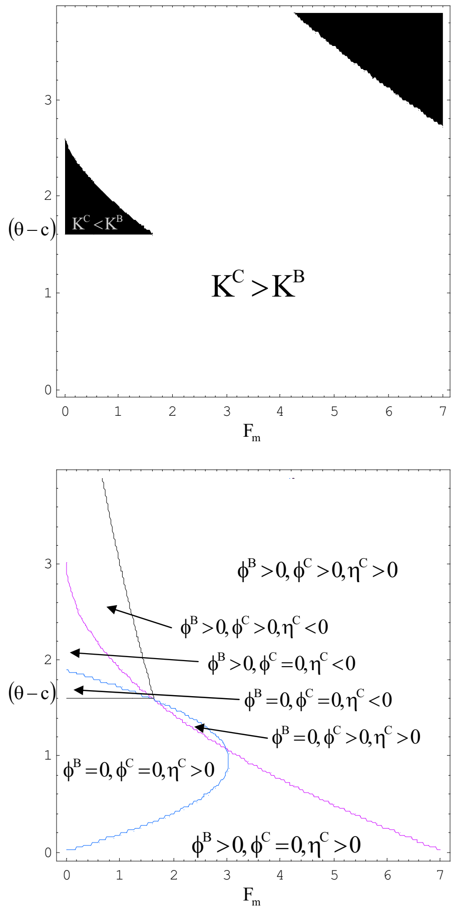

Figure 1.8a: $(K^C - K^B)$, ϕ^B, ϕ^C, and η^C with $\omega(1+\lambda) - \lambda^2 > 0$

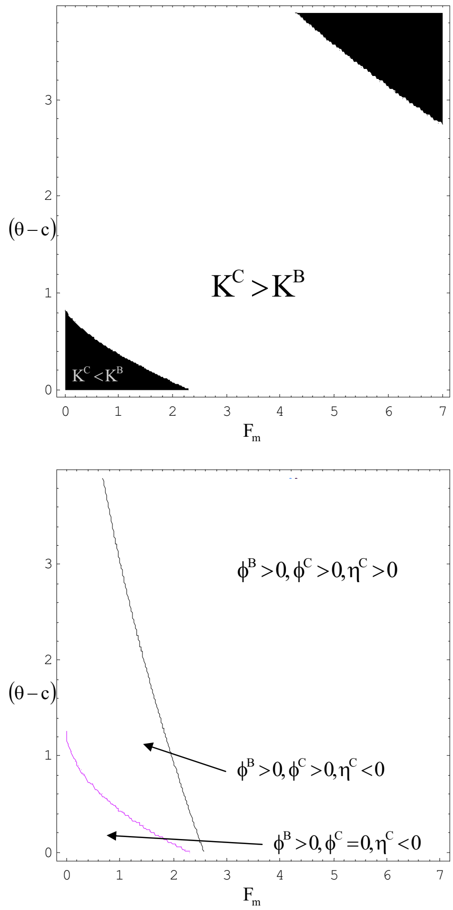

Figure 1.8b: $(K^C - K^B)$, ϕ^B, ϕ^C and η^C with $\omega(1+\lambda) - \lambda^2 < 0$

Comparing the upper and lower parts of Figures 1.8a and 1.8b, we see that whenever the solution under scheme C yields $\eta^C > 0$, the capacity differential is such that $K^C - K^B > 0$. However, a necessary condition for the sign of the shadow cost of the profit-maximization constraint to reveal a negative sign for the capacity differential, i.e., $sign[K^C - K^B] = sign[\eta^C]$ when $\eta^C < 0$, is that firm's profits be strictly positive ($\phi^C = 0$). Moreover, we see from the lower part of Figure 1.8a that when $\eta^C < 0$ the set of interior solutions under B ($\phi^B = 0$) is included in the set of interior solutions under C ($\phi^C = 0$), and hence no situations under which simultaneously $\phi^B = 0$, $\phi^C > 0$, and $\eta^C < 0$ may arise. Finally, with the functional forms (1.19), condition $Q'_M \left[C''(K) - \frac{C'(K)}{K}\right] - \frac{\lambda K}{Q'_M} Q''_M C''(K) < 0$ does not hold and Figure 1.8b confirms the statement in Proposition 1.2 that whenever $\omega(1+\lambda) - \lambda^2 < 0$, the solution under B has $\phi^B > 0$.[33]

1.6.3 Absence of transfers and lack of price control

Finally, let us assume that the social planner initially has three control instruments, price, capacity, and transfers, and then he can neither use transfers nor set price. The effect of such a removal of two control instruments can be analyzed by comparing schemes A and C. Let us express the first-order conditions associated with scheme C, (1.62), (1.63), and (1.66) as

$$\frac{\partial W^A}{\partial p_M} - \lambda \frac{\partial \Pi_m}{\partial p_M} - \eta^C \Omega = 0 \tag{1.90}$$

$$\frac{\partial W^A}{\partial K} + (\lambda - \phi^C)(p_M - \theta) + \eta^C = 0 \tag{1.91}$$

We observe from these first-order conditions that the shadow cost of the constraint of nonnegative firm's output under A, ν^A, that of the participation constraint under C, ϕ^C, and that of the profit-maximization constraint under C, η^C, are going to play an important role in the determination of the relative size of transport capacity. The next proposition characterizes this role.

Proposition 1.6 *When price, capacity and transfers are available to the social planner as tools to fight market power and he looses the ability to use transfers and set price, the impact on the capacity of the transport network is as follows. Provided that after the reduction in the set of control instruments the firm earns strictly positive profits, when the social marginal cost of letting the firm maximize profits is positive, i.e., when $\eta^C > 0$, the loss of the two control instruments entails "excess" capacity, i.e., $K^C > K^A$. When it is beneficial to allow the firm to maximize profits, i.e., when $\eta^C < 0$, the ranking between K^C and K^A is undetermined.*

33. This condition represents the inequality $(1+\lambda)Q'_M C''(0) + \lambda^2 > 0$ stated in Proposition 1.2.

In the particular case where there is no marginal cost gap ($\theta = c$), $K^C > K^A$, independently of the sign of η^C.

Figures 1.9a and 1.9b show the sign of the capacity differential, $(K^C - K^A)$, and that of ν^A, ϕ^C, and η^C in terms of the marginal cost gap, $(\theta - c)$, and the fixed cost, F_m, assuming the functional forms given by (1.19) and under the parameter values used in the previous subsections.

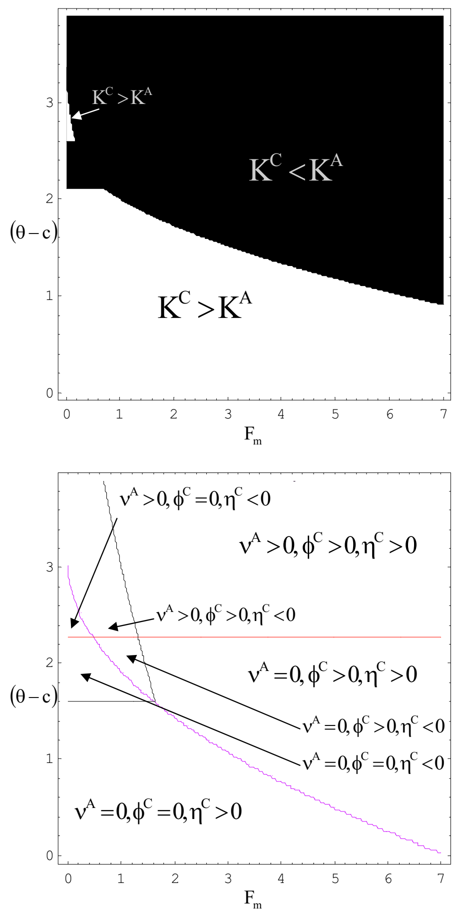

Figure 1.9a: $(K^C - K^A)$, ν^A, ϕ^C, and η^C with $\omega(1+\lambda) - \lambda^2 > 0$

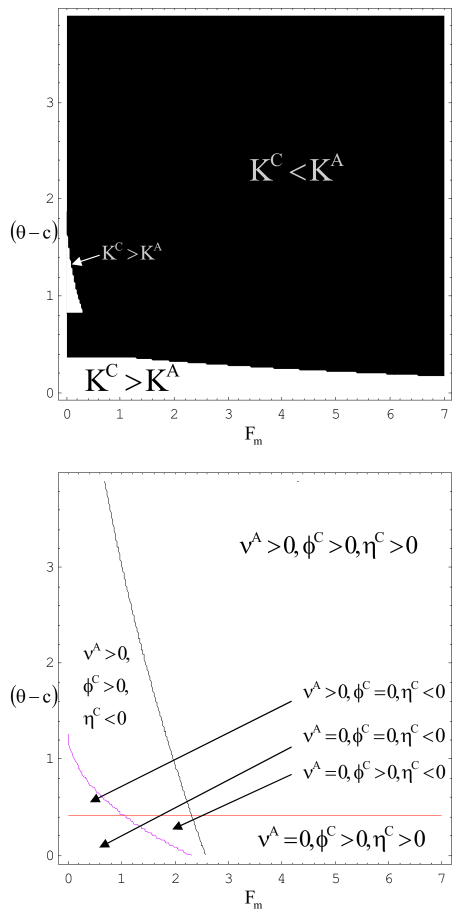

Figure 1.9b: $(K^C - K^A)$, ν^A, ϕ^C and η^C with $\omega(1+\lambda) - \lambda^2 < 0$

As stated in Proposition 1.6, we see from Figures 1.9a and 1.9b that when firm's profits are not only maximized ($\eta^C \neq 0$) but also strictly positive ($\phi^C = 0$),

$sign[K^C - K^A] = sign[\eta^C]$ when $\eta^C > 0$. Observe from these figures that there does not exist a case where $\nu^A > 0$, $\phi^C = 0$, and $\eta^C > 0$. The reason for this is that if under A the firm is shut down ($q_m = 0$) and if allowing it to maximize profits under C is socially costly ($\eta^C > 0$), then there is no reason for letting it earn strictly positive profits under this scheme ($\phi^C > 0$). Finally, comparing the upper parts of Figures 1.9a and 1.9b, we easily verify that when there is no marginal cost gap ($\theta = c$), transport capacity is oversized under scheme C, i.e., $K^C > K^A$.

1.7 Conclusion

The gas industry throughout the world, in particular in the European Union has been facing an important question that is shared by most of the public utility sectors. In a context where reforms aimed at opening some segments of the industry to competition are conducted, how to make sure that monopoly power inherited from the historical market structure is not going to be exercised by incumbent firms. The work in this chapter has provided an initial analysis of some policies that a social planner can use to mitigate regional monopoly power in the gas commodity market. We have considered optimal policies implementable through three control instruments, transfers, price and transport capacity, and we have focused on the way capacity responds to market power.

As a starting point, we have considered a situation where the social planner, having complete information, may use transfers between consumers and a regional monopoly, control the gas commodity price, and set the capacity of a pipeline used to import competitive gas into the regional market. This is the control scheme that we have used as a reference regime. We then have examined the effect on the pipeline capacity of the planner's loss of ability to use transfers and control the price. The analysis has allowed us to shed light on the extent to which these various tools of mitigating regional market power are substitutes or complements. In particular, we have characterized the conditions under which a reduction in the set of control instruments available to the social planner results in a transport network that is "over"- or "under"-sized.

The analysis has also allowed us to investigate the incentives of a social planner to develop transport infrastructure in order to fight market power. In addition to the standard allocative inefficiency due to market power (of a geographically isolated firm), in our model with complete information the social planner has to account for a potential productive inefficiency and a possible financing of a fixed cost. Moreover, our model explicitly accounts for the the fact that public funds are costly. Clearly then, the incentives of the social planner to build infrastructure capacity depend on the available control instruments, how relatively inefficient the regional firm is, whether there is indeed a fixed cost of this firm to be financed, the cost structure of the capacity building activity, and how costly raising public funds through taxation is. Putting these factors together and solving the various tradeoffs involved is, as can be expected, not straightforward and Propositions 1.1-1.3 demonstrate that. Nonetheless, these propositions yield some instructive qualitative information on the degree to which the social planner should intensify investments in infrastructure in order to exert competitive pressure on regional monopolies.

In the benchmark case where the social planner has full control of the regional firm through transfers, capacity, and price the only relevant factor is how severe the productive inefficiency might be. If the marginal cost gap is nil, in which case productive inefficiency is not of concern, there is no need to invest in capacity. Indeed, since the firm has the "right" marginal cost, the social planner allows it to meet the entire market demand while pricing at a markup that would finance a fixed cost, if there is any, and generate revenues that are socially valuable and transferable to consumers. If the marginal cost gap is substantially large, the social planner finds it worthwhile to intensively invest in transport capacity to the point of inducing the shutting down of the regional firm even if a fixed cost needs to be financed. Finally, if the marginal cost gap is small the social planner finds it beneficial to put some, but not extreme, competitive pressure on the regional firm by moderately investing in transport capacity and letting the firm earn a markup that is recoverable through transfers anyway.

When transfers are no longer available but the social planner still controls capacity and price, it is optimal not to build capacity in two cases. In the first case, three conditions are simultaneously met, namely, the marginal cost gap is nil, there is no fixed cost to finance, and the capacity building technology and the cost of public funds λ are such that the fiscal value of imported gas is dominated by the cost of building transport capacity. The second case is when the fixed cost is so large that the social planner is merely constrained to let the firm entirely meet market demand so as to earn enough profits to finance such an extremely large fixed cost. The decision to induce the shutting down of the regional firm initially depends on whether or not the financing of a fixed cost is of concern. When it is not and the marginal cost gap is nil or relatively small, extreme competitive pressure is exerted only when the fiscal value of imported gas dominates the cost of building transport capacity. However, if the productive inefficiency is substantial, no matter what this "net" fiscal value of imports is, the absence of a fixed cost makes shutting down the regional firm optimal. In all the remaining cases, limited competition allowing both the firm and the import activity to earn markups is optimal.

When not only transfers but also pricing are out of the social planner's control, competitive pressure through investment in transport capacity, be it arbitrarily small, is always optimal. The extreme policy that consists in intensively investing in capacity to the point of inducing the shutting down of the regional firm is optimal only when the firm's productive inefficiency is extremely high and there is no fixed cost to be financed.

Control of monopoly power is to a large extent the subject of regulatory economics. The purpose of this chapter was to explore the analysis of the interaction among regulatory tools under the admittedly strong assumption of complete information. A necessary extension of our analysis is to introduce asymmetric information on the firm's production technology, and this is undertaken in the second chapter of the dissertation. Our conjecture is that under incomplete information, the relationship between instruments of control of market power will be affected in some important ways.

Appendix

Proof of Proposition 1.1 *As indicated in the discussion of this proposition, the optimal policy under this control scheme does not depend on the fixed cost F_m. Hence, two cases need to be considered.*

The no-cost-gap case: Substitute $\theta - c = 0$ into (1.7) and use the fact that $\nu \geq 0$ to obtain $K = 0$ and $\nu = 0$. Rewrite (1.6) as (1.11).

The cost-gap case: With $0 < (\theta - c) < C'(Q_M)$, (1.7) yields $\nu = 0$ in which case (1.10) yields $0 < K < Q_M$ and (1.6) and (1.7) are rewritten as (1.12) and (1.13). When $(\theta - c) \geq C'(Q_M)$, (1.7) yields $\nu > 0$ in which case (1.10) yields $K = Q_M$, and (1.6) combined with (1.7) yield (1.14). ■

Proof of Proposition 1.2 *Under this control scheme, four cases need to be considered. We prove them in turn.*

The no-cost-gap-no-fixed-cost case:

When $\theta - c = 0$ and $F_m = 0$, since $C'(0) = 0$, the first-order conditions (1.31)-(1.34) give $K = 0$, $p_M = \theta$ $(= c)$, and $\phi = 0$. The relevant second-order conditions, given by (1.38), are satisfied when $(1 + \lambda)Q'_M C''(0) + \lambda^2 < 0$. These features characterize policy (i) given in the proposition.

When $(1+\lambda)Q'_M C''(0)+\lambda^2 > 0$, from the discussion that precedes the proposition in the text, since the functions representing (1.36) and (1.37) cross at $K = 0$, they cross at most once at a point where $K > 0$. If such a second crossing point exists and belongs to the interior of the participation set (in which case $q_m > 0$), it is defined by $(1 + \lambda)Q'_M C'(K) + \lambda^2 K = 0$, rewritten as (1.43), which results from (1.36) and (1.37), rewritten as (1.41) and (1.42). Now, to guarantee that it exists, solving (1.43) for λ^2 and substituting into the second-order conditions (1.38) yields the technical condition $Q'_M \left[C''(K) - \frac{C'(K)}{K}\right] - \frac{\lambda K}{Q'_M} Q''_M C''(K) < 0$. Finally, to insure that this second crossing point belongs to the participation set, (1.37) cannot be satisfied when this constraint is binding (in which case $K = Q_M$), i.e., $(1 + \lambda)[(\theta - c) - C'(Q_M)] + \lambda(p_M - \theta) < 0$, rewritten as $(1+\lambda)[c+C'(Q_M)]-\lambda p_M > \theta$. Substituting $\theta = c$ and p_M from (1.42) yields $C'(Q_M)+\frac{\lambda^2}{1+\lambda}\frac{Q_M}{Q'_M} > 0$. This characterizes policy (ii-a).

If the second crossing point with $K > 0$ does not exist or lies outside the participation set, the optimization program picks the boundary solution with $K = Q_M$, and from (1.40) we obtain (1.44). This characterizes policy (ii-b).

Figures 1.A1a-1.A1d illustrate these policies for specific functional forms in the $K - p_M$ space.[34]

34. Figures 1.A1a and 1.A1d are based on the functional forms (1.19) and $(\lambda, \omega, \gamma, \theta = c) \in \{(\frac{1}{3}, \frac{1}{2}, 10, 2), (\frac{3}{2}, \frac{1}{2}, 10, 2)\}$, respectively. Figures 1.A1b and 1.A1c employ the linear demand in (1.19), the capacity building cost function $C(K) = (\frac{\omega}{3}K + \frac{\sigma}{2})K^2$, and $(\lambda, \omega, \sigma, \gamma, \theta = c) \in \{(\frac{3}{2}, \frac{1}{2}, \frac{1}{200}, 10, 2), (\frac{3}{2}, \frac{1}{15}, \frac{1}{200}, 10, 2)\}$.

Solutions are marked by a bold point on these figures.

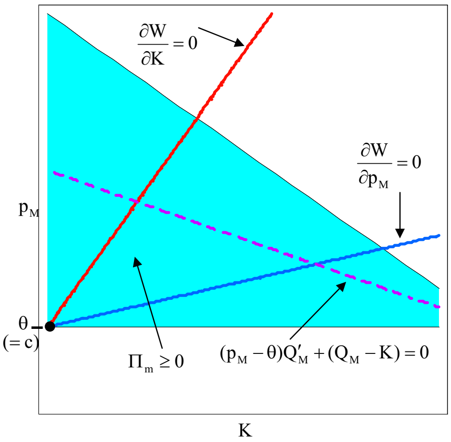

Figure 1.A1a: *Policy (i)*

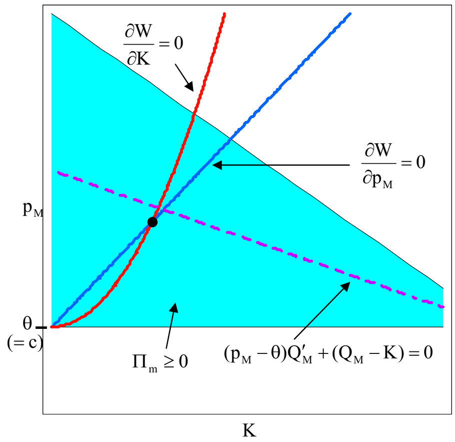

Figure 1.A1b: *Policy (ii-a)*

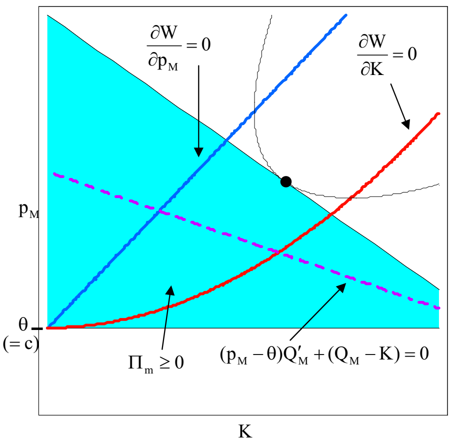

Figure 1.A1c: *Policy (ii-b)*

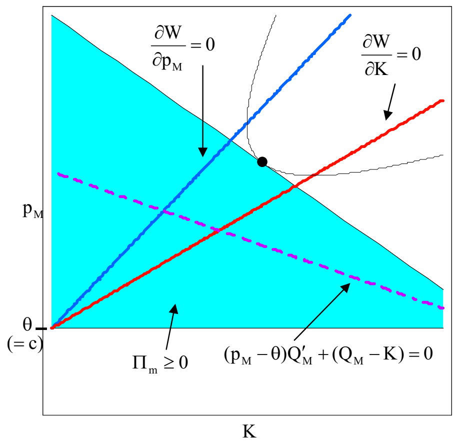

Figure 1.A1d: *Policy (ii-b)*

The no-cost-gap-with-fixed-cost case:

When $\theta - c = 0$ and $F_m > 0$, the crossing point of the functions representing (1.36) and (1.37) at which $K = 0$ and $p_M = \theta$ $(= c)$ does not belong to the participation set. However, a policy that prescribes $K = 0$ might still be optimal if F_m is high enough to satisfy (1.35) with equality, i.e., if $F_m = -\frac{\lambda}{1+\lambda}\frac{Q_M^2}{Q_M'}$. We see from (1.45) that $-\frac{\lambda}{1+\lambda}\frac{Q_M}{Q_M'} \equiv (p_M - \theta)$ $(= p_M - c)$, and hence the constraint on the fixed cost can be rewritten as $F_m = (p_M - \theta)Q_M$ $(= (p_M - c)Q_M)$. This characterizes policy (i).

If $F_m < -\frac{\lambda}{1+\lambda}\frac{Q_M^2}{Q_M'}$, only policies with $K > 0$ may arise. Following the reasoning used in the previous case, if a second crossing point of the functions representing (1.36) and (1.37) exists *and belongs to the participation set, i.e., using (1.34) and (1.36), if* $F_m < -\lambda K \frac{(Q_M - K)}{Q'_M}$*, this interior point, which from (1.37) is characterized by* $(1+\lambda)[c + C'(K)] - \lambda p_M = \theta \ (= c)$*, is picked up as the solution of the constrained welfare maximization program. This characterizes policy (ii-a).*

If the second crossing point with $K > 0$ *does not exist or lies outside the participation set, the optimization program picks the boundary solution satisfying (1.31), (1.32), and (1.40). These conditions are rewritten, respectively, as (1.46), (1.47) and (1.48). This corresponds to policy (ii-b). Figures 1.A2a-1.A2d illustrate these policies for specific functional forms.*[35]

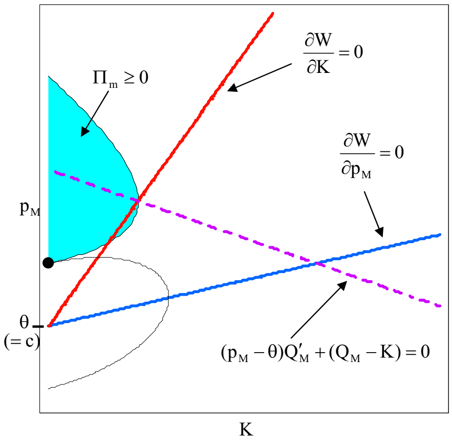

Figure 1.A2a: *Policy (i)*

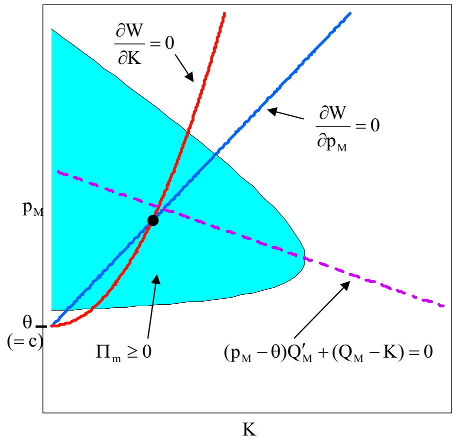

Figure 1.A2b: *Policy (ii-a)*

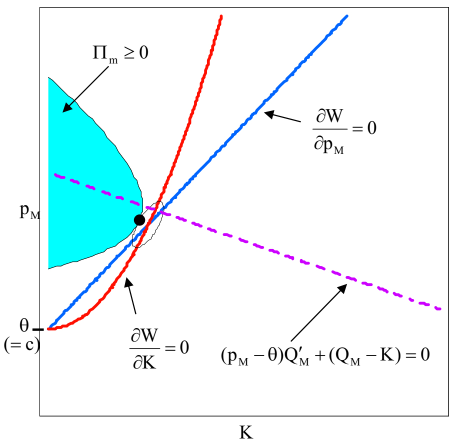

Figure 1.A2c: *Policy (ii-b)*

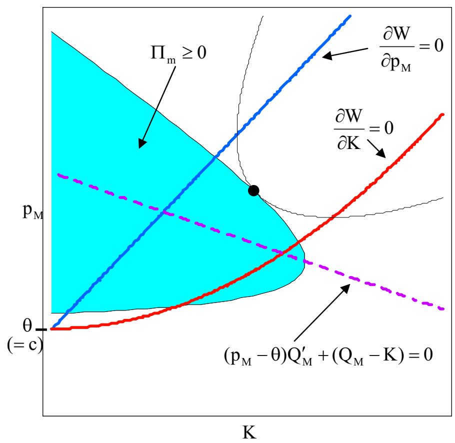

Figure 1.A2d: *Policy (ii-b)*

35. Figure 1.A2a has the same underlying functional forms and parameters as Figure 1.A1a with $F_m = 10.24$. Figures 1.A2b and 1.A2c employ the same assumptions as Figure 1.A1-b with $F_m = 3$ and $F_m = 10$, respectively. Finally, Figure 1.A2d uses the specification and parameter values in Figure 1.A1c with $F_m = 3$.

The with-cost-gap-no-fixed-cost case:

When $\theta - c > 0$, the functions representing (1.36) and (1.37) do not cross at $K = 0$, but we know that they cross at most once at a point where $K > 0$. Applying the same reasoning as above, if indeed they cross once it must satisfy $\lambda^2 K = (1+\lambda)Q'_M[(\theta - c) - C'(K)]$, rewritten as (1.49). To insure that this crossing point belongs to the participation set, (1.37) cannot be satisfied when this constraint is binding (in which case $K = Q_M$), i.e., $(1+\lambda)[c + C'(Q_M)] - \lambda p_M > \theta$. Substituting p_M from (1.42) yields $0 < (\theta - c) < C'(Q_M) + \frac{\lambda^2}{1+\lambda}\frac{Q_M}{Q'_M}$. This condition together with (1.41), (1.42), and (1.49) characterizes policy (i).

Again, if the crossing point with $K > 0$ does not exist or lies outside the participation set, the maximization program picks the boundary solution with $K = Q_M$, and from (1.40) we obtain (1.44). This defines policy (ii).

For an illustration of these policies in the $K - p_M$ space the reader may see Figures 1.3a and 1.3b in section 1.4.

The with-cost-gap-with-fixed-cost case:

By now the reader should realize that the proof of this case clearly combines steps from those of the no-cost-gap-with-fixed-cost and the with-cost-gap-no-fixed-cost case, and hence is omitted. ■

Proof of Proposition 1.3 *Before considering the four cases, let us recall from our discussion that precedes the proposition in the text that $K = 0$ is never a solution to the constrained welfare maximization program.*

The no-cost-gap-no-fixed-cost case:

When $\theta - c = 0$ and $F_m = 0$, clearly the system of first-order conditions (1.62)-(1.66) does not admit a solution with $K = Q_M$. Indeed, direct substitution of $K = Q_M$ into (1.66) leads to the violation of (1.62). Therefore, in this case the only solution entails $0 < K < Q_M$ and satisfies (1.62), (1.63), and (1.66), rewritten as (1.68), (1.69), and (1.70). Figures 1.A3a and 1.A3b show the unique solution under this policy for two different sets of parameter values.[36]

36. Figure 1.A3a and A3b draw on the same assumptions of Figure 1.A1a and 1.A1d respectively.

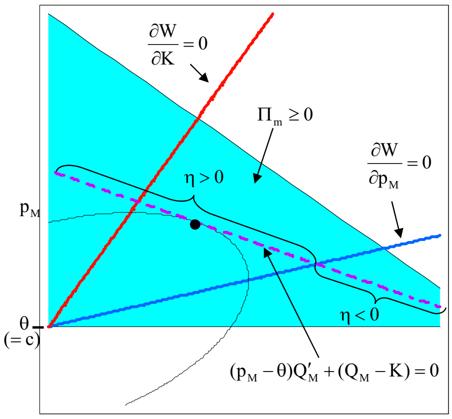

Figure 1.A3a: *Policy (i)*

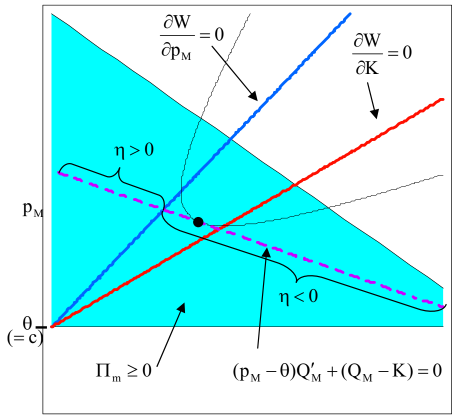

Figure 1.A3b: *Policy (i)*

The no-cost-gap-with-fixed-cost case:

When $\theta - c = 0$ and $F_m > 0$, the capacity-price pair that maximizes the firm's profit, defined by (1.66), belongs to the participation set if (1.65) holds with a strict inequality, i.e., if the fixed cost belongs to the interval $0 < F_m < -\frac{(Q_m - K)^2}{Q'_M}$. Since by definition an interior solution satisfies (1.67), which stems from (1.62), (1.63), and (1.66), pricing and capacity building obey (1.68)-(1.70) obtained in the previous case. Finally, given that $\phi = 0$, (1.63) can be rewritten as $(1 + \lambda)[c + C'(K)] - \lambda p_M = \theta + \eta$. This characterizes policy (i).

If the tangency point between a welfare level curve and the function representing the profit-maximization constraint, defined by (1.67), does not belong to the participation set, transport capacity is used by the planner as a residual instrument to make the local monopoly just break even. From the discussion in the text that precedes the statement of Proposition 1.3, we know that the social planner will choose a point where the boundary of the participation set has an infinite slope. From (1.39), we see that such a point satisfies $Q'_M F_m + (Q_M - K)^2 = 0$, rewritten as (1.73). Rewriting the first-order condition with respect to price (1.62), and plugging the condition $Q'_M F_m + (Q_M - K)^2 = 0$ into it, yields (1.71). Finally, (1.62) and (1.63) yield (1.72). This defines policy (ii).

The nature of these policies is illustrated in the $K - p_M$ space for particular functional forms and parameter values in Figures 1.6a and 1.6b in section 1.5. The reader should abstract that in this case the functions representing the first order conditions (1.36) and (1.37) cross at $(0, c)$ as there is no cost gap.

The with-cost-gap-no-fixed-cost case:

To insure that the solution to (1.67) belongs to the interior of participation set, provided $\phi = 0$, *(1.63) cannot be satisfied when the participation constraint is binding (in which case $K = Q_M$), i.e.,* $(1+\lambda)[c+C'(Q_M)]-\lambda p_M > \theta+\eta$*. Replacing p_M and η for their values obtained from direct substitution of $K = Q_M$ into (1.62) and (1.66) yields the condition* $0 < (\theta - c) < C'(Q_M) - \frac{1}{2}\frac{\lambda}{1+\lambda}\frac{Q_M}{Q'_M}$*. This characterizes policy (i). Otherwise, the solution is $K = Q_M$, $p_M = \theta$ and $\eta < 0$, under which rewriting (1.62) and (1.63) yields (1.75). This defines policy (ii).*

Figures 1.A4a and 1.A4b illustrate these two policies.[37]

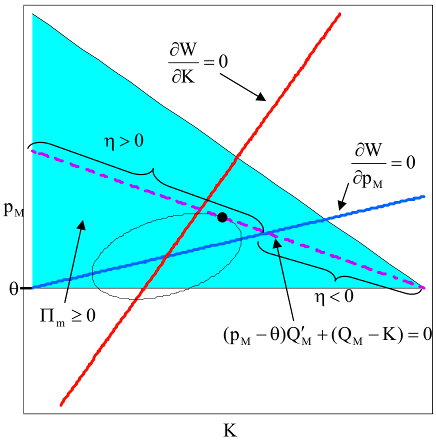

Figure 1.A4a: *Policy (i)*

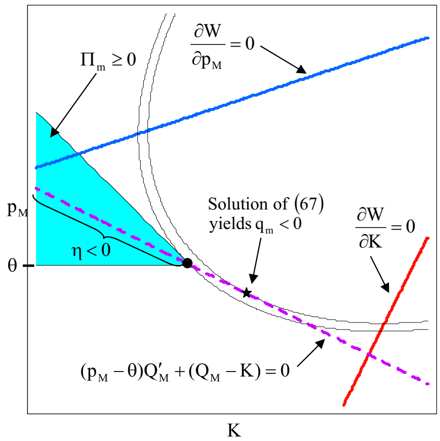

Figure 1.A4b: *Policy (ii)*

More specifically, Figure 1.A4b shows the case where the marginal cost gap hits the upper bound given by (1.30). In such a case the solution under the scheme where both price and capacity are available to the planner to control market power yields $p_M = \theta$ and $q_m = 0$. For such an extreme value for the marginal cost gap, the solution to (1.67) is such that $q_m < 0$ and hence the optimization program picks up the point at which the profit-maximization constraint and the boundary of the participation set cross each other, which for $F_m = 0$ is defined by $p_M = \theta$ and $K = Q_M$.

The with-cost-gap-with-fixed-cost case:

The proof of this last case just cross-uses the arguments that prove the no-cost-gap-with-fixed-cost and the with-cost-gap-no-fixed-cost cases. It is therefore omitted. However, the policies obtained in this case are illustrated in the $K - p_M$ space, for particular functional forms and parameter values, in Figures 1.6a and 1.6b of section 1.5. ■

37. Figures 1.A4a and 1.A4b employ the functional forms (1.19) with parameter values $(\lambda, \omega, \gamma, \theta, c) \in \{(\frac{1}{3}, \frac{1}{2}, 10, 3, 2), (\frac{3}{2}, \frac{1}{2}, 10, 5.43, 2)\}$.

Proof of Proposition 1.4 *As $C'(K) \geq 0$ and looking at (1.7) and (1.32), we have*

$$\begin{aligned} sign[K^B - K^A] &= sign[(1+\lambda)[C'(K^B) - C'(K^A)]] \\ &= sign[(\lambda - \phi^B)(p_M^B - \theta) + \nu^A] \end{aligned} \qquad (1.A1)$$

Given that $\nu^A \geq 0$, it follows from (1.A1) that if $(\lambda - \phi^B) \geq 0$, $sign[K^B - K^A] \geq 0$. When $(\lambda - \phi^B) < 0$, we need to show that $sign[K^B - K^A] < 0$. We do so, by analyzing the optimal capacity level only in the case where $sign[K^B - K^A]$ might be ambiguous, i.e., when both ϕ^B and ν^A are strictly positive.

If $\phi^B > 0$ and $\nu^A > 0$, from (1.81)-(1.84), $\frac{\partial W^A}{\partial p_M^A} > 0$, $\frac{\partial W^A}{\partial K^A} > 0$, and $\frac{\partial W^B}{\partial K^B} > 0$.[38] *Under B, the solution lies on the boundary of the participation set and is characterized by (1.40), rewritten as $-\frac{\partial W^B/\partial K}{\partial W^B/\partial p_M} = \frac{(p_M - \theta)}{\partial \Pi_m^B/\partial p_M}$. Using (1.85) and (1.86), we obtain $-\frac{\partial W^B/\partial K}{\partial W^B/\partial p_M} = -\frac{\partial W^A/\partial K}{\partial W^A/\partial p_M} = \frac{(p_M - \theta)}{\partial \Pi_m^B/\partial p_M}$. This says that at the point where the boundary of the participation set is tangent to a welfare level curve in B, the former is also tangent to a welfare level curve in A. Since $\nu^A > 0$, the solution under A has $K^A = Q_M$ characterized by (1.18). Figures 1.A5a and 1.A5b illustrate this feature for both cases where $F_m > 0$ and $F_m = 0$.*[39]

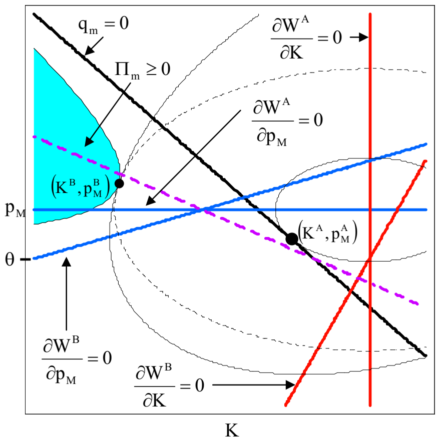

Figure 1.A5a: *Solutions with $\nu^A > 0$, $\phi^B > 0$, and $F_m > 0$*

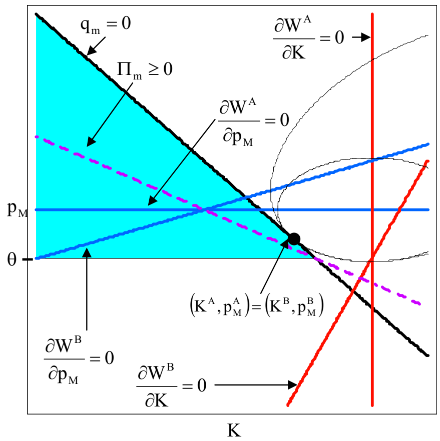

Figure 1.A5b: *Solutions with $\nu^A > 0$, $\phi^B > 0$, and $F_m = 0$*

We know from section 1.4 that the participation set is included in the nonnegativity set for $p_M \geq \theta$ (see Figure 1.A5a). Hence, any boundary solution under scheme B yields a level of capacity no greater than that under A, i.e., $K^B \leq K^A$. Note that in the particular case where $F_m = 0$ (see Figure 1.A5b), the participation and nonnegativity sets coincide for $p_M \geq \theta$ and the solution

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38. To simplify notation, from now on we define $\frac{\partial W^i}{\partial p_M^i} \equiv \frac{\partial W^i}{\partial p_M}|_{p_M = p_M^i}$ and $\frac{\partial W^i}{\partial K^i} =\equiv \frac{\partial W^i}{\partial K}|_{K=K^i}$ for $i \in \{A, B, C\}$.

39. These figures employ the functional forms (1.19) with parameter values $(\lambda, \omega, \gamma, \theta, c) = (1/3, 1/2, 10, 5, 2)$. The size of the fixed cost is $F_m = 3$ and $F_m = 0$, respectively.

under B is characterized by (1.40) which is identical to (1.18), and hence $K^B = K^A$*. The above argument allows us to conclude that when* $F_m = 0$, $K^B \geq K^A$*.* ■

Proof of Proposition 1.5 *Direct comparison of the first-order conditions with respect to capacity under schemes B and C, (1.32) and (1.63), yields*

$$\begin{aligned} sign[K^C - K^B] &= sign[(1+\lambda)[C'(K^C) - C'(K^B)]] \\ &= sign[(\lambda - \phi^C)(p_M^C - \theta) - (\lambda - \phi^B)(p_M^B - \theta) + \eta^C] \end{aligned} \quad (1.A2)$$

We proceed to analyze the behavior of (1.A2) *for the possible realizations of* ϕ^B, ϕ^C*, and* η^C*, assuming first that the latter is positive and then negative.*

If $\eta^C > 0$ *and* $\phi^C = 0$*, we see from (1.87) and (1.88) that the constrained solution of* C*, which lies inside the participation set, satisfies* $\frac{\partial W^B}{\partial p_M^C} < 0$, $\frac{\partial W^B}{\partial K^C} < 0$*, and* $\frac{\partial \Pi_m}{\partial p_M^C} = 0$*.*[40] *Two cases might arise according to whether or not* ϕ^B *is zero. First, when the solution to the constrained program under B is interior,* $\phi^B = 0$, $\frac{\partial W^B}{\partial p_M^B} = \frac{\partial W^B}{\partial K^B} = 0$*. It is straightforward to see that* $K^C > K^B$ *and* $p_M^C > p_M^B$*. See Figure 1.A3a. Second, when the solution to the constrained welfare maximization program under B yields* $\phi^B > 0$*, we see from (1.84) that* $\frac{\partial W^B}{\partial K^B} > 0$*. Given that* $\eta^C > 0$*, this solution satisfies* $\frac{\partial W^B}{\partial p_M^B} < 0$*.*[41] *Putting these properties together, we see from (1.83) that* $\frac{\partial \Pi_m}{\partial p_M^B} > 0$*, saying that at this boundary solution under B, firm's marginal revenue is lower than its marginal cost. It then directly follows that* $p_M^C > p_M^B$ *and* $K^C > K^B$*.*

If $\eta^C > 0$ *and* $\phi^C > 0$*, we know from section 1.5 that the solution of the constrained program under C is at the point where the boundary of the participation set is infinitely sloped, which has the largest K of all the points in the participation set. From (1.87)-(1.89), the constrained solution of C satisfies* $\frac{\partial W^B}{\partial p_M^C} < 0$ *and* $\frac{\partial \Pi_m}{\partial p_M^C} = 0$*. Again, two cases are to be considered. First, if the solution under scheme B yields* $\phi^B = 0$*, since it lies in the interior of the participation set, it automatically implies a lower level of capacity than that under C, i.e.,* $K^C > K^B$*. Second, if the solution of B yields* $\phi^B > 0$*, we see from (1.84) that* $\frac{\partial W^B}{\partial K^B} > 0$*. From* $\eta^C > 0$*, it should be the case that* $\frac{\partial W^B}{\partial p_M^B} < 0$*. Using the latter inequality in (1.83) we obtain* $\frac{\partial \Pi_m}{\partial p_M^B} > 0$*, and hence* $p_M^C > p_M^B$ *and* $K^C > K^B$*. See Figure 1.6b.*

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40. It is worthwhile noting that the existence of this type of solution depends of the fact that there exists a $K > 0$ satisfying the condition $Q'_M\left[C''(K) - \frac{C'(K)}{K}\right] - \frac{\lambda K}{Q'_M} Q''_M C''(K) < 0$. When the former condition is not satisfied, no solution with $\eta^C > 0$ and $\phi^C = 0$ exists.

41. If we assume that the boundary solution of B lies on the region with $\frac{\partial W^B}{\partial p_M^B} > 0$, the tangency between a welfare level curve and the boundary of the participation set lies in their negatively sloped regions. By definition, when the boundary of the participation set is negatively sloped, it lies to the right of the function representing the profit-maximization constraint. Then, the solution to the constrained program in C should be characterized by $\frac{\partial W^B}{\partial p_M^C} > 0$. But, this contradicts $\eta^C > 0$.

To sum up, so far we have that when $\eta^C > 0$, $K^C > K^B$ *and* $p_M^C > p_M^B$. *Let us now consider the cases where the Lagrange multiplier of the profit-maximization constraint* η^C *is negative.*

When $\eta^C < 0$ *and* $\phi^C = 0$, *we see from (1.87)-(1.89) that the constrained solution of C satisfies* $\frac{\partial W^B}{\partial p_M^C} > 0$, $\frac{partial W^B}{\partial K^C} > 0$, *and* $\frac{\partial \Pi_m}{\partial p_M^C} = 0$. *Two cases arise depending on the sign of* ϕ^B. *First, when* $\phi^B = 0$, *we directly see that* $K^C < K^B$ *and* $p_M^C < p_M^B$. *Second, when* $\phi^B > 0$, *the boundary solution satisfies* $\frac{\partial W^B}{\partial p_M^B} > 0$, $\frac{\partial W^B}{\partial K^B} > 0$, *and* $\frac{\partial \Pi_m}{\partial p_M^B} < 0$. *In this case,* $(\frac{\partial W^B}{\partial K^C} - \frac{\partial W^B}{\partial K^B}) = -\eta^C - \phi^B(p_M^B - \theta) \gtrless 0$, *and hence the capacity comparison is ambiguous. It is worth noting that while the capacity ranking is ambiguous, that of pricing is not. Indeed, since* $\frac{\partial \Pi_m}{\partial p_M^B} < 0$, *we obtain* $p_M^C < p_M^B$.

When $\eta^C < 0$ *and* $\phi^C > 0$, *we see from (1.87)-(1.89) that the constrained solution of C satisfies* $\frac{\partial W^B}{\partial p_M^C} > 0$, $\frac{\partial W^B}{\partial K^C} > 0$, *and* $\frac{\partial \Pi_m}{\partial p_M^C} = 0$. *The only case to be analyzed then is when* $\phi^B > 0$.[42] *Under this case, since* $\eta^C < 0$, *we have* $\frac{\partial W^B}{\partial p_M^B} > 0$, $\frac{\partial W^B}{\partial K^B} > 0$, *and* $\frac{\partial \Pi_m}{\partial p_M^B} < 0$. *In this case,* $(\frac{\partial W^B}{\partial K^C} - \frac{\partial W^B}{\partial K^B}) = -\eta^C - \phi^B(p_M^B - \theta) + \phi^C(p_M^C - \theta) \gtrless 0$, *and again the capacity comparison is ambiguous. Note that from* $\partial \Pi_m / \partial p_M^B < 0$, *we obtain* $p_M^C < p_M^B$.

Summarizing, we see that when $\eta^C < 0$, $p_M^C < p_M^B$, *but the capacity ranking remains undetermined. However, this indeterminacy is waived when* $\theta = c$ *and* $F_m = 0$. *Indeed, we see from Propositions 1.2 and 1.3 that in this case* $(\lambda - \phi^B) > 0$, *and* $\phi^C = 0$, *respectively. Thus,* $sign[K^C - K^B] = sign[\eta^C]$. *For an illustration, see Figures 1.A3a and 1.A3b.* ■

Proof of Proposition 1.6 *A cross-examination of the first-order conditions with respect to capacity under schemes A and C, (1.7) and (1.63), shows that*

$$\begin{aligned} sign[K^C - K^A] &= sign[(1+\lambda)[C'(K^C) - C'(K^A)]] \\ &= sign[(\lambda - \phi^C)(p_M^C - \theta) + \eta^C + \nu^A] \end{aligned} \tag{1.A3}$$

We proceed to analyze the behavior of (1.A3) *for the possible realizations of* ν^A, ϕ^C, *and* η^C, *assuming first that the latter is positive and then negative. If* $\eta^C > 0$ *and* $\phi^C = 0$, *from (1.91) we get that the solution under C satisfies* $\frac{\partial W^A}{\partial K^C} = -\lambda(p_M^C - \theta) - \eta^C < 0$. *The only case that is relevant to examine is when* $\nu^A = 0$.[43] *In this case,* $\frac{\partial W^A}{\partial K^A} = 0$ *and then it is easy to see that* $K^C > K^A$.

If $\eta^C > 0$ *and* $\phi^C > 0$, *two cases might arise according to whether or not* $\nu^A = 0$. *When* $\nu^A = 0$, *we see from (1.91) that the solution under C satisfies* $\frac{\partial W^A}{\partial K^C} = -(\lambda - \phi^C)(p_M^C - \theta) - \eta^C \gtrless 0$, *and hence the capacity comparison is undetermined. When* $\nu^A > 0$, *the solution under A satisfies* $K^A = Q_M$ *and we directly conclude that* $K^C \leq K^A$.

42. Indeed, the largest K attained by the participation set is strictly lower than that obtained from the condition $\frac{\partial W^B}{\partial p_M^B} = \frac{\partial W^B}{\partial K^B} = 0$ which defines an interior solution under B.

43. Indeed, if $\nu^A > 0$, we see from (1.82) and (1.91) that $\eta^C = -\nu^A - \lambda(p_M^A - \theta)$. Since $\phi^C = 0$, it should be the case that under A, $p_M^A > \theta$ and hence $\eta^C < 0$, a contradiction.

Summarizing, we have obtained that $sign[K^C - K^A] = sign[\eta^C]$ *when* $\eta^C > 0$ *but only in the case where* $\phi^C = 0$*. Let us now consider the case where the Lagrange multiplier of the profit-maximization constraint* η^C *is negative. If* $\eta^C < 0$ *and* $\phi^C \geq 0$*, the capacity ranking is undetermined since the solution under C satisfies* $\frac{\partial W^A}{\partial K^C} = -(\lambda - \phi^C)(p_M^C - \theta) - \eta^C \gtrless 0$.

Finally, if $\theta = c$ *and* $F_m = 0$*, we see from Propositions 1.1 and 1.3 that* $K^A = 0$ *and* $K^C > 0$*, respectively. See Figures 1.A3a and A3b. Thus, independently of the sign of* η^C*,* $K^A < K^C$*.* ■

Simulation results *This section of the appendix presents the simulation material underlying Figures 7a-9b. These simulations yield the optimal levels of the endogenous variables achieved by schemes A, B, and C assuming that* $Q_M(p_M) = \gamma - p_M$*,* $C(K) = \frac{\omega}{2}K^2$*,* $\gamma > c > 0$*,* $\omega > 0$*,* $\{\lambda, \omega, \gamma, c\} = \{1/3, 1/2, 10, 2\}$ *leading to* $\omega(1+\lambda) - \lambda^2 > 0$*,* $\{\lambda, \omega, \gamma, c\} = \{1/3, 1/15, 10, 2\}$ *leading to* $\omega(1+\lambda) - \lambda^2 < 0$*, and* $(\theta - c)$ *and* F_m *varying continuously in the intervals [0,3.9] and [0,7] respectively.*

The information is displayed in Figures 1.A6a and 1.A6b (scheme A), 1.A7a and 1.A7b (scheme B), and 1.A8a and 1.A8b (scheme C) below. Each figure first shows the capacity (price) levels achieved under the corresponding control scheme for alternative values of the marginal cost gap and fixed cost in a 3D plot. Then, it exhibits a contour plot that represents the alternative combinations of $(\theta - c)$ *and* F_m *that yield the same level of capacity (price). The regions between these contour lines are shaded and colored with gray levels running from black to white with increasing capacity (price).*

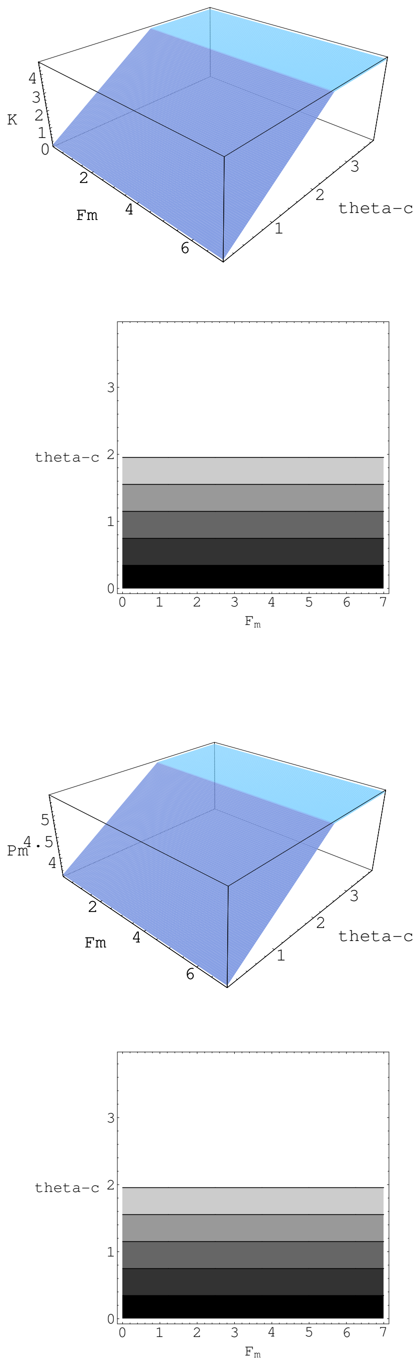

Figure 1.A6a: K^A *and* p_M^A *with* $\omega(1+\lambda)-\lambda^2>0$

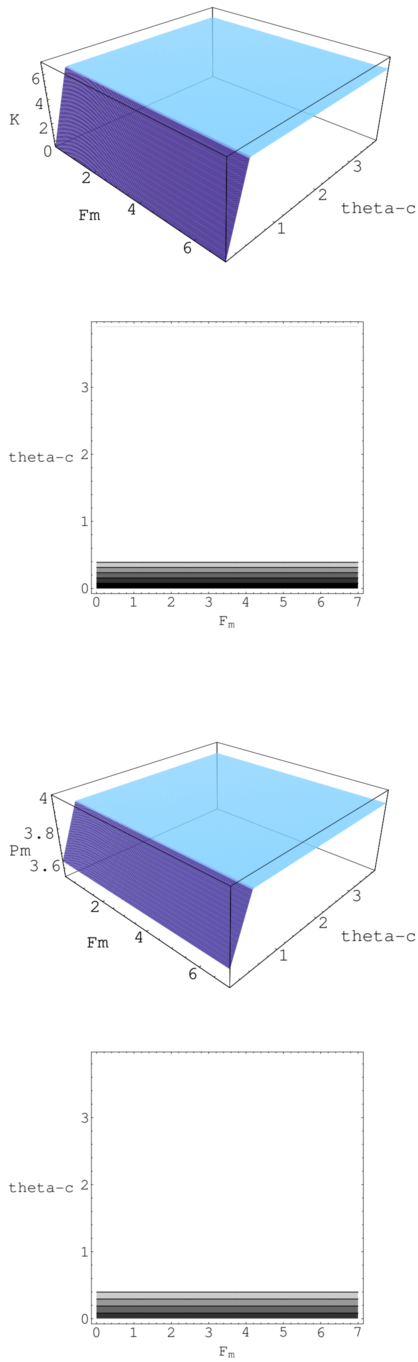

Figure 1.A6b: K^A *and* p_M^A *with* $\omega(1+\lambda)-\lambda^2<0$

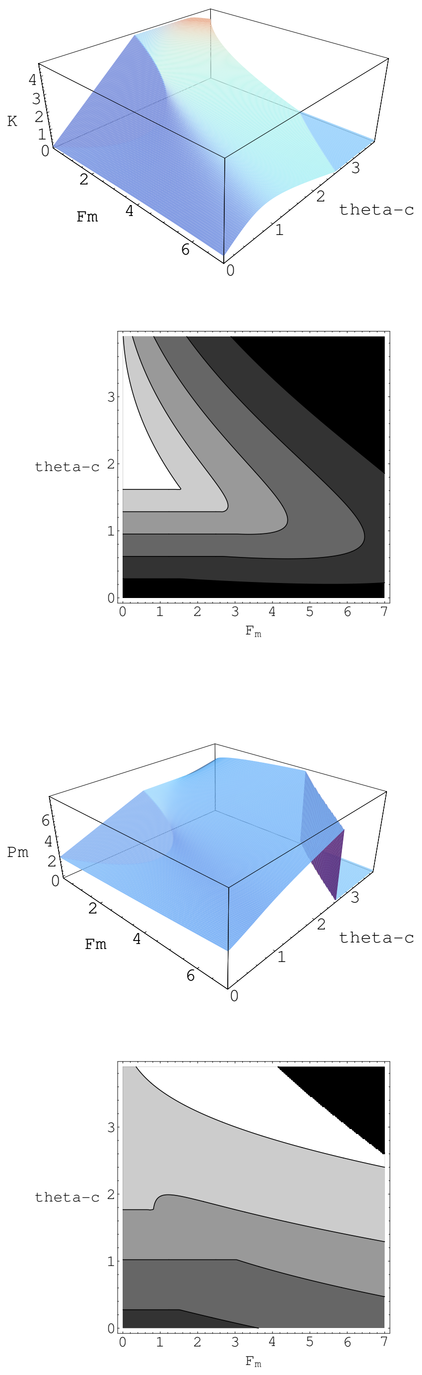

Figure 1.A7a: *K^B and p_M^B with $\omega(1+\lambda)-\lambda^2>0$*

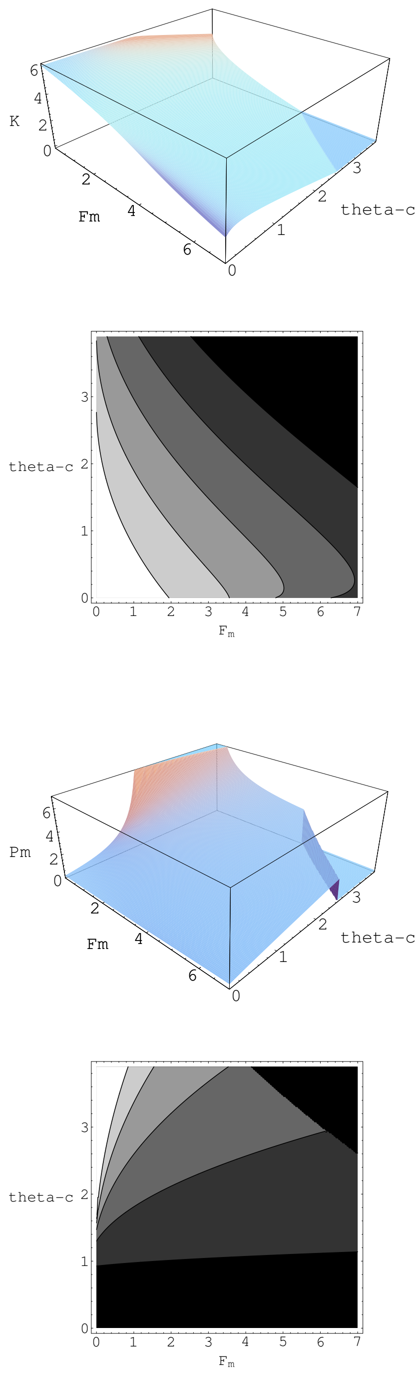

Figure 1.A7b: *K^B and p_M^B with $\omega(1+\lambda)-\lambda^2<0$*

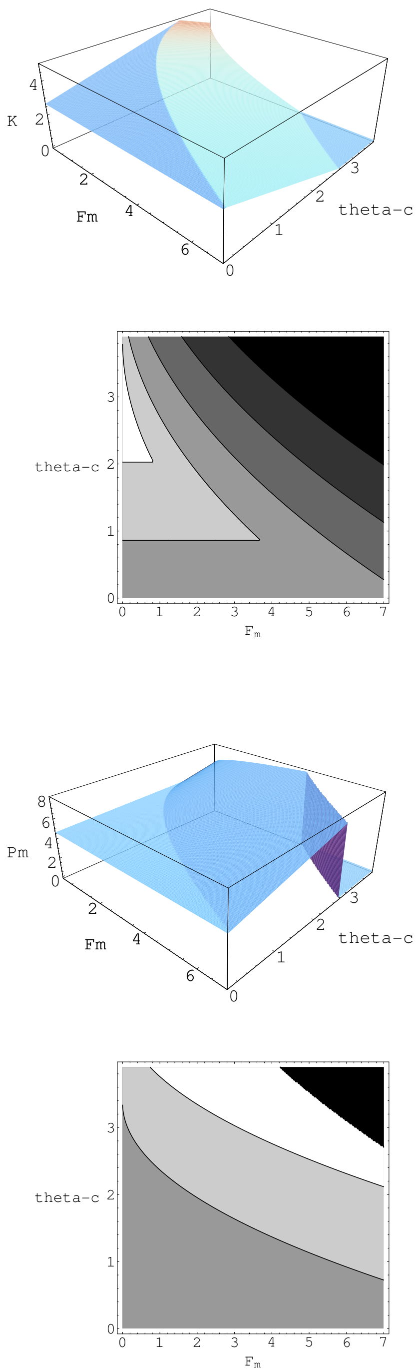

Figure 1.A8a: K^B *and* p_M^B
with $\omega(1+\lambda)-\lambda^2>0$

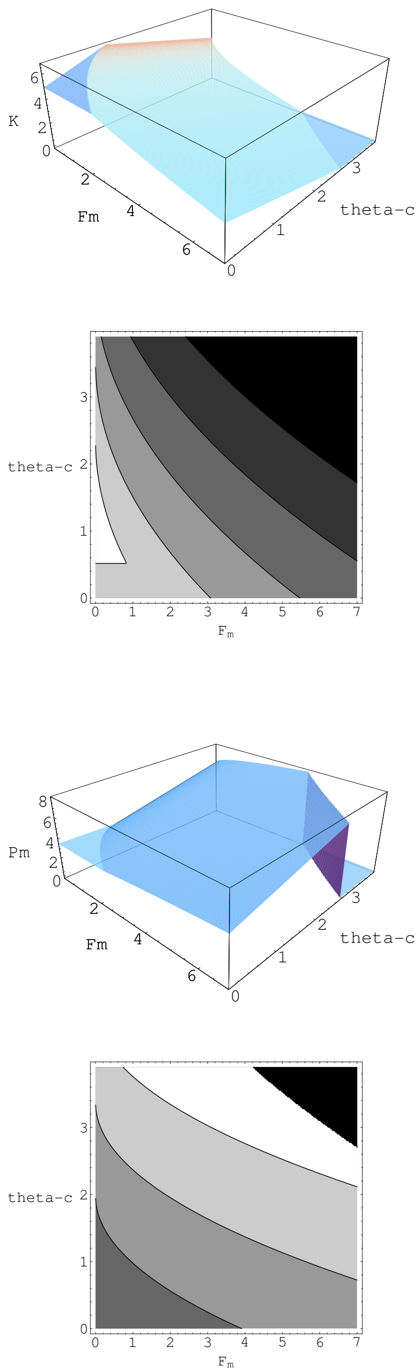

Figure 1.A8b: K^B *and* p_M^B
with $\omega(1+\lambda)-\lambda^2<0$

Chapter 2

Regulation of regional monopolies in natural gas markets

2.1 Introduction

This chapter explores the issue of how the regulator's objective of mitigating market power, typically emphasized in policy reforms of the natural gas industry, should affect the capacity of transport networks.[1] With the advent of liberalization, large investments have been devoted to building pipelines in anticipation of high demand, on the one hand, but also as safeguards against the possible emergence of regional monopolies, on the other hand.[2] The goal of this chapter is to investigate this second role of transport capacity of pipelines, i.e., network capacity as an instrument to mitigate the welfare consequences of monopoly power that can be exercised in regional gas commodity markets.[3]

Following an approach initiated by Cremer et al. (2003) for the case of perfect competition and Cremer and Laffont (2002) and Chapter 1 of this dissertation for

1. Such reforms have for example been conducted over the last two decades, first in the US and the UK and more recently in the EU. See Cremer et al. (2003) for an overview of these reforms.

2. This last point has been made clear by Borenstein et al. (2000) for the case of the electricity industry.

3. Such "local monopolies" can indeed be expected to appear in the EU at least in the early stages of the liberalization process that has been initiated in the late 90s.

the case of imperfect competition under complete information, we develop a model of the regulator-firm relationship under incomplete information that allows us to highlight this issue. We assume that the regulator disposes of two potential means of affecting the working of a regional monopoly market besides building a pipeline link of a given capacity between this market and a competitive market providing an alternative source of gas: operating transfers between the firm and consumers and regulating the firm's price. We derive and analyze the optimal policies assuming different sets of available regulatory instruments. By focusing on the capacity variable, we then investigate how information and incentive issues affect pipeline capacity. Finally, when neither transfers nor price control are possible, we explore the effect on capacity of the regulator's ability to commit to investments in the transport network.

This chapter is organized as follows. The next section presents the simple network configuration considered and the two basic information structures assumed; one, used as a benchmark, in which the regulator has some uncertainty about the firm's marginal cost at the time he sets the level of transport capacity, and another in which he faces adverse selection due to the fact that marginal cost is privately known by the firm. The next two sections are structured in a similar fashion but with two different assumptions about the availability of regulatory instruments: the optimal regulatory regimes under uncertainty and asymmetric information are derived and then compared. In section 2.3, the regulator can use transfers and price to reduce monopoly rents while in section 2.4 transfers are not allowed. Section 2.5 considers a decentralized environment in which the firm is allowed to maximize its profits and the regulator can only engage in investments in transport capacity. We then explore the role of commitment to these investments by the regulator. Section 2.6 summarizes the main policy implications suggested by this work. Formal proofs are given in the appendix.

2.2 Basic market configuration and information structures

Consider a regional natural gas commodity market, market M, covered by a firm, firm m, producing with a technology $C_m(q_m) = \widetilde{\theta} q_m + F_m$, where q_m is output, $\widetilde{\theta}$ is marginal cost, and F_m is fixed cost.[4] Gas is also supplied at marginal cost c in a competitive market, market C_p, which is geographically distinct from market M but could be linked to it through a pipeline of capacity K built at cost $C(K)$, where $C(\cdot)$ is increasing convex with $C'(0) = 0$ and $C''(0) > 0$. We assume that $\widetilde{\theta} \in \{c, \theta\}$ where θ and c are known and $\theta > c$ so that the regional monopoly's marginal cost is at least as large as that in the competitive market. Gas produced under competitive conditions in market C_p and shipped into the regional market M should counter the exercise of monopoly power by the firm (see Figure 2.1).

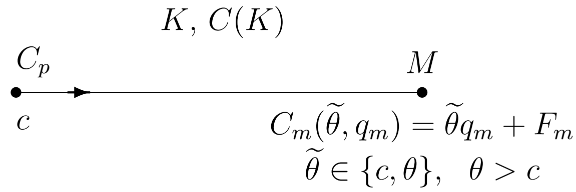

Figure 2.1: Market configuration

We indeed take the view that the fundamental reason for society to invest in a transport line linking these two markets is to allow imports of gas from market C_p into market M that would bring consumers the benefits of competition.[5] Let us note that those benefits should be balanced against, among other things, the firm's fixed cost which needs to be recovered. Letting $Q_M(\cdot)$ represent demand in market M assumed to be linear with $Q'_M(\cdot) < 0$ and $Q''_M(\cdot) = 0$, if a volume of gas corresponding to the pipeline full capacity K is shipped from the competitive market into the regional market, the firm remains a monopoly on the residual demand $Q_M(p_M) - K$ where p_M is market price.

4. The financing of the fixed cost F_m is always accounted for in the policies considered in this chapter. However, as will be made more precise later, we assume that it is bounded.

5. We focus on consumption in market M where market power is an issue.

Control of monopoly power is exercised by a regulator facing adverse selection.[6] More specifically, we assume that the regional monopoly privately knows the value of its marginal cost $\widetilde{\theta}$ whereas the regulator has only some prior beliefs that it takes on the values θ and c with probabilities α and $(1-\alpha)$ respectively. We further assume that regulation can be potentially implemented by means of three instruments: transfers between consumers and the firm, pricing of the gas commodity, and investment in transport capacity. We begin with the case where these three instruments are available to the regulator and then restrict the set of regulatory instruments by first removing transfers and then price.

Given that asymmetric information is a maintained hypothesis, we use as a situation of reference regulation with uncertainty only. Under this benchmark, the regulator first chooses the capacity of the pipeline. Then, nature draws $\widetilde{\theta}$ which is discovered by both the regulator and the firm. Finally, the regulator sets the levels of the remaining regulatory instruments. However, when determining the transport capacity level, the regulator is uncertain about the value of the firm's marginal cost $\widetilde{\theta}$. This timing of events is exhibited in Figure 2.2 below.

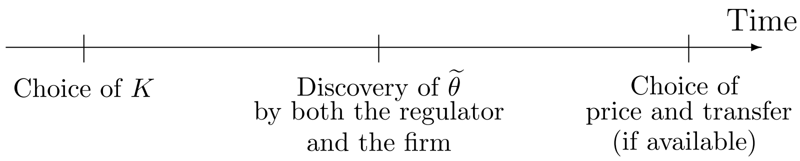

Figure 2.2: Sequence of events under uncertainty (benchmark)

To obtain the optimal policies corresponding to the various regulatory schemes under uncertainty one should be solving backward. First, at the price-(transfer- if available) setting stage the regulator maximizes ex-post social welfare under the ex-post constraints associated with the regulatory scheme for a given level of capacity. This yields the optimal price (and transfer) and the Lagrange multipliers associated with these constraints as functions of firm's type and network capacity. Second, at the capacity-setting stage, the regulator maximizes ex-ante welfare

6. The case of monopoly power control under complete information has been considered in Chapter 1.

under the ex-post constraints, accounting for optimal price (and transfer) and Lagrange multipliers functions obtained in the first stage. Since capacity is always controlled by the regulator, the solution of this sequential constrained welfare maximization program is the same as that obtained by maximizing ex-ante welfare with respect to the available regulatory instruments, under the ex-post constraints associated with the regulatory scheme.

The way we introduce asymmetric information follows the standard approach of the new regulatory economics. The timing of events is shown in Figure 2.3 below. The important point here is that, at the time of setting price and transfers (if available), the regulator has to offer an incentive compatible contract to the firm. In the same vein as in the case of the regulatory schemes under uncertainty, the optimal regulatory policies under asymmetric information are obtained by maximizing ex-ante social welfare under the complete set of ex-post constraints which now should include those guaranteeing incentive compatibility.[7]

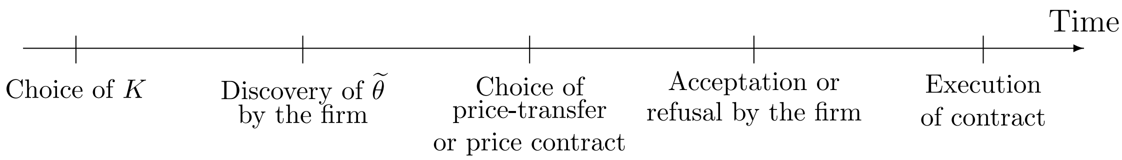

Figure 2.3: Sequence of events under asymmetric information

One of our objectives is to analyze, within a normative framework, the impact of asymmetric information on the size of the transport network. For a given control scheme and hence for a fixed set of available control instruments, we wish to characterize both the uncertainty (benchmark) and the asymmetric information regulatory mechanisms and compare the achieved optimal levels of pipeline capacity. This is what is carried out in the next two sections on the basis of an analysis of control schemes A and B with respectively $\{K, p_M, T\}$ and $\{K, p_M\}$ as the sets of available control instruments. This analysis highlights the effect of accounting for the firm's incentives on the transport network size when the regulator sets price besides capacity, i.e., controls firm's output, and can potentially use transfers.

7. See Laffont and Martimort (2002).

When the regulator can only control capacity, as is the case in scheme C, incentive compatibility constraints are implicit in both the uncertainty and the asymmetric information versions of this scheme which makes their comparison vacuous.[8] While regulation under schemes A and B is modeled under the standard assumption used in regulatory economics that the whole contractual bargaining power is put on the regulator's side, under regulation with scheme C there is no contractual relationship between the regulator and the firm. But, under C and assuming the timing of events in Figure 2.2, the regulator still has the ability to internalize the effect of firm's profit-maximization behavior on social welfare. Section 2.5 offers an exploration free of incentives issues of the effect of this ability on transport capacity.

2.3 Firm's incentives and transport capacity under scheme A

In this section we consider control scheme A in which, in addition to controlling transport capacity, K, and gas commodity price, p_M, the regulator can use public funds raised through taxes to make monetary transfers between consumers and the firm. Since taxation generates a deadweight loss, transferring T monetary units to the firm, costs taxpayers $(1 + \lambda)T$ where λ is the social cost of public funds. We let $S(\cdot)$ be the gross surplus of consumers in market M and $U(\widetilde{\theta})$ the utility of the firm of type $\widetilde{\theta}$ given by

$$U(\widetilde{\theta}) = (p_M(\widetilde{\theta}) - \widetilde{\theta})[Q_M(p_M(\widetilde{\theta})) - K] - F_m + T(\widetilde{\theta}) \tag{2.1}$$

Ex post social welfare is given by

$$\begin{aligned} W(\widetilde{\theta}) = &\Big\{S(Q_M(p_M(\widetilde{\theta}))) + \lambda p_M(\widetilde{\theta})Q_M(p_M(\widetilde{\theta}))\Big\} \\ &- \Big\{(1+\lambda)\Big[\widetilde{\theta}(Q_M(p_M(\widetilde{\theta})) - K) + cK + C(K) + F_m\Big]\Big\} - \lambda U(\widetilde{\theta}) \end{aligned} \tag{2.2}$$

8. That within scheme C incentive constraints are accounted for both under uncertainty and asymmetric information can be readily seen from the timings of events described in Figures 2.2 and 2.3.

This expression shows that social welfare is equal to the social value of total supply of gas (gross consumer surplus plus fiscal value of revenues from gas supply), minus the social cost of gas supply, minus the social opportunity cost of the firm's rent.[9]

The firm's participation and output nonnegativity constraints that will be accounted for in the upcoming regulatory programs are given by

$$U(\widetilde{\theta}) \geq 0 \tag{2.3}$$

$$q_m(\widetilde{\theta}) = Q_M(p_M(\widetilde{\theta})) - K \geq 0 \tag{2.4}$$

With control scheme A, given the timings described in Figures 2.2 and 2.3, optimal regulation under uncertainty and asymmetric information both entail maximizing ex ante social welfare

$$\mathrm{E}[W(\widetilde{\theta})] = \alpha W(\theta) + (1-\alpha) W(c) \tag{2.5}$$

with respect to $p_M(\theta)$, $p_M(c)$, $U(\theta)$, $U(c)$, and K, and taking into account the ex-post constraints[10]

$$U(\theta) \geq 0 \quad (\overline{\phi}) \tag{2.6}$$

$$U(c) \geq 0 \quad (\underline{\phi}) \tag{2.7}$$

$$q_m(\theta) \geq 0 \quad (\overline{\nu}) \tag{2.8}$$

$$q_m(c) \geq 0 \quad (\underline{\nu}) \tag{2.9}$$

where the corresponding Lagrange multipliers are shown in parentheses. Hereafter, we use the definitions $\overline{p}_M \equiv p_M(\theta)$, $\underline{p}_M \equiv p_M(c)$, $\overline{U} \equiv U(\theta)$, $\underline{U} = U(c)$, $\overline{q}_m \equiv q_m(\theta)$, $\underline{q}_m \equiv q_m(c)$, $\overline{Q}_M \equiv Q_M(p_M(\theta))$, $\underline{Q}_M \equiv Q_M(p_M(c))$, and $Q'_M \equiv Q'_M(p_M(\theta))$ $(= Q'_M(p_M(c))$.

9. For more details on the derivation of this expression of social welfare and its components' economic interpretation, refer to Chapter 1 (section 1.3).

10. In fact, under asymmetric information, incentive compatibility constraints need to be added.

2.3.1 Scheme A under uncertainty

Under control scheme A with uncertainty, the regulatory program merely consists in maximizing (2.5) with respect to $p_M(\theta)$, $p_M(c)$, $U(\theta)$, $U(c)$, and K, subject to the constraints (2.6)-(2.9). The corresponding first-order conditions are given by

$$\alpha\lambda\overline{Q}_M + [\alpha(1+\lambda)(\overline{p}_M - \theta) + \overline{\nu}]Q'_M = 0 \tag{2.10}$$

$$(1-\alpha)\lambda\underline{Q}_M + [(1-\alpha)(1+\lambda)(\underline{p}_M - c) + \underline{\nu}]Q'_M = 0 \tag{2.11}$$

$$(1+\lambda)\left[\alpha(\theta - c) - C'(K)\right] - (\overline{\nu} + \underline{\nu}) = 0 \tag{2.12}$$

$$-(\alpha\lambda - \overline{\phi}) = -((1-\alpha)\lambda - \underline{\phi}) = 0 \tag{2.13}$$

$$\overline{\phi U} = \underline{\phi}\underline{U} = 0 \tag{2.14}$$

$$\overline{\nu}\,\overline{q}_m = 0 \tag{2.15}$$

$$\underline{\nu}\,\underline{q}_m = 0 \tag{2.16}$$

From (2.14) it is straightforward to see that the participation constraint is binding for both types of firm, i.e., $\overline{U} = \underline{U} = 0$. Some further interesting properties implied by this system of first-order conditions are stated in the lemma that follows.

Lemma 2.1 *Under control scheme A with uncertainty, optimal prices and shadow costs of the firm's output nonnegativity constraints satisfy* $\underline{p}_M \leq \overline{p}_M$ *and* $\underline{\nu} \leq \overline{\nu}$.

Out of the four possible combinations of active and inactive firm's output nonnegativity constraints, $(\overline{\nu} = 0, \underline{\nu} = 0)$, $(\overline{\nu} > 0, \underline{\nu} = 0)$, $(\overline{\nu} > 0, \underline{\nu} > 0)$, and $(\overline{\nu} = 0, \underline{\nu} > 0)$, this lemma rules out the latter combination as a solution. It can be shown that a solution with $\overline{\nu} > 0$ and $\underline{\nu} > 0$ cannot arise.[11] Hence, one can ignore the nonnegativity constraint (2.9) and write that $\underline{\nu} = 0$, i.e., the more efficient firm is active, in which case, from the proof of the lemma, we obtain $\underline{p}_M < \overline{p}_M$. Letting $\varepsilon(\overline{Q}_M) \equiv -Q'_M\overline{p}_M/\overline{Q}_M$, $\varepsilon(\underline{Q}_M) \equiv -Q'_M\underline{p}_M/\underline{Q}_M$, and rewriting the first-order conditions (2.10)-(2.16) yields the following proposition that describe the solutions with the two remaining combinations $(\overline{\nu} = 0, \underline{\nu} = 0)$ and $(\overline{\nu} > 0, \underline{\nu} = 0)$:

11. If $\overline{\nu} > 0$ and $\underline{\nu} > 0$, we obtain $\overline{q}_m = \underline{q}_m = 0$. Solve the first-order conditions (2.10) and (2.11) for $\overline{\nu}$ and $\underline{\nu}$ and substitute into (2.12) to obtain that $\lambda\overline{Q}_M + (1+\lambda)[\overline{p}_M - c - C'(\overline{Q}_M)]Q'_M = 0$. However, $\underline{\nu} > 0$ implies $\lambda\overline{Q}_M + (1+\lambda)(\overline{p}_M - c)Q'_M \geq 0$. Hence, since $C'(\cdot) \geq 0$, we have $\overline{Q}_M \leq 0$ which contradicts $K > 0$.

Proposition 2.1 *When capacity, price, and transfers are the regulatory instruments, and there is uncertainty about the marginal cost of the regional monopoly at the time of setting transport capacity, there are two types of policies* $(K, \overline{p}_M, \underline{p}_M, \overline{\phi}, \underline{\phi}, \overline{\nu})$.

$(A1_u)$ *The policy* $(0 < K < \overline{Q}_M < \underline{Q}_M, \overline{p}_M > \theta, \underline{p}_M > c, \overline{\phi} = \alpha\lambda, \underline{\phi} = (1-\alpha)\lambda, \overline{\nu} = 0)$ *summarized by*

$$\frac{\overline{p}_M - \theta}{\overline{p}_M} = \frac{\lambda}{1+\lambda}\frac{1}{\varepsilon(\overline{Q}_M)} \tag{2.17}$$

$$\frac{\underline{p}_M - c}{\underline{p}_M} = \frac{\lambda}{1+\lambda}\frac{1}{\varepsilon(\underline{Q}_M)} \tag{2.18}$$

$$(1+\lambda)C'(K) = \alpha(1+\lambda)(\theta - c) \tag{2.19}$$

$(A2_u)$ *The policy* $(0 < K = \overline{Q}_M < \underline{Q}_M, \overline{p}_M > c, \underline{p}_M > c, \overline{\phi} = \alpha\lambda, \underline{\phi} = (1-\alpha)\lambda, \overline{\nu} > 0)$ *summarized by*

$$\frac{\overline{p}_M - \theta}{\overline{p}_M} = \frac{\lambda}{1+\lambda}\frac{1}{\varepsilon(\overline{Q}_M)} - \frac{\overline{\nu}}{\alpha(1+\lambda)\overline{p}_M}, \tag{2.20}$$

(2.18), and

$$(1+\lambda)C'(\overline{Q}_M) = \alpha(1+\lambda)(\theta - c) - \overline{\nu} \tag{2.21}$$

Policies $(A1_u)$ *and* $(A2_u)$ *are exclusive in that under policy* $(A1_u)$ *the condition* $0 < (\theta - c) < \frac{C'(\overline{Q}_M)}{\alpha}$ *holds while under policy* $(A2_u)$ *the reverse is true.*

Proposition 2.1 says that under policy $(A1_u)$ even if the local monopoly does not have the "right" marginal cost, it meets part of the market demand. Capacity is such that the social marginal cost of imports $(1+\lambda)[c + C'(K)]$ is equal to the expected social marginal cost of the firm $(1+\lambda)[\alpha\theta + (1-\alpha)c]$. This policy arises when the latter is smaller than the social marginal cost of imports at the level that makes the less efficient firm inactive, $(1+\lambda)[c + C'(\overline{Q}_M)]$. Under policy $(A2_u)$ the less efficient firm is shut down and the social marginal cost of imports is equal to the expected social marginal cost of the firm net of the shadow cost of the θ-type firm's output nonnegativity constraint $\overline{\nu}$.[12] To illustrate this proposition, let us consider the case where demand is linear and the capacity building technology is quadratic:

$$Q_M(p_M) = \gamma - p_M, \quad C(K) = \frac{\omega}{2}K^2; \quad \gamma, \omega > 0, \quad \gamma > \theta > c \tag{2.22}$$

Then, by Proposition 2.1, if

$$0 \leq (\theta - c) < \left[\frac{\omega(1+\lambda)}{\omega(1+\lambda) + \alpha(1+2\lambda)}\right](\gamma - c) \tag{2.23}$$

holds, a policy of the type $(A1_u)$ emerges as the optimal policy. Such a policy is described by $\overline{q}_m > 0$ ($\overline{\nu} = 0$) and

$$K = \frac{\alpha(\theta - c)}{\omega} \tag{2.24}$$

$$\overline{p}_M = \theta + \left[\frac{\lambda}{1+2\lambda}\right](\gamma - \theta) \tag{2.25}$$

$$\underline{p}_M = c + \left[\frac{\lambda}{1+2\lambda}\right](\gamma - c) \tag{2.26}$$

When condition (2.23) does not hold, namely, when

$$\left[\frac{\omega(1+\lambda)}{\omega(1+\lambda) + \alpha(1+2\lambda)}\right](\gamma - c) \leq (\theta - c) < (\gamma - c) \tag{2.27}$$

a policy of type $(A2_u)$ is optimal with $\overline{q}_m = 0$ ($\overline{\nu} > 0$) and

$$K = \left[\frac{\alpha(1+\lambda)}{\omega(1+\lambda) + \alpha(1+2\lambda)}\right](\gamma - c) \tag{2.28}$$

$$\overline{p}_M = c + \left[\frac{\alpha\lambda + \omega(1+\lambda)}{\omega(1+\lambda) + \alpha(1+2\lambda)}\right](\gamma - c) \tag{2.29}$$

$$\underline{p}_M = c + \left[\frac{\lambda}{1+2\lambda}\right](\gamma - c) \tag{2.30}$$

12. From (2.20), we see that $\overline{\nu}$ can be interpreted as the social marginal valuation of the expected price reduction required to guarantee that the θ-type firm is at worst shut down $\overline{\nu} = \alpha(1 + \lambda)\left[\left(\theta - \frac{\lambda \overline{Q}_M}{(1+\lambda)Q'_M}\right) - \overline{p}_M\right]$.

2.3.2 Scheme A under asymmetric information

Under asymmetric information on the value of the firm's marginal cost $\widetilde{\theta}$, after building transport capacity the regulator has to offer *feasible* contracts to the regional firm. Such contracts need to satisfy, in addition to the firm's participation and output nonnegativity constraints (2.6)-(2.9), the firm's incentive compatibility constraints which can be written as:

$$\overline{U} \geq \underline{U} - (\theta - c)\underline{q}_m \quad (\overline{\mu}) \tag{2.31}$$

$$\underline{U} \geq \overline{U} + (\theta - c)\overline{q}_m \quad (\underline{\mu}) \tag{2.32}$$

where the corresponding Lagrange multipliers are shown in parentheses.[13] Adding up (2.31) and (2.32) yields $\underline{q}_m \geq \overline{q}_m$ which implies $\underline{p}_M \leq \overline{p}_M$.[14] As a consequence, the Lagrange multiplier associated with the c-type firm's output nonnegativity constraint (2.9), $\underline{\nu}$, is equal to zero.[15] Moreover, because a firm of the more efficient type can always mimic one of the less efficient type at a lower level of cost, as can be seen from (2.32), the participation constraint of the former (2.7) can also be ignored.

Maximizing expected social welfare given by (2.5) subject to the remaining constraints yields the following first-order conditions:

$$\alpha\lambda\overline{Q}_M + [\alpha(1+\lambda)(\overline{p}_M - \theta) + \overline{\nu} - \underline{\mu}(\theta - c)]Q'_M = 0 \tag{2.33}$$

$$(1-\alpha)\lambda\underline{Q}_M + [(1-\alpha)(1+\lambda)(\underline{p}_M - c) + \overline{\mu}(\theta - c)]Q'_M = 0 \tag{2.34}$$

$$(1+\lambda)\left[\alpha(\theta - c) - C'(K)\right] - \overline{\nu} - (\overline{\mu} - \underline{\mu})(\theta - c) = 0 \tag{2.35}$$

$$-[\alpha\lambda - \overline{\phi} - (\overline{\mu} - \underline{\mu})] = 0 \tag{2.36}$$

13. These expressions of the firm's incentive compatibility constraints are derived by using the definition of the firm's utility (2.1) and a standard add-and-substract technique.

14. This is the standard result in regulatory economics that price is nondecreasing in the efficiency parameter $\widetilde{\theta}$ (Baron, 1989, Laffont and Tirole, 1993).

15. To see why this is true note that since $\underline{q}_m \geq \overline{q}_m$, clearly the more efficient firm cannot be shut down while the less efficient one is left active, i.e., $\overline{\nu} = 0 \Rightarrow \underline{\nu} = 0$. When the nonnegativity constraints (2.8) and (2.9) are both binding, i.e., both firms are shut down ($\overline{\nu}, \underline{\nu} > 0$), the incentive constraints (2.31) and (2.32) are trivially satisfied and we are back to the case with uncertainty analyzed in the previous subsection. But then in this case, we have already shown (see footnote 11) that such a solution cannot arise.

$$-[(1-\alpha)\lambda + (\overline{\mu} - \underline{\mu})] = 0 \tag{2.37}$$

$$\overline{\mu}[\overline{U} - \underline{U} + (\theta - c)\underline{q}_m] = \underline{\mu}[\underline{U} - \overline{U} - (\theta - c)\overline{q}_m] = 0 \tag{2.38}$$

$$\overline{\phi}\overline{U} = 0 \tag{2.39}$$

$$\overline{\nu}\,\overline{q}_m = 0 \tag{2.40}$$

From (2.36) and (2.37), we see that the participation constraint of the less efficient firm (of type (θ)) is binding, i.e., $\overline{\phi} = \lambda > 0$ and hence $\overline{U} = 0$. It is then straightforward to see that the incentive compatibility constraint for the c-type firm is binding, i.e., $\underline{U} = (\theta - c)\overline{q}_m$.[16] This property, together with the fact that feasible prices satisfy $\underline{p}_M \leq \overline{p}_M$, implies that the incentive compatibility of the θ-type firm (2.31) holds with strict inequality, and hence $\overline{\mu} = 0$. The following proposition summarizes these results.

Proposition 2.2 *When capacity, price, and transfers are the regulatory instruments and there is asymmetric information on the firm's marginal cost, there are two types of optimal policies* $(K, \overline{p}_M, \underline{p}_M, \overline{\phi}, \overline{\nu}, \underline{\mu})$.

($A1_{ai}$) *The policy* $(0 < K < \overline{Q}_M < \underline{Q}_M, \overline{p}_M > \theta, \underline{p}_M > c, \overline{\phi} = \lambda, \overline{\nu} = 0, \underline{\mu} = (1-\alpha)\lambda)$ *characterized by*

$$\frac{\overline{p}_M - \theta}{\overline{p}_M} = \frac{\lambda}{1+\lambda}\left[\frac{1}{\varepsilon(\overline{Q}_M)} + \frac{(1-\alpha)}{\alpha}\frac{(\theta - c)}{\overline{p}_M}\right] \tag{2.41}$$

$$\frac{\underline{p}_M - c}{\underline{p}_M} = \frac{\lambda}{1+\lambda}\frac{1}{\varepsilon(\underline{Q}_M)} \tag{2.42}$$

$$(1+\lambda)C'(K) = (\alpha + \lambda)(\theta - c) \tag{2.43}$$

($A2_{ai}$) *The policy* $(0 < K < \overline{Q}_M < \underline{Q}_M, \overline{p}_M > \theta, \underline{p}_M > c, \overline{\phi} = \lambda, \overline{\nu} > 0, \underline{\mu} = (1-\alpha)\lambda)$ *defined by*

$$\frac{\overline{p}_M - \theta}{\overline{p}_M} = \frac{\lambda}{1+\lambda}\left[\frac{1}{\varepsilon(\overline{Q}_M)} + \frac{(1-\alpha)}{\alpha}\frac{(\theta - c)}{\overline{p}_M}\right] - \frac{\overline{\nu}}{\alpha(1+\lambda)\overline{p}_M}, \tag{2.44}$$

16. This is consistent with the fact that rents are socially costly (see (2.2)).

(2.42), and

$$(1+\lambda)C'(\overline{Q}_M) \quad = (\alpha+\lambda)(\theta - c) - \overline{\nu} \tag{2.45}$$

Under policy $(A1_{ai})$ *the condition* $0 < (\theta - c) < \frac{C'(\overline{Q}_M)}{\alpha+\lambda}$ *holds while under policy* $(A2_{ai})$ *the reverse is true.*

Under policy $(A1_{ai})$, even if it is of the less efficient type, the firm meets part of the market demand and the social marginal cost of imports is equal to the expected social marginal cost of the firm, plus the expected social opportunity cost of distorting the pricing rule of the less efficient firm for the purpose of decreasing the informational rent of the more efficient firm, $\alpha\lambda\left[\frac{(1-\alpha)}{\alpha}(\theta - c)\right]$. This type of policy arises when the expected social marginal cost of the regional firm plus the expected social opportunity cost of the distortion on pricing is smaller than the social marginal cost of imports at the level where the less efficient firm is shut down. Under policy $(A2_{ai})$ the less efficient firm is shut down and the social marginal cost of imports, $(1+\lambda)[c+C'(\overline{Q}_M)]$, equals the expected social marginal cost of the firm, $(1+\lambda)[\alpha\theta + (1-\alpha)c]$, plus the social opportunity cost of the c-type firm's informational rent, minus the shadow cost of the θ-type firm's output nonnegativity constraint $\overline{\nu}$.

Using the functional forms given in (2.22), the solution to the system of first-order conditions (2.33)-(2.40) is of two types depending on the size of $(\theta - c)$. When the condition

$$0 \leq (\theta - c) < \frac{\alpha(1+\lambda)}{(\alpha+\lambda)}\left[\frac{\omega(1+\lambda)}{\omega(1+\lambda)+\alpha(1+2\lambda)}\right](\gamma - c) \tag{2.46}$$

holds, the optimal policy is of type $(A1_{ai})$ and $\overline{q}_m > 0$ ($\overline{\nu} = 0$),

$$K = \frac{(\alpha+\lambda)(\theta - c)}{\omega(1+\lambda)} \tag{2.47}$$

$$\overline{p}_M = \theta + \frac{\lambda\left[(1-2\alpha)(\theta - c) + \alpha(\gamma - c)\right]}{\alpha(1+2\lambda)} \tag{2.48}$$

$$\underline{p}_M = c + \left[\frac{\lambda}{1+2\lambda}\right](\gamma - c) \tag{2.49}$$

If condition (2.46) does not hold, i.e.,

$$\frac{\alpha(1+\lambda)}{(\alpha+\lambda)}\left[\frac{\omega(1+\lambda)}{\omega(1+\lambda)+\alpha(1+2\lambda)}\right](\gamma-c)\leq(\theta-c)<(\gamma-c) \qquad (2.50)$$

a policy of type ($A2_{ai}$), described by (2.28)-(2.30) with $\overline{q}_m = 0$ ($\overline{\nu} > 0$) arises.

2.3.3 Incentives and capacity investments under scheme A

By comparing the capacity levels achieved under control scheme A with uncertainty (K_u^A) and asymmetric information (K_{ai}^A), we are now able to assess the impact, on investment in transport capacity, of the firm's incentives when the latter has private information on its marginal cost.[17] Since $C'(\cdot)$ is increasing, from (2.12) and (2.35), we obtain

$$\begin{aligned} sign[K_{ai}^A - K_u^A] &= sign[(1+\lambda)[C'(K_{ai}^A) - C'(K_u^A)]] \\ &= sign[(1-\alpha)\lambda(\theta-c) - (\overline{\nu}_{ai}^A - \overline{\nu}_u^A)] \end{aligned} \qquad (2.51)$$

and then, the following proposition synthesizes our findings.

Proposition 2.3 *When capacity, price, and transfers are available as regulatory instruments, accounting for incentives of the firm calls for "excess" capacity in the weak sense, namely,* $K_{ai}^A \geq K_u^A$.

We now verify this proposition using the functional forms given in (2.22). A first step is to directly compare the capacity levels given in (2.24), (2.28), and (2.47). This is straightforward and left to the reader. However, since the intervals defining the parameter space for each policy are not always compatible, we complete the verification with numerical simulations. Because control scheme A is not responsive to the fixed cost, we ran simulations with $F_m = 0$ and focused on the relationship between the capacity gap ($K_{ai}^A - K_u^A$) and the endogenous variables $\overline{\nu}_{ai}^A$ and $\overline{\nu}_u^A$ in the $\{\alpha, (\theta - c)\}$-space. We used the following grids of parameters:

17. We account for the firm's incentives through the incentive compatibility constraints (2.31) and (2.32).

- Case 1: $\{\gamma, c, \omega, \lambda\} = \{10, 2, 0.50, 0.33\}$, $(\theta - c) \in [0, 4.94]$, and $\alpha \in [0, 1]$
- Case 2: $\{\gamma, c, \omega, \lambda\} = \{10, 2, 0.52, 0.85\}$, $(\theta - c) \in [0, 4.94]$, and $\alpha \in [0, 1]$
- Case 3: $\{\gamma, c, \omega, \lambda\} = \{10, 2, 0.17, 0.25\}$, $(\theta - c) \in [0, 2.24]$, and $\alpha \in [0, 1]$

Figure 2.4 (a-b) exhibits the results of the simulated values of $(K_{ai}^A - K_u^A)$, $\overline{\nu}_{ai}^A$, and $\overline{\nu}_u^A$.

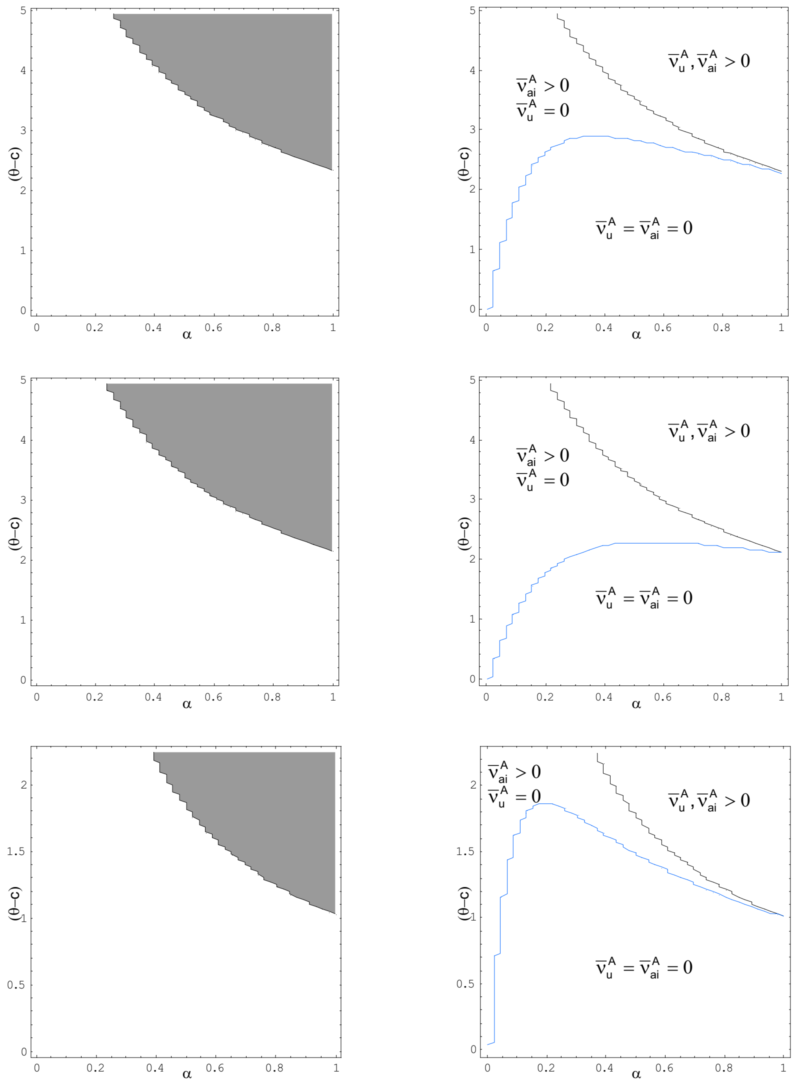

Figure 2.4a: $K_{ai}^A - K_u^A$ **Figure 2.4b:** $\overline{\nu}_{ai}^A$ and $\overline{\nu}_u^A$

Figure 2.4a shows in white and gray the regions where respectively $(K_{ai}^A - K_u^A) > 0$ and $(K_{ai}^A - K_u^A) = 0$. Figure 2.4b exhibits the curves formed by the $(\alpha, (\theta - c))$ pairs such that $\overline{\nu}_{ai}^A = 0$ and $\overline{\nu}_u^A = 0$. A cross-examination of these figures shows that whenever $\overline{\nu}_{ai}^A = 0$, $\overline{\nu}_u^A = 0$, $K_{ai}^A > K_u^A$, as stated in the proof of Proposition 2.3 given in the appendix. When both $\overline{\nu}_{ai}^A$ and $\overline{\nu}_u^A$ are strictly positive, i.e., when the θ-type firm is shut down under both uncertainty and asymmetric information, $K_{ai}^A = K_u^A$. Finally, we see that when $\overline{\nu}_{ai}^A > 0$ and $\overline{\nu}_u^A = 0$, i.e., when the θ-type firm is shut down under asymmetric information but remains active under uncertainty, $K_{ai}^A > K_u^A$.

2.4 Firm's incentives and transport capacity under scheme B

Let us now consider regulatory scheme B in which the regulator can still set transport capacity and commodity gas price but transfers between consumers and the firm are no longer permitted. In this case, the $\widetilde{\theta}$-type firm's utility is merely its profits $\Pi(\widetilde{\theta})$ given by:

$$\Pi_m(\widetilde{\theta}) = (p_M(\widetilde{\theta}) - \widetilde{\theta})[Q_M(p_M(\widetilde{\theta})) - K] - F_m \tag{2.52}$$

Ex post social welfare is expressed as

$$\begin{aligned} W(\widetilde{\theta}) = \quad & \{S(Q_M(p_M(\widetilde{\theta}))) - p_M(\widetilde{\theta})Q_M(p_M(\widetilde{\theta}))\} \\ & +\{(1+\lambda)\left[(p_M(\widetilde{\theta}) - c)K - C(K)\right]\} \\ & +\{(p_M(\widetilde{\theta}) - \widetilde{\theta})\left[Q_M(p_M(\widetilde{\theta})) - K\right] - F_m\} \end{aligned} \tag{2.53}$$

This social welfare is the sum of the net consumer surplus, the social value of the profits generated by the K units imported from the competitive market, and the profits of the firm that now cannot be taxed as transfers are not allowed. Gathering terms, we obtain[18]

$$\begin{aligned} W(\widetilde{\theta}) = & \left\{ S(Q_M(p_M(\widetilde{\theta}))) + \lambda p_M(\widetilde{\theta})K \right\} \\ & - \left\{ \widetilde{\theta}(Q_M(p_M(\widetilde{\theta})) - K) + (1+\lambda)\left[cK + C(K)\right] + F_m \right\} \end{aligned} \tag{2.54}$$

As to the firm's participation and output nonnegativity constraints, they are respectively given by

$$\Pi_m(\widetilde{\theta}) \geq 0 \tag{2.55}$$

$$q_m(\widetilde{\theta}) = Q_M(p_M(\widetilde{\theta})) - K \geq 0 \tag{2.56}$$

With control scheme B optimal regulation under uncertainty and asymmetric information both call for maximizing ex ante social welfare

$$\mathrm{E}[W(\widetilde{\theta})] = \alpha W(\theta) + (1-\alpha) W(c) \tag{2.57}$$

with respect to $\overline{p}_M$, $\underline{p}_M$, and K under the ex-post participation and output nonnegativity constraints

$$\overline{\Pi}_m = (\overline{p}_M - \theta)\overline{q}_m - F_m \geq 0 \quad (\overline{\phi}) \tag{2.58}$$

$$\underline{\Pi}_m = (\underline{p}_M - c)\underline{q}_m - F_m \geq 0 \quad (\underline{\phi}) \tag{2.59}$$

$$\overline{q}_m = \overline{Q}_M - K \geq 0 \quad (\overline{\nu}) \tag{2.60}$$

$$\underline{q}_m = \underline{Q}_M - K \geq 0 \quad (\underline{\nu}) \tag{2.61}$$

where the corresponding Lagrange multipliers are shown in parentheses. A property of the set defined by the above constraints that turns out to be very useful for analyzing the regulator's optimization program is described in the lemma that follows.

Lemma 2.2 *The constraint set defined by (2.58)-(2.61) is convex and satisfies the nondegenerate constraint qualification (NDCQ) condition. In order to satisfy the*

18. Note that since transfers are not allowed, the regulator assigns a fiscal value $\lambda p_M(\widetilde{\theta})K$ only to the revenues generated by the K units shipped from the competitive market C_p into the regional market M.

linear independence constraint qualification (LICQ) condition, when there is no fixed cost, the participation constraints (2.58) and (2.59) should be ignored when either (2.60) or (2.61) is satisfied with equality, in which case (2.58) and (2.59) become liminal constraints, i.e., they are active with $\overline{\phi} = \underline{\phi} = 0$. *When there is fixed cost, the LICQ condition is always satisfied since the firm is always active, i.e.,* $\overline{\nu} = \underline{\nu} = 0$.

Lemma 2.2 basically shows that the constraint set faced by the regulator is well behaved and helps to clarify the interpretation of the optimal values of the Lagrange multipliers (the ϕ's and the ν's). Whenever a ν is strictly positive, i.e., the firm is shut down, the interpretation of the ϕ somewhat looses its full significance. For example, take the case of the less efficient firm. If $F_m > 0$, it can be shown by contradiction from (2.58) that the firm is always active, i.e., $\overline{\nu} = 0$. Hence, for this firm to be inactive, i.e., for $\overline{\nu} > 0$, it must be the case that $F_m = 0$. But then, the participation constraint (2.58) can be neglected. Technically, this is taken care of by setting $\overline{\phi} = 0$ in the slack complementarity condition, $\overline{\phi}\ \overline{\Pi} = 0$, associated with the firm's participation constraint, which would suggest that the firm is making positive profits.

2.4.1 Scheme B under uncertainty

Under control scheme B with uncertainty, the regulator maximizes (2.57) with respect to $\overline{p}_M$, $\underline{p}_M$, and K, subject to the constraints (2.58)-(2.61). The corresponding first-order conditions are given by

$$\alpha[\lambda K + (\overline{p}_M - \theta)Q'_M] + \overline{\phi}[(\overline{p}_M - \theta)Q'_M + \overline{q}_m] + \overline{\nu}Q'_M = 0 \tag{2.62}$$

$$(1-\alpha)[\lambda K + (\underline{p}_M - c)Q'_M] + \underline{\phi}[(\underline{p}_M - c)Q'_M + \underline{q}_m] + \underline{\nu}Q'_M = 0 \tag{2.63}$$

$$(1+\lambda)\left[\alpha(\theta - c) - C'(K)\right] + (\alpha\lambda - \overline{\phi})(\overline{p}_M - \theta) + ((1-\alpha)\lambda - \underline{\phi})(\underline{p}_M - c) - \overline{\nu} - \underline{\nu} = 0 \tag{2.64}$$

$$\overline{\phi}[(\overline{p}_M - \theta)\overline{q}_m - F_m] = 0 \tag{2.65}$$

$$\underline{\phi}[(\underline{p}_M - c)\underline{q}_m - F_m] = 0 \tag{2.66}$$

$$\overline{\nu}\ \overline{q}_m = \underline{\nu}\ \underline{q}_m = 0 \tag{2.67}$$

Some properties implied by (2.62)-(2.67) are indicated in the next lemma.

Lemma 2.3 *Under control scheme B with uncertainty, provided second-order conditions are satisfied, at the optimum we have* $\underline{p}_M \leq \overline{p}_M$, $\underline{\Pi}_m \geq \overline{\Pi}_m$, $\underline{\phi} \leq \overline{\phi}$, *and* $\underline{\nu} \leq \overline{\nu}$.

Lemma 2.2 reduces the number of possible combinations of active and inactive constraints (2.58)-(2.61), at a candidate solution to the regulator's optimization program, to seven. Lemma 2.3 further reduces this number to five at the optimum. Indeed, this lemma rules out solutions with either $(\overline{\phi} = 0, \underline{\phi} = 0, \overline{\nu} = 0, \underline{\nu} > 0)$ or $(\overline{\phi} = 0, \underline{\phi} > 0, \overline{\nu} = 0, \underline{\nu} = 0)$. The next proposition characterizes the five remaining solutions.

Proposition 2.4 *When only capacity and price are controlled by the regulator, and the latter has uncertainty about the regional firm's marginal cost when setting capacity, the optimal policy* $(K, \overline{p}_M, \underline{p}_M, \overline{\phi}, \underline{\phi}, \overline{\nu}, \underline{\nu})$ *is of one of the following types.*

$(B1_u)$ *The policy* $(0 < K < \overline{Q}_M < \underline{Q}_M, \overline{p}_M > \theta, \underline{p}_M > c, \overline{\phi} = 0, \underline{\phi} = 0, \overline{\nu} = 0, \underline{\nu} = 0)$ *characterized by the following conditions:*

$$\frac{\overline{p}_M - \theta}{\overline{p}_M} = \frac{\lambda K}{\overline{Q}_M} \frac{1}{\varepsilon(\overline{Q}_M)} \tag{2.68}$$

$$\frac{\underline{p}_M - c}{\underline{p}_M} = \frac{\lambda K}{\underline{Q}_M} \frac{1}{\varepsilon(\underline{Q}_M)} \tag{2.69}$$

$$(1+\lambda)C'(K) = \alpha(1+\lambda)(\theta - c) + \lambda[\alpha(\overline{p}_M - \theta) + (1-\alpha)(\underline{p}_M - c)] \tag{2.70}$$

$(B2_u)$ *The policy* $(0 < K < \overline{Q}_M < \underline{Q}_M, \overline{p}_M \geq \theta, \underline{p}_M > c, \overline{\phi} > 0, \underline{\phi} = 0, \overline{\nu} = 0, \underline{\nu} = 0)$ *described by*

$$\frac{\overline{p}_M - \theta}{\overline{p}_M} = \left[\frac{\alpha\lambda K + \overline{\phi}\,\overline{q}_m}{(\alpha + \overline{\phi})\overline{Q}_M}\right] \frac{1}{\varepsilon(\overline{Q}_M)} = \frac{F_m}{\overline{p}_M \overline{q}_m}, \tag{2.71}$$

(2.69), and

$$(1+\lambda)C'(K) = \alpha(1+\lambda)(\theta - c) + \lambda\left[\alpha\frac{F_m}{\overline{q}_m} + (1-\alpha)(\underline{p}_M - c)\right] - \overline{\phi}\frac{F_m}{\overline{q}_m} \tag{2.72}$$

$(B3_u)$ *The policy* $(0 < K = \overline{Q}_M < \underline{Q}_M, \overline{p}_M > c, \underline{p}_M > c, \overline{\phi} = 0, \underline{\phi} = 0, \overline{\nu} > 0, \underline{\nu} = 0)$ *described by*

$$\frac{\overline{p}_M - \theta}{\overline{p}_M} = \frac{\lambda}{\varepsilon(\overline{Q}_M)} - \frac{\overline{\nu}}{\alpha\overline{p}_M}, \tag{2.73}$$

(2.69), and

$$(1+\lambda)C'(\overline{Q}_M) = \alpha(1+\lambda)(\theta - c) + \lambda[\alpha(\overline{p}_M - \theta) + (1-\alpha)(\underline{p}_M - c)] - \overline{\nu} \tag{2.74}$$

$(B4_u)$ *The policy* $(0 < K < \overline{Q}_M < \underline{Q}_M, \overline{p}_M > \theta, \underline{p}_M > c, \overline{\phi} > 0, \underline{\phi} > 0, \overline{\nu} = 0, \underline{\nu} = 0)$ *characterized by (2.71),*

$$\frac{\underline{p}_M - c}{\underline{p}_M} = \left[\frac{(1-\alpha)\lambda K + \underline{\phi}\underline{q}_m}{(1-\alpha+\underline{\phi})\underline{Q}_M}\right]\frac{1}{\varepsilon(\underline{Q}_M)} = \frac{F_m}{\underline{p}_M\underline{q}_m}, \tag{2.75}$$

and

$$\begin{aligned}(1+\lambda)C'(K) &= \alpha(1+\lambda)(\theta - c)\\ &\quad + \lambda\left[\alpha\frac{F_m}{\overline{q}_m} + (1-\alpha)\frac{F_m}{\underline{q}_m}\right] - \left(\overline{\phi}\frac{F_m}{\overline{q}_m} + \underline{\phi}\frac{F_m}{\underline{q}_m}\right)\end{aligned} \tag{2.76}$$

$(B5_u)$ *The policy* $(0 < K = \overline{Q}_M = \underline{Q}_M, \overline{p}_M = \underline{p}_M > c, \overline{\phi} = 0, \underline{\phi} = 0, \overline{\nu} > 0, \underline{\nu} > 0)$ *described by (2.73),*

$$\frac{\underline{p}_M - c}{\underline{p}_M} = \frac{\lambda}{\varepsilon(\underline{Q}_M)} - \frac{\underline{\nu}}{(1-\alpha)\underline{p}_M}, \tag{2.77}$$

and

$$(1+\lambda)C'(\overline{Q}_M) = (\alpha+\lambda)(\theta - c) + \lambda(\overline{p}_M - \theta) - (\overline{\nu} + \underline{\nu}) \tag{2.78}$$

When there is no fixed cost $(F_m = 0)$*, only policies* $(B1_u)$*,* $(B3_u)$*, and* $(B5_u)$ *may arise and they are exclusive. Policy* $(B5_u)$ *arises when* $\lambda^2 K + (1+\lambda)Q'_M C'(K) > 0$*. When* $\lambda^2 K + (1+\lambda)Q'_M C'(K) \leq 0$*,* $\lambda^2 + (1+\lambda)Q'_M C''(K) < 0$*, and* $0 < \alpha(\theta - c) < C'(\overline{Q}_M) + \frac{\lambda^2\overline{Q}_M}{(1+\lambda)Q'_M}$*, policy* $(B1_u)$ *arises, while when* $\lambda^2 K + (1+\lambda)Q'_M C'(K) \leq 0$*,*

$\lambda^2 + (1+\lambda)Q'_M C''(K) < \alpha(1+\lambda)^2$ *and* $\alpha(\theta - c) \geq C'(\overline{Q}_M) + \frac{\lambda^2 \overline{Q}_M}{(1+\lambda)Q'_M}$, *policy* $(B3_u)$ *arises.*

When there is a fixed cost $(F_m > 0)$, *only policies* $(B1_u)$, $(B2_u)$, *and* $(B4_u)$ *may arise and they are exclusive. If* $\lambda^2 K + (1+\lambda)Q'_M C'(K) \leq 0$, $\lambda^2 + (1+\lambda)Q'_M C''(K) < 0$, $0 < \alpha(\theta - c) < C'(K) + \frac{\lambda^2 K}{Q'_M} - \alpha\lambda(\frac{\lambda K \overline{q}_m + Q'_M F_m}{\overline{q}_m Q'_M})$, *and* $\lambda K \overline{q}_m + Q'_M F_m > 0$, *policy* $(B1_u)$ *arises. When* $C'(K) + \frac{\lambda^2 K}{Q'_M} - \alpha\lambda(\frac{\lambda K \overline{q}_m + Q'_M F_m}{\overline{q}_m Q'_M}) \leq \alpha(\theta - c) < C'(K) - \frac{\lambda F_m}{1+\lambda}[\frac{\overline{q}_m + \alpha(\underline{q}_m - \overline{q}_m)}{\overline{q}_m \underline{q}_m}]$, *policy* $(B2_u)$ *arises.*[19] *Finally, when* $\alpha(\theta - c) \geq C'(K) - \frac{\lambda F_m}{1+\lambda}[\frac{\overline{q}_m + \alpha(\underline{q}_m - \overline{q}_m)}{\overline{q}_m \underline{q}_m}]$, *policy* $(B4_u)$ *is optimal and second-order conditions are always satisfied.*

Proposition 2.4 shows that under policy $(B1_u)$ even the relatively less efficient firm is active and capacity is such that the social marginal cost of imports, $(1+\lambda)[c + C'(K)]$, net of the expected marginal fiscal revenue of imported gas, $\lambda[\alpha\overline{p}_M + (1-\alpha)\underline{p}_M]$, is equal to the expected marginal cost of the firm, $\alpha\theta + (1-\alpha)c$.

Under policy $(B2_u)$ the less efficient firm just breaks even and capacity is such that the social marginal cost of imports net of the expected marginal fiscal revenue of imported gas is equal to the expected marginal cost of the firm net of the social value of the contribution of the marginal unit of the less efficient firm to the relaxation of its participation constraint, $\overline{\phi}\frac{F_m}{\overline{q}_m}$.

Under policy $(B3_u)$, the less efficient firm is shut down and capacity is such that the social marginal cost of imports (at the level that makes the less efficient firm inactive) net of the expected marginal fiscal revenue of imported gas, is equal to the expected marginal cost of the firm net of the shadow cost of the θ-type firm's output nonnegativity constraint $\overline{\nu}$.[20]

Under policy $(B4_u)$, the firm, independently of its type, just breaks even and capacity is such that the social marginal cost of imports net of the expected marginal

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19. Second-order conditions for this policy are summarized by $\alpha^2\lambda^2(\alpha^2 K + (\overline{q}_m + \lambda K((1-\alpha)\overline{q}_m - K(\lambda - \alpha(2+\lambda))))) - 2\alpha^2\lambda\overline{\phi}\overline{q}_m(\overline{q}_m - (2+\lambda)K) + \alpha\overline{\phi}^2\overline{q}_m(3\overline{q}_m + 2\lambda K) + 2\overline{\phi}^3\overline{q}_m{}^2 - \alpha^2(1+\lambda)(\overline{q}_m - \lambda K)^2 Q'_M C''(K) > 0$.

20. From (2.73), we see that $\overline{\nu} = \alpha\left[\left(\theta - \frac{\lambda\overline{Q}_M}{Q'_M}\right) - \overline{p}_M\right] > 0$, and hence it can be interpreted as the marginal valuation of the expected price reduction required to guarantee that the less efficient firm is at worse shut down.

fiscal revenue of imported gas, is equal to the expected marginal cost of the firm, net of the aggregate ex-post social value of the contribution of the marginal unit of the firm to the relaxation of its participation constraint, $\overline{\phi}\frac{F_m}{\overline{q}_m} + \underline{\phi}\frac{F_m}{\underline{q}_m}$.

Finally, under policy $(B5_u)$ the firm, independently of its type, is shut down and capacity is such that the social marginal cost of imports net of the expected marginal fiscal revenue of imported gas, is equal to the expected marginal cost of the firm net of the aggregate ex-post shadow cost of the firm's output nonnegativity constraint, $\overline{\nu} + \underline{\nu}$.[21] Note that when there is no cost of public funds, i.e., $\lambda = 0$, policy $(B5_u)$ is never optimal.

To illustrate this control scheme, let us assume that $F_m = 0$ and use the functional forms given by (2.22). Note that in this particular case the sign of both expressions $\lambda^2 K + (1+\lambda)Q'_M C'(K)$ and $\lambda^2 + (1+\lambda)Q'_M C''(K)$, used as criteria for selecting an optimal policy, is the same as the sign of $-\Psi$, where $\Psi \equiv \omega(1+\lambda) - \lambda^2$. Solving (2.62)-(2.67) yields the following policies. If $\Psi \geq 0$, and the condition

$$0 \leq (\theta - c) < \left[\frac{\Psi}{\Psi + \alpha(1+\lambda)^2}\right](\gamma - c) \tag{2.79}$$

holds, policy $(B1_u)$ arises with $\overline{q}_m > 0$ ($\overline{\nu} = 0$), and

$$K = \left[\frac{\alpha(1+\lambda)}{\Psi}\right](\theta - c) \tag{2.80}$$

$$\overline{p}_M = \theta + \left[\frac{\alpha\lambda(1+\lambda)}{\Psi}\right](\theta - c) \tag{2.81}$$

$$\underline{p}_M = c + \left[\frac{\alpha\lambda(1+\lambda)}{\Psi}\right](\theta - c) \tag{2.82}$$

If $\Psi \geq 0$ but condition (2.79) does not hold, i.e.,

$$\left[\frac{\Psi}{\Psi + \alpha(1+\lambda)^2}\right](\gamma - c) \leq (\theta - c) < (\gamma - c) \tag{2.83}$$

21. We have $(\overline{\nu} + \underline{\nu}) = \left[\left(\alpha\theta + (1-\alpha)c - \frac{\lambda\overline{Q}_M}{Q'_M}\right) - \overline{p}_M\right] > 0$, and hence it can be interpreted as the marginal valuation of the expected price reduction required to guarantee that the firm, independently of its type, is at worse shut down.

we obtain policy $(B3_u)$ with $\overline{q}_m = 0$ $(\overline{\nu} > 0)$, and

$$K = \left[\frac{\alpha(1+\lambda)}{\Psi + \alpha(1+\lambda)^2}\right](\gamma - c) \tag{2.84}$$

$$\overline{p}_M = c + \left[\frac{\Psi + \alpha\lambda(1+\lambda)}{\Psi + \alpha(1+\lambda)^2}\right](\gamma - c) \tag{2.85}$$

$$\underline{p}_M = c + \left[\frac{\alpha\lambda(1+\lambda)}{\Psi + \alpha(1+\lambda)^2}\right](\gamma - c) \tag{2.86}$$

Finally, if $\Psi < 0$ we obtain policy $(B5_u)$ which is characterized by $\overline{q}_m = 0$ $(\overline{\nu} > 0)$, $\underline{q}_m = 0$ $(\underline{\nu} > 0)$, and

$$K = \left[\frac{1+\lambda}{\Psi + (1+\lambda)^2}\right](\gamma - c) \tag{2.87}$$

$$\overline{p}_M = \underline{p}_M = c + \left[\frac{\Psi + \lambda(1+\lambda)}{\Psi + (1+\lambda)^2}\right](\gamma - c) \tag{2.88}$$

2.4.2 Scheme B under asymmetric information

Control scheme B under asymmetric information entails maximizing expected social welfare given by (2.57) under the participation and firm's output nonnegativity constraints given by (2.58)-(2.61), and the incentive compatibility constraints, with Lagrange multipliers shown in parentheses,

$$(\overline{p}_M - \theta)\overline{q}_m \geq (\underline{p}_M - \theta)\underline{q}_m \quad (\overline{\mu}) \tag{2.89}$$

$$(\underline{p}_M - c)\underline{q}_m \geq (\overline{p}_M - c)\overline{q}_m \quad (\underline{\mu}) \tag{2.90}$$

directly derived from the expression of the profit function (2.52). From (2.58) and (2.90), we obtain that the participation constraint of the c-type firm (2.59) can be ignored ($\underline{\phi} = 0$). Furthermore, adding up (2.89) and (2.90) yields that price is a nondecreasing function of firm's type, $\underline{p}_M \leq \overline{p}_M$.

For the purpose of solving this regulatory program, it is important, for the problem to be concave, that the constraint set defined by (2.58)-(2.61) and (2.89)-(2.90) be convex, which it turns out not to be. To circumvent this difficulty, we assume that pricing policies are restricted to type-contingent prices. The next lemma shows that, indeed, such a restriction takes care of this problem.

Lemma 2.4 *When* $\underline{p}_M < \overline{p}_M$*, the constraint set defined by (2.58)-(2.61) and (2.89)-(2.90) is convex and "qualified," i.e., it satisfies the NDCQ and LICQ conditions. Moreover, if, at the optimum,* $\lambda^2 + (1+\lambda)Q'_M C''(K) < 0$*, the expected welfare function given in (2.57) is locally concave.*

In an optimization problem, non-convexity of the constraint set generally leads to multiple solutions. In our case (see the proof of Lemma 2.4) multiplicity arises in the form of the existence of two solutions, one of which reflects *bunching* in prices, i.e., $\overline{p}_M = \underline{p}_M$. Hence, in essence, Lemma 2.4 allows us to rule out bunching.

The first-order conditions are then

$$\alpha[\lambda K + (\overline{p}_M - \theta)Q'_M] + (\overline{\phi} + \overline{\mu} - \underline{\mu})[(\overline{p}_M - \theta)Q'_M + \overline{q}_m] - \underline{\mu}(\theta - c)Q'_M + \overline{\nu}Q'_M = 0 \tag{2.91}$$

$$(1-\alpha)[\lambda K + (\underline{p}_M - c)Q'_M] - (\overline{\mu} - \underline{\mu})[(\underline{p}_M - c)Q'_M + \underline{q}_m] + \overline{\mu}(\theta - c)Q'_M = 0 \tag{2.92}$$

$$(1+\lambda)\left[\alpha(\theta - c) - C'(K)\right] + (\alpha\lambda - \overline{\phi})(\overline{p}_M - \theta) + (1-\alpha)\lambda(\underline{p}_M - c) - (\overline{\mu} - \underline{\mu})(\overline{p}_M - \underline{p}_M) - \overline{\nu} = 0 \tag{2.93}$$

$$\overline{\phi}[(\overline{p}_M - \theta)\overline{q}_m - F_m] = 0 \tag{2.94}$$

$$\overline{\nu}\,\overline{q}_m = 0 \tag{2.95}$$

$$\overline{\mu}[(\overline{p}_M - \theta)\overline{q}_m - (\underline{p}_M - \theta)\underline{q}_m] = 0 \tag{2.96}$$

$$\underline{\mu}[(\underline{p}_M - c)\underline{q}_m - (\overline{p}_M - c)\overline{q}_m] = 0 \tag{2.97}$$

From now on, we make use of the assumption $\underline{p}_M < \overline{p}_M$ which eliminates bunching solutions ($\underline{p}_M = \overline{p}_M$, with either $\underline{\mu} = \overline{\mu} = 0$ or $\underline{\mu}, \overline{\mu} > 0$) and clearly solutions with $\underline{\nu} > 0$. The incentive compatibility constraints (2.89) and (2.90) further eliminate solutions with $\underline{\phi} > 0$. The next proposition characterizes the remaining eight possible solutions.

Proposition 2.5 *When only capacity and price are the regulatory instruments and there is asymmetric information, there are eight types of optimal policies*

$(K, \overline{p}_M, \underline{p}_M, \overline{\phi}, \overline{\nu}, \overline{\mu}, \underline{\mu})$ designated by $(B1_{ai})$-$(B8_{ai})$. Three of them, namely, $(B1_{ai})$-$(B3_{ai})$, are identical to policies $(B1_u)$-$(B3_u)$ obtained under uncertainty (see Proposition 2.4).[22] *The remaining ones are described as follows:*

$(B4_{ai})$ *The policy $(0 < K < \overline{Q}_M < \underline{Q}_M, \overline{p}_M > \theta, \underline{p}_M > c, \overline{\phi} = 0, \overline{\nu} = 0, \overline{\mu} = 0, \underline{\mu} > 0)$ described by*

$$\frac{\overline{p}_M - \theta}{\overline{p}_M} = \left[\frac{\alpha\lambda K - \underline{\mu}\, \overline{q}_m}{(\alpha - \underline{\mu})\overline{Q}_M}\right]\frac{1}{\varepsilon(\overline{Q}_M)} + \frac{\underline{\mu}(\theta - c)}{(\alpha - \underline{\mu})\overline{p}_M} \tag{2.98}$$

$$\frac{\underline{p}_M - c}{\underline{p}_M} = \left[\frac{(1-\alpha)\lambda K + \underline{\mu}\, \underline{q}_m}{(1 - \alpha + \underline{\mu})\underline{Q}_M}\right]\frac{1}{\varepsilon(\underline{Q}_M)} \tag{2.99}$$

$$\begin{aligned}(1+\lambda)C'(K) = {} & [\alpha(1+\lambda) + \underline{\mu}](\theta - c) + \underline{\mu}[(\overline{p}_M - \theta) - (\underline{p}_M - c)] \\ & + \lambda[\alpha(\overline{p}_M - \theta) + (1-\alpha)(\underline{p}_M - c)]\end{aligned} \tag{2.100}$$

$(B5_{ai})$ *The policy $(0 < K < \overline{Q}_M < \underline{Q}_M, \overline{p}_M > \theta, \underline{p}_M > c, \overline{\phi} > 0, \overline{\nu} = 0, \overline{\mu} = 0, \underline{\mu} > 0)$ described by*

$$\frac{\overline{p}_M - \theta}{\overline{p}_M} = \left[\frac{\alpha\lambda K - (\underline{\mu} - \overline{\phi})\overline{q}_m}{(\alpha + \overline{\phi} - \underline{\mu})\overline{Q}_M}\right]\frac{1}{\varepsilon(\overline{Q}_M)} + \frac{\underline{\mu}(\theta - c)}{(\alpha - \underline{\mu})\overline{p}_M} = \frac{F_m}{\overline{p}_M \overline{q}_m} \tag{2.101}$$

(2.99), and

$$\begin{aligned}(1+\lambda)C'(K) = {} & [\alpha(1+\lambda) + \underline{\mu}](\theta - c) + \underline{\mu}\left[\frac{F_m}{\overline{q}_m} - (\underline{p}_M - c)\right] \\ & + \lambda\left[\alpha\frac{F_m}{\overline{q}_m} + (1-\alpha)(\underline{p}_M - c)\right] - \overline{\phi}\frac{F_m}{\overline{q}_m}\end{aligned} \tag{2.102}$$

$(B6_{ai})$ *The policy $(0 < K < \overline{Q}_M < \underline{Q}_M, \overline{p}_M > \theta, \underline{p}_M > c, \overline{\phi} = 0, \overline{\nu} = 0, \overline{\mu} > 0, \underline{\mu} = 0)$*

22. This is due to the fact that when the incentive compatibility constraints (2.89) and (2.90) are not active ($\overline{\mu} = \underline{\mu} = 0$), we are back to the case under uncertainty.

described by

$$\frac{\overline{p}_M-\theta}{\overline{p}_M}=\left[\frac{\alpha\lambda K+\overline{\mu}\ \overline{q}_m}{(\alpha+\overline{\mu})\overline{Q}_M}\right]\frac{1}{\varepsilon(\overline{Q}_M)} \tag{2.103}$$

$$\frac{\underline{p}_M-c}{\underline{p}_M}=\left[\frac{(1-\alpha)\lambda K-\overline{\mu}\ \underline{q}_m}{(1-\alpha-\overline{\mu})\underline{Q}_M}\right]\frac{1}{\varepsilon(\underline{Q}_M)}+\frac{\overline{\mu}(\theta-c)}{(1-\alpha-\overline{\mu})\underline{p}_M} \tag{2.104}$$

$$\begin{aligned}(1+\lambda)C'(K)=&[\alpha(1+\lambda)-\overline{\mu}](\theta-c)-\overline{\mu}[(\overline{p}_M-\theta)-(\underline{p}_M-c)]\\&+\lambda[\alpha(\overline{p}_M-\theta)+(1-\alpha)(\underline{p}_M-c)]\end{aligned} \tag{2.105}$$

($B7_{ai}$) *The policy* $(0<K<\overline{Q}_M<\underline{Q}_M,\overline{p}_M>\theta,\underline{p}_M>c,\overline{\phi}>0,\overline{\nu}=0,\overline{\mu}>0,\underline{\mu}=0)$ *described by*

$$\frac{\overline{p}_M-\theta}{\overline{p}_M}=\left[\frac{\alpha\lambda K+(\overline{\phi}+\overline{\mu})\overline{q}_m}{(\alpha+\overline{\phi}+\overline{\mu})\overline{Q}_M}\right]\frac{1}{\varepsilon(\overline{Q}_M)}=\frac{F_m}{\overline{p}_M\overline{q}_m} \tag{2.106}$$

(2.104), and

$$\begin{aligned}(1+\lambda)C'(K)=&[\alpha(1+\lambda)-\overline{\mu}](\theta-c)-\overline{\mu}\left[\frac{F_m}{\overline{q}_m}-(\underline{p}_M-c)\right]\\&+\lambda\left[\alpha\frac{F_m}{\overline{q}_m}+(1-\alpha)(\underline{p}_M-c)\right]-\overline{\phi}\frac{F_m}{\overline{q}_m}\end{aligned} \tag{2.107}$$

($B8_{ai}$) *The policy* $(0<K=\overline{Q}_M<\underline{Q}_M,\overline{p}_M>\theta,\underline{p}_M=\theta,\overline{\phi}=0,\overline{\nu}>0,\overline{\mu}>0,\underline{\mu}=0)$ *described by*

$$\frac{\overline{p}_M-\theta}{\overline{p}_M}=\left[\frac{\alpha\lambda}{(\alpha+\overline{\mu})}\right]\frac{1}{\varepsilon(\overline{Q}_M)}-\frac{\overline{\nu}}{(\alpha+\overline{\mu})\overline{p}_M}, \tag{2.108}$$

$\underline{p}_M=\theta$*, and*

$$(1+\lambda)C'(\overline{Q}_M)=(\alpha+\lambda)(\theta-c)+(\alpha\lambda-\overline{\mu})(\overline{p}_M-\theta)-\overline{\nu} \tag{2.109}$$

When there is no fixed cost ($F_m=0$)*, only policies* ($B1_{ai}$)*,* ($B3_{ai}$)*,* ($B4_{ai}$)*,* ($B6_{ai}$)*, and* ($B8_{ai}$) *may arise as optimal policies and these policies are exclusive. When there is a fixed cost* ($F_m>0$)*, only policies* ($B1_{ai}$)*,* ($B2_{ai}$)*,* ($B4_{ai}$)*,* ($B5_{ai}$)*,* ($B6_{ai}$)*,* *and* $(B7_{ai})$ *may arise as optimal policies and these policies are exclusive.*[23] *From Lemma 2.4, when* $\lambda^2 + (1+\lambda)Q'_M C''(K) < 0$ *second-order conditions of all policies are satisfied.*

Under policy $(B4_{ai})$, even the θ-type firm is active and the social marginal cost of imports, $(1+\lambda)[c + C'(K)]$, net of the expected marginal fiscal revenue of imported gas, $\lambda[\alpha\overline{p}_M + (1-\alpha)\underline{p}_M]$, is equal to the expected marginal cost of the firm, $\alpha\theta + (1-\alpha)c$, plus the social marginal cost associated with the price distortion of both the θ- and c-type firms required to minimize the informational rent of the c-type firm, $\underline{\mu}(\overline{p}_M - \underline{p}_M) > 0$.

Under policy $(B5_{ai})$, the less efficient firm just breaks even and capacity is such that the social marginal cost of imports net of the expected marginal fiscal revenue of imported gas, is equal to the expected marginal cost of the firm plus the social marginal cost associated with the price distortion necessary to minimize the informational rent of the more efficient firm, net of the ex-post social value of the contribution of the marginal unit of the firm to the relaxation of its participation constraint, $\overline{\phi}\frac{F_m}{\overline{q}_m}$.

Under policy $(B6_{ai})$, even the less efficient firm is active and the social marginal cost of imports net of the expected marginal fiscal revenue of imported gas, is equal to the expected marginal cost of the firm net of the social marginal cost associated with the price distortion of both the θ- and c-type firms required to minimize the informational rent of the less efficient firm, $\overline{\mu}(\overline{p}_M - \underline{p}_M) > 0$.

Under policy $(B7_{ai})$, the θ-type firm just breaks even and capacity is such that the social marginal cost of imports net of the expected marginal fiscal revenue of imported gas, is equal to the expected marginal cost of the firm, net of the social marginal cost associated with the price distortion necessary to minimize the informational rent of the less efficient firm and of the ex-post social value of the contribution of the marginal unit of the firm to the relaxation of its participation constraint, $\overline{\phi}\frac{F_m}{\overline{q}_m}$.

23. The conditions under which these policies may arise cannot be obtained in the general case as $\overline{\phi}$, $\overline{\mu}$, and $\underline{\mu}$ affect the system of first-order conditions in a nonlinear way. However, such conditions will be derived for the particular functional forms given in (2.22).

Under policy ($B8_{ai}$), the less efficient firm is shut down and capacity is such that the social marginal cost of imports (at the level they make the less efficient firm inactive) net of the expected marginal fiscal revenue of imported gas, is equal to the expected marginal cost of the firm plus the social marginal cost associated with the price distortions necessary to minimize the informational rent of the less efficient firm, net of the shadow cost of the θ-type firm's output nonnegativity constraint $\overline{\nu}$.

Let us illustrate this control scheme assuming that $F_m = 0$ and using the functional forms given by (2.22). Again, as in the case under uncertainty, the sign of $\lambda^2 + (1+\lambda)Q'_M C''(K)$ (see Lemma 2.4) is the same as that of $-\Psi$, where $\Psi \equiv \omega(1+\lambda) - \lambda^2$. Solving (2.91)-(2.97) under the restriction that $\underline{p}_M < \overline{p}_M$, yields the following policies:[24]

When $\Psi \geq \alpha\lambda(1+\lambda)$ the following group of policies might arise. Policy ($B4_{ai}$) arises when

$$\frac{(1-2\alpha)}{\alpha}\left[\frac{\Psi}{2\Psi+(\alpha+\lambda)(1+2\lambda)}\right](\gamma-c) < (\theta-c) \leq \left[\frac{\Psi}{\Psi+\alpha(1+\lambda)(1+2\lambda)}\right](\gamma-c) \qquad (2.110)$$

with

$$K = \frac{\alpha\left[(1-\alpha)(1+2\lambda)(\gamma-c) - [\lambda-\alpha(1+2\lambda)](\theta-c)\right]}{\Psi+\alpha(1-\alpha)(1+2\lambda)^2} \qquad (2.111)$$

$$\overline{p}_M = \theta + (1-\alpha)\left[\frac{\Psi+\alpha\lambda(1+2\lambda)}{\Psi+\alpha(1-\alpha)(1+2\lambda)^2}\right](\gamma-c) - \left[\frac{(1-\alpha)[\Psi+\alpha(1+2\lambda)^2]-\alpha\lambda(1+\lambda)}{\Psi+\alpha(1-\alpha)(1+2\lambda)^2}\right](\theta-c) \qquad (2.112)$$

$$\underline{p}_M = c + \alpha\left[\frac{\Psi+(1-\alpha)\lambda(1+2\lambda)}{\Psi+\alpha(1-\alpha)(1+2\lambda)^2}\right](\gamma-c) - \alpha\left[\frac{\Psi+\alpha(1+2\lambda)+\lambda^2}{\Psi+\alpha(1-\alpha)(1+2\lambda)^2}\right](\theta-c) \qquad (2.113)$$

24. Details about the derivation of these policies are given in the appendix.

Policy $(B1_{ai})$, identical to $(B1_u)$, described by (2.80)-(2.82), arises when

$$\left[\frac{\Psi}{\Psi+\alpha(1+\lambda)(1+2\lambda)}\right](\gamma-c)<(\theta-c)\leq\left[\frac{\Psi}{\Psi+\alpha(1+\lambda)^2}\right](\gamma-c) \qquad (2.114)$$

Policy $(B3_{ai})$, identical to $(B3_u)$, described by (2.84)-(2.86), arises when

$$\left[\frac{\Psi}{\Psi+\alpha(1+\lambda)^2}\right](\gamma-c)<(\theta-c)<(\gamma-c) \qquad (2.115)$$

When $0<\Psi<\alpha\lambda(1+\lambda)$ the following group of policies might arise. Policy $(B4_{ai})$ arises when condition (2.110) holds. Policy $(B1_{ai})$, identical to $(B1_u)$, described by (2.80)-(2.82), arises when

$$\left[\frac{\Psi}{\Psi+\alpha(1+\lambda)(1+2\lambda)}\right](\gamma-c)<(\theta-c)\leq\left[\frac{\Psi}{\alpha(1+\lambda)(1+2\lambda)}\right](\gamma-c) \qquad (2.116)$$

Policy $(B6_{ai})$ arises when

$$\left[\frac{\Psi}{\alpha(1+\lambda)(1+2\lambda)}\right](\gamma-c)<(\theta-c)\leq \left[\frac{\alpha[\Psi+(1-\alpha)\lambda(1+2\lambda)]}{\Psi+\alpha(1-\alpha)\lambda(1+2\lambda)+\alpha(1+\lambda)^2}\right](\gamma-c) \qquad (2.117)$$

with

$$K=\frac{\alpha[(1-\alpha)(1+2\lambda)(\gamma-c)+(1+\lambda)(\theta-c)]}{\Psi+\alpha(1-\alpha)(1+2\lambda)^2} \qquad (2.118)$$

$$\overline{p}_M=\theta+(1-\alpha)\left[\frac{\Psi+\alpha\lambda(1+2\lambda)}{\Psi+\alpha(1-\alpha)(1+2\lambda)^2}\right](\gamma-c) -\alpha(1+\lambda)\left[\frac{(1-\alpha)+(1-2\alpha)\lambda}{\Psi+\alpha(1-\alpha)(1+2\lambda)^2}\right](\theta-c) \qquad (2.119)$$

$$\underline{p}_M=c+\alpha\left[\frac{(1-\alpha)\lambda(1+2\lambda)+\Psi}{\Psi+\alpha(1-\alpha)(1+2\lambda)^2}\right](\gamma-c) +\alpha(1+\lambda)\left[\frac{\lambda-\alpha(1+2\lambda)}{\Psi+\alpha(1-\alpha)(1+2\lambda)^2}\right](\theta-c) \qquad (2.120)$$

Policy $(B8_{ai})$ arises when

$$\left[\frac{\alpha[\Psi+(1-\alpha)\lambda(1+2\lambda)]}{\Psi+\alpha(1-\alpha)\lambda(1+2\lambda)+\alpha(1+\lambda)^2}\right](\gamma-c)<(\theta-c)\leq \left[\frac{\alpha\lambda(1+\lambda)}{\Psi+\alpha(1+\lambda)^2}\right](\gamma-c) \quad (2.121)$$

with

$$K=\frac{\alpha(1+\lambda)(\gamma-c)+(1-\alpha)\lambda(\theta-c)}{\Psi+\lambda^2+\alpha(1+2\lambda)} \quad (2.122)$$

$$\overline{p}_M=c+\frac{[\Psi+(\alpha+\lambda)\lambda](\gamma-c)-(1-\alpha)\lambda(\theta-c)}{\Psi+\lambda^2+\alpha(1+2\lambda)} \quad (2.123)$$

$$\underline{p}_M=\theta \quad (2.124)$$

Finally, policy $(B3_{ai})$, identical to $(B3_u)$, described by (2.84)-(2.86), arises when

$$\left[\frac{\alpha\lambda(1+\lambda)}{\Psi+\alpha(1+\lambda)^2}\right](\gamma-c)<(\theta-c)<(\gamma-c) \quad (2.125)$$

2.4.3 Incentives and capacity investments under scheme B

In order to compare the capacity levels achieved by control scheme B under uncertainty (K_u^B) and asymmetric information (K_{ai}^B), it will prove useful to provide alternative expressions, allowed by our linear demand assumption, for the incentive constraints (2.89) and (2.90). Indeed, linearity of demand implies $(\overline{q}_m-\underline{q}_m)=(\overline{p}_M-\underline{p}_M)Q'_M$. Hence, the incentives constraints can be rewritten as

$$\left.\begin{array}{l}(\underline{p}_M-\theta)Q'_M+\overline{q}_m\geq 0\\ (\overline{p}_M-\theta)Q'_M+\underline{q}_m\geq 0\end{array}\right\}\quad(\overline{\mu}) \quad (2.126)$$

$$\left.\begin{array}{l}(\underline{p}_M-c)Q'_M+\overline{q}_m\leq 0\\ (\overline{p}_M-c)Q'_M+\underline{q}_m\leq 0\end{array}\right\}\quad(\underline{\mu}) \quad (2.127)$$

where (2.126) provides two alternative ways to express (2.89) while (2.127) provides two alternative ways to express (2.90).

Since $C'(K)$ is an increasing function, looking at (2.64) and (2.93) yields that when there is no fixed cost,

$$\begin{aligned} sign[K_{ai}^B - K_u^B] &= sign[(1+\lambda)[C'(K_{ai}^B) - C'(K_u^B)]] \\ &= sign[\alpha\lambda(\overline{p}_{M,ai}^B - \overline{p}_{M,u}^B) + (1-\alpha)\lambda(\underline{p}_{M,ai}^B - \underline{p}_{M,u}^B) \\ &\quad -(\overline{\mu}^B - \underline{\mu}^B)(\overline{p}_{M,ai}^B - \underline{p}_{M,ai}^B) - (\overline{\nu}_{ai}^B - \overline{\nu}_u^B)] \end{aligned} \tag{2.128}$$

and when there is a fixed cost,

$$\begin{aligned} sign[K_{ai}^B - K_u^B] &= sign[(1+\lambda)[C'(K_{ai}^B) - C'(K_u^B)]] \\ &= sign[\alpha\lambda(\overline{p}_{M,ai}^B - \overline{p}_{M,u}^B) + (1-\alpha)\lambda(\underline{p}_{M,ai}^B - \underline{p}_{M,u}^B) \\ &\quad +\overline{\phi}_u^B(\overline{p}_{M,u}^B - \theta) + \underline{\phi}_u^B(\underline{p}_{M,u}^B - c) \\ &\quad -(\overline{\mu}^B - \underline{\mu}^B)(\overline{p}_{M,ai}^B - \underline{p}_{M,ai}^B) - \overline{\phi}_{ai}^B(\overline{p}_{M,ai}^B - \theta)] \end{aligned} \tag{2.129}$$

Analyzing these signs allows us to state the following proposition:

Proposition 2.6 *When only capacity and price control are available as regulatory instruments, accounting for incentives has the following effect on capacity:*

Independently of the existence of a fixed cost, if the regulator does not minimize the informational rents of both types of firms, $\overline{\mu}^B = \underline{\mu}^B = 0$, there is no effect of incentives on capacity, i.e., $K_{ai}^B = K_u^B$.

If there is no fixed cost ($F_m = 0$) and the regulator is constrained to minimize the informational rent of the more (less) efficient firm, $\underline{\mu}^B > 0$ ($\overline{\mu}^B > 0$), excess (less) transport capacity in the strict sense should arise, i.e., $K_{ai}^B > K_u^B$ ($K_{ai}^B < K_u^B$).

If there is a fixed cost ($F_m > 0$), three cases need to be considered.

> *When the regulator minimizes the informational rent of the more efficient firm, $\underline{\mu}^B > 0$, excess transport capacity in the strict sense should arise, i.e., $K_{ai}^B > K_u^B$.*
>
> *When the regulator minimizes the informational rent of the less efficient firm, $\overline{\mu}^B > 0$, but lets it earn strictly positive profits, $\overline{\phi}_{ai}^B = 0$, less capacity in the strict sense should arise, i.e., $K_{ai}^B < K_u^B$.*

When the regulator minimizes the informational rent of the less efficient firm, $\overline{\mu}^B > 0$*, but the latter just breaks-even,* $\overline{\phi}_{ai}^B > 0$*,* $\overline{\mu}^B > 0$ *does not allow us to rank* K_{ai}^B *and* K_u^B*.*

Let us now illustrate this proposition using the functional forms (2.22). When $F_m = 0$, we simulate the optimal values of $(K_{ai}^B - K_u^B)$, $\overline{\mu}^B$, $\underline{\mu}^B$, $\overline{\nu}_{ai}^B$, and $\overline{\nu}_u^B$ in the $\{\alpha, (\theta - c)\}$-space for the parameter grids in Cases 1-3, given in the illustration of Proposition 2.3. When $F_m > 0$, we simulate the optimal values of $(K_{ai}^B - K_u^B)$, $\overline{\mu}^B$, $\underline{\mu}^B$, $\overline{\phi}_{ai}^B$, $\overline{\phi}_u^B$, and $\underline{\phi}_u^B$ in the $\{F_m, (\theta - c)\}$-space for the following parameter grids:

- Case 1^+: $\{\gamma, c, \omega, \lambda, \alpha\} = \{10, 2, 0.50, 0.33, 0.43\}$, $(\theta - c) \in [0, 4.94]$, and $F_m \in [0, 2.24]$
- Case 2^+: $\{\gamma, c, \omega, \lambda, \alpha\} = \{10, 2, 0.52, 0.85, 0.43\}$, $(\theta - c) \in [0, 2.24]$, and $F_m \in [0, 5.14]$
- Case 3^+: $\{\gamma, c, \omega, \lambda, \alpha\} = \{10, 2, 0.17, 0.25, 0.68\}$, $(\theta - c) \in [0, 2.24]$, and $F_m \in [0, 2.24]$

Figure 2.5 (a-b) summarizes the results of the simulated values of $(K_{ai}^B - K_u^B)$, $\overline{\mu}^B$, $\underline{\mu}^B$, $\overline{\nu}_{ai}^B$, and $\overline{\nu}_u^B$ for Cases 1, 2 and 3, respectively from the top to the bottom. Figure 2.5a shows in white, gray and black the regions where respectively $(K_{ai}^B - K_u^B) > 0$, $(K_{ai}^B - K_u^B) = 0$, and $(K_{ai}^B - K_u^B) < 0$. The dashed regions in these figures represent the $(\alpha, (\theta - c))$ pairs for which a solution under asymmetric information with $\underline{p}_M < \overline{p}_M$ cannot arise. Figure 2.5b exhibits the curves formed by the $(\alpha, (\theta - c))$ pairs such that $\overline{\nu}_{ai}^B = 0$, $\overline{\nu}_u^B = 0$, $\underline{\mu}^B = 0$, and $\overline{\mu}^B = 0$.

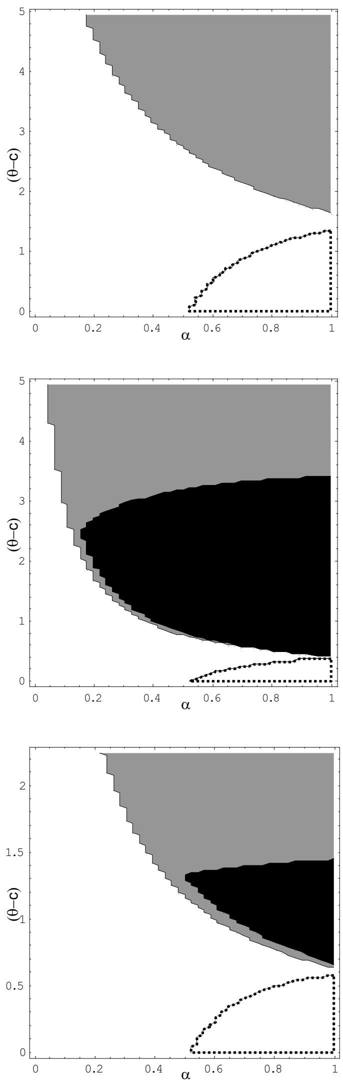


Figure 2.5a: $K^B_{ai} - K^B_u$

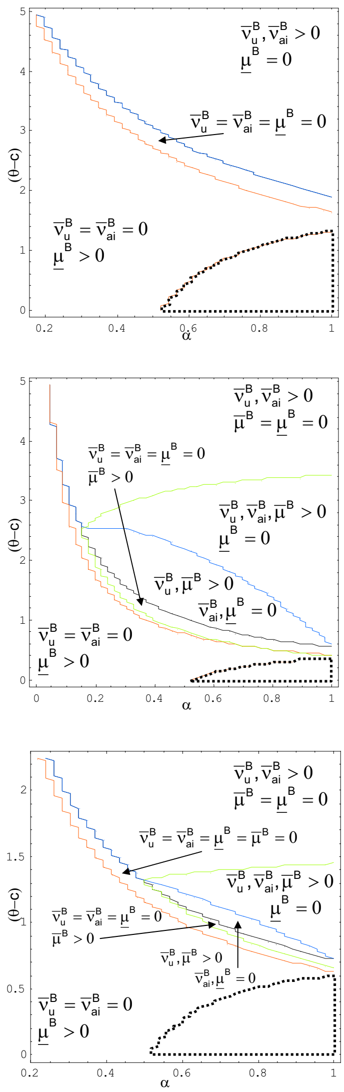


Figure 2.5b: $\overline{\mu}^B$ and $\underline{\mu}^B$

For the parameter grid of Case 1, we have $\Psi \equiv \omega(1+\lambda) - \lambda^2 > \alpha\lambda(1+\lambda)$ for any $\alpha \in [0,1]$, and hence no solution with $\overline{\mu}^B > 0$ arises. Cross-examining Figures 2.5a and 2.5b, we see that whenever $\underline{\mu}^B > 0$, irrespective of whether or not $\overline{\nu}^B_{ai}$ and $\overline{\nu}^B_u$ are positive, $K^B_{ai} > K^B_u$, as stated in the proposition. For Case 2, $\Psi \equiv \omega(1+\lambda) - \lambda^2 > \alpha\lambda(1+\lambda)$ for any $\alpha \in [0, 0.16]$, and hence solutions with $\overline{\mu}^B > 0$ exclusively arise for $\alpha \in (0.16, 1]$. We observe that whenever $\underline{\mu}^B > 0$

$(\overline{\mu}^B > 0)$, independently of $\overline{\nu}_{ai}^B$ and $\overline{\nu}_u^B$ being equal to zero or positive, $K_{ai}^B > K_u^B$ $(K_{ai}^B < K_u^B)$. For Case 3, $\Psi \equiv \omega(1+\lambda) - \lambda^2 > \alpha\lambda(1+\lambda)$ for any $\alpha \in [0, 0.50]$, and hence solutions with $\overline{\mu}^B > 0$ exclusive arise for $\alpha \in (0.50, 1]$. Cross-examining Figures 2.5a and 2.5b, leads to similar conclusions as in Case 2.

Figure 2.6 (a-b) summarizes the results of the simulated values of $(K_{ai}^B - K_u^B)$, $\overline{\mu}^B$, $\underline{\mu}^B$, $\overline{\phi}_{ai}^B$, $\overline{\phi}_u^B$, and $\underline{\phi}_u^B$ for Cases 1$^+$-3$^+$. Figure 2.6b exhibits the curves formed by the $(\alpha, (\theta - c))$ pairs such that $\overline{\phi}_{ai}^B = 0$, $\overline{\phi}_u^B = 0$, $\underline{\phi}_u^B = 0$, $\underline{\mu}^B = 0$, and $\overline{\mu}^B = 0$.

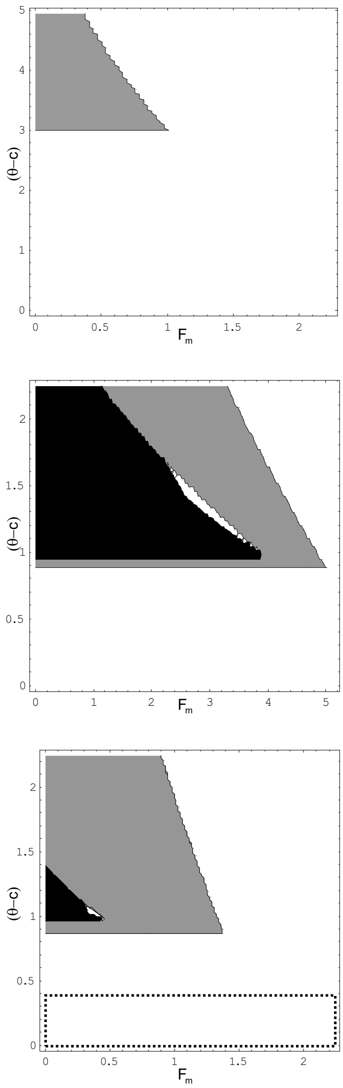


Figure 2.6a: $K_{ai}^B - K_u^B$

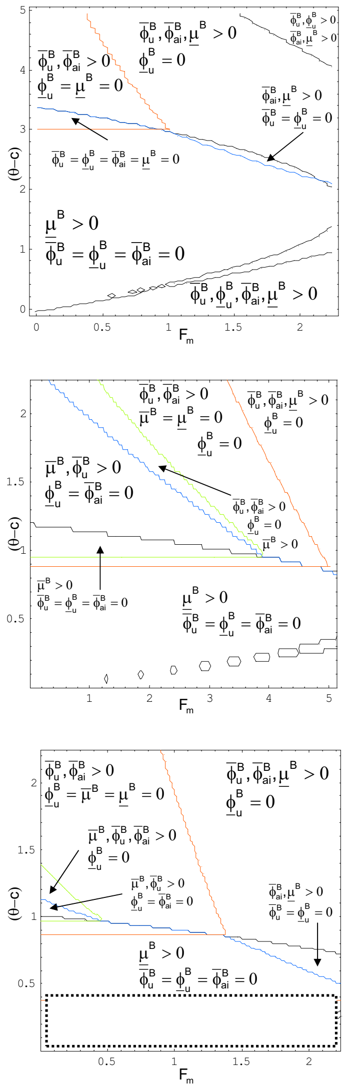


Figure 2.6b: $\overline{\mu}^B$ and $\underline{\mu}^B$

For Case 1^+, $\Psi \equiv \omega(1+\lambda) - \lambda^2 > \alpha\lambda(1+\lambda)$ for any $\alpha \in [0,1]$, and hence no solution with $\overline{\mu}^B > 0$ arises. From Figures 2.6a and 2.6b, we see that whenever $\underline{\mu}^B > 0$, irrespective of whether or not $\overline{\phi}_{ai}^B$, $\overline{\phi}_u^B$, and $\underline{\phi}_u^B$ are equal to zero, $K_{ai}^B > K_u^B$. For Case 2+, $\Psi \equiv \omega(1+\lambda) - \lambda^2 > \alpha\lambda(1+\lambda)$ for any $\alpha \in [0, 0.16]$, and hence solutions with $\overline{\mu}^B > 0$ exclusively arise for $\alpha \in (0.16, 1]$. Since under Case 2^+, $\alpha = 0.43$, solutions with $\overline{\mu}^B > 0$ are possible. Cross-examining Figures 2.6a and 2.6b, we see that $\underline{\mu}^B > 0$, irrespective of whether the remaining Lagrange multipliers are positive or equal to zero, $K_{ai}^B > K_u^B$. Moreover, when $\overline{\mu}^B > 0$ and $\overline{\phi}_{ai}^B = 0$, $sign[K_{ai}^B - K_u^B] = -sign[\overline{\mu}^B] < 0$, implying $K_{ai}^B < K_u^B$. However, when $\overline{\phi}_{ai}^B > 0$, this relationship does not hold as can be seen from the white region in Figure 2.6a which shows cases with $\overline{\mu}^B > 0$ and $K_{ai}^B > K_u^B$. This illustrates the result stated at the end of Proposition 2.6. Case 3^+ demonstrates similar properties as those obtained under Case 2^+.[25]

2.5 Timing of decisions and transport capacity under scheme C

In this section, we analyze regulatory scheme C in which the regulator can only set transport capacity. In contrast to the previously analyzed schemes A and B, in C the regulator can only partially affect market price by affecting firm's residual demand. Apart from this, the firm maximizes its profit and hence under this scheme, although we introduce uncertainty, there are no incentive issues to be addressed.

One way to analyze control scheme C is to follow the timing depicted in Figure 2.2. Such a mechanism would give the regulator the ability to internalize the impact of the firm's profit-maximizing behavior since capacity is determined prior to the setting of price by the firm.[26] Alternatively, one could assume that the

25. For $\Psi \equiv \omega(1+\lambda) - \lambda^2 > \alpha\lambda(1+\lambda)$ for any $\alpha \in [0, 0.50]$, and hence solutions with $\overline{\mu}^B > 0$ exclusively arise for $\alpha \in (0.50, 1]$. Since under Case 3^+, $\alpha = 0.68$, it is possible to get solutions with $\overline{\mu}^B > 0$.

26. In practice though, we model this case as if the regulator sets the price level within the firm's profit-maximizing range.

regulator looses this ability, and hence that decisions on capacity and price are simultaneous. Analyzing these two mechanisms allows us to explore the effect of the timing of decisions on transport capacity by comparing the optimal levels achieved.

For a given volume of gas K imported from the competitive market, the $\widetilde{\theta}$-type firm remains a monopoly in its local commodity gas market on the residual demand $Q_M(p_M(\widetilde{\theta}))-K$. Given this demand, the firm sets price so as to maximize its profit $\Pi_m(\widetilde{\theta})$ given by

$$\Pi_m(\widetilde{\theta}) = (p_M(\widetilde{\theta}) - \widetilde{\theta})[Q_M(p_M(\widetilde{\theta})) - K] - F_m \tag{2.130}$$

subject to its output nonnegativity constraint[27]

$$q_m(\widetilde{\theta}) = Q_M(p_M(\widetilde{\theta})) - K \geq 0 \quad (\nu(\widetilde{\theta})) \tag{2.131}$$

where the Lagrange multiplier shown in parentheses is such that $\overline{\nu} \equiv \nu(\theta)$ and $\underline{\nu} \equiv \nu(c)$. The first-order conditions of this profit-maximization problem are[28]

$$[p_M(\widetilde{\theta}) - \widetilde{\theta} + \nu(\widetilde{\theta})]Q'_M + q_m(\widetilde{\theta}) = 0 \tag{2.132}$$

$$\nu(\widetilde{\theta})\ q_m(\widetilde{\theta}) = 0 \tag{2.133}$$

Under this control scheme C, ex post social welfare is the same as that under B given by (2.53). However, when it comes to solving the regulator's optimization program, the fact that the firm's objective function is only defined for firm nonnegative output, should be accounted for. This is done by adding the firm's slackness complementarity term, $\nu(\widetilde{\theta})\ q_m(\widetilde{\theta})$, in the regulator's objective function. Hence, in practice, the regulator's program consists in maximizing "adjusted" expected

27. The fact that this output nonnegativity constraint is decentralized to the firm does not affect at all both interior solutions (with and without fixed cost) and boundary solutions (with fixed cost). Moreover, this assumption allows us to work on an economically meaningful firm's reaction function.

28. Since we assume a linear demand function, second-order conditions are always satisfied when $q_m(\widetilde{\theta}) \geq 0$.

social welfare given by

$$\mathrm{E}[W(\widetilde{\theta}) + \nu(\widetilde{\theta})q_m(\widetilde{\theta})] = \alpha[W(\theta) + \overline{\nu}\ \overline{q}_m] + (1-\alpha)[W(c) + \underline{\nu}\ \underline{q}_m] \tag{2.134}$$

with respect to $\overline{p}_M$, $\underline{p}_M$, and K under the ex-post participation and output non-negativity constraints

$$\overline{\Pi}_m + \overline{\nu}\ \overline{q}_m = (\overline{p}_M - \theta + \overline{\nu})\overline{q}_m - F_m \geq 0 \quad (\overline{\phi}) \tag{2.135}$$

$$\underline{\Pi}_m + \underline{\nu}\ \underline{q}_m = (\underline{p}_M - c + \underline{\nu})\underline{q}_m - F_m \geq 0 \quad (\underline{\phi}) \tag{2.136}$$

$$\overline{\nu}\ \overline{q}_m = 0 \tag{2.137}$$

$$\underline{\nu}\ \underline{q}_m = 0 \tag{2.138}$$

2.5.1 Regulation with uncertainty and sequential decisions

When the regulator first sets transport capacity and then the firm determines price, the former's optimization program should account for the latter's profit-maximizing behavior. Thus, the regulator maximizes (2.134) subject to the constraints (2.135)-(2.138), and

$$(\overline{p}_M - \theta + \overline{\nu})Q'_M + \overline{q}_m = 0 \quad (\overline{\eta}) \tag{2.139}$$

$$(\underline{p}_M - c + \underline{\nu})Q'_M + \underline{q}_m = 0 \quad (\underline{\eta}) \tag{2.140}$$

with Lagrange multipliers shown in parentheses. An important property of the constraint set is stated in the next lemma.

Lemma 2.5 *The constraint set defined by (2.135)-(2.138) and (2.139)-(2.140) is convex ans satisfies the NDCQ and LICQ constraint qualification conditions.*

The first-order conditions of the regulator's optimization program are given by

$$\alpha[\lambda K + (\overline{p}_M - \theta + \overline{\nu})Q'_M] - 2\overline{\eta}Q'_M = 0 \tag{2.141}$$

$$(1-\alpha)[\lambda K + (\underline{p}_M - c + \underline{\nu})Q'_M] - 2\underline{\eta}Q'_M = 0 \tag{2.142}$$

$$\begin{aligned}(1+\lambda)\left[\alpha(\theta-c)-C'(K)\right]+(\overline{\eta}+\underline{\eta})-(\alpha\overline{\nu}+(1-\alpha)\underline{\nu})& \\ +(\alpha\lambda-\overline{\phi})(\overline{p}_M-\theta)+((1-\alpha)\lambda-\underline{\phi})(\underline{p}_M-c)=0 &\quad (2.143)\end{aligned}$$

$$\overline{\phi}[(\overline{p}_M-\theta)\overline{q}_m-F_m]=0 \quad (2.144)$$

$$\underline{\phi}[(\underline{p}_M-c)\underline{q}_m-F_m]=0 \quad (2.145)$$

$$\overline{\nu}\,\overline{q}_m=\underline{\nu}\,\underline{q}_m=0 \quad (2.146)$$

$$(\overline{p}_M-\theta)Q'_M+\overline{q}_m+\overline{\nu}Q'_M=0 \quad (2.147)$$

$$(\underline{p}_M-c)Q'_M+\underline{q}_m+\underline{\nu}Q'_M=0 \quad (2.148)$$

The next lemma states some useful implications of (2.141)-(2.148).

Lemma 2.6 *Under control scheme C with uncertainty and sequential decisions, at the optimum, we have* $\underline{p}_M \leq \overline{p}_M$, $\underline{\Pi}_m \geq \overline{\Pi}_m$, $\underline{\phi} \leq \overline{\phi}$, $\underline{\nu} \leq \overline{\nu}$, *and* $\underline{\eta} > \overline{\eta}$.

From Lemma 2.6, we directly see that solutions with either $(\overline{\phi}=0, \underline{\phi}=0, \overline{\nu}=0, \underline{\nu}>0)$ or $(\overline{\phi}=0, \underline{\phi}>0, \overline{\nu}=0, \underline{\nu}=0)$ are ruled out. Moreover, it can be shown that solutions with either $(\overline{\phi}=0, \underline{\phi}=0, \overline{\nu}>0, \underline{\nu}>0)$ or $(\overline{\phi}>0, \underline{\phi}>0, \overline{\nu}=0, \underline{\nu}=0)$ cannot arise.[29] The following proposition characterizes the remaining solutions.

Proposition 2.7 *When only capacity is controlled by the regulator who sets it under uncertainty prior to the firm's price decision, the optimal policy* $(K, \overline{p}_M, \underline{p}_M, \overline{\phi}, \overline{\nu}, \overline{\eta}, \underline{\eta})$ *is of one of the following three types:*

($C1_u$) *The policy* $(0<K<\overline{Q}_M<\underline{Q}_M, \overline{p}_M>\theta, \underline{p}_M>c, \overline{\phi}=0, \overline{\nu}=0, \overline{\eta}\neq 0, \underline{\eta}\neq 0)$ *described by*

$$\frac{\overline{p}_M-\theta}{\overline{p}_M}=\frac{\lambda K}{\overline{Q}_M}\frac{1}{\varepsilon(\overline{Q}_M)}+\frac{2\overline{\eta}}{\alpha\overline{p}_M}=\frac{\overline{q}_m}{\overline{Q}_M}\frac{1}{\varepsilon(\overline{Q}_M)} \quad (2.149)$$

29. To show that $(\overline{\phi}=0, \underline{\phi}=0, \overline{\nu}>0, \underline{\nu}>0)$ is not a solution, start from $\overline{\nu}>0$ and $\underline{\nu}>0$ which implies $\overline{q}_m=\underline{q}_m=0$ and $\overline{p}_M=\underline{p}_M$. Solving (2.147) and (2.148) for $\overline{\nu}$ and $\underline{\nu}$, respectively, one obtains that $\overline{\nu}=-(\overline{p}_M-\theta)$ and $\underline{\nu}=-(\overline{p}_M-c)$. Thus, $\overline{\nu}, \underline{\nu}>0$ implies $\overline{p}_M<c$. Now, solving (2.141) and (2.142) for $\overline{\eta}$ and $\underline{\eta}$ and substituting into (2.143) yields $\lambda K-[(1-\alpha)(\theta-c)-(3+2\lambda)(\overline{p}_M-c)]Q'_M=0$ which implies $K<0$, an impossibility. To see why $(\overline{\phi}>0, \underline{\phi}>0, \overline{\nu}=0, \underline{\nu}=0)$ is not a solution, assume $\overline{\phi}>0$ and $\underline{\phi}>0$ which implies $F=(\overline{p}_M-\theta)\overline{q}_m=(\underline{p}_M-c)\underline{q}_m$. From (2.147) and (2.148) one obtains $FQ'_M=-\overline{q}_m^2=-\underline{q}_m^2$. Hence, $\overline{q}_m=\underline{q}_m$, i.e., $\overline{p}_M=\underline{p}_M$ which violates $\theta>c$.

$$\frac{\underline{p}_M - c}{\underline{p}_M} = \frac{\lambda K}{\underline{Q}_M}\frac{1}{\varepsilon(\underline{Q}_M)} + \frac{2\underline{\eta}}{(1-\alpha)\underline{p}_M} = \frac{\underline{q}_m}{\underline{Q}_M}\frac{1}{\varepsilon(\underline{Q}_M)} \tag{2.150}$$

$$\begin{aligned}(1+\lambda)C'(K) &= \alpha(1+\lambda)(\theta - c) + \overline{\eta} + \underline{\eta} \\ &\quad + \lambda[\alpha(\overline{p}_M - \theta) + (1-\alpha)(\underline{p}_M - c)]\end{aligned} \tag{2.151}$$

($C2_u$) *The policy* $(0 < K < \overline{Q}_M < \underline{Q}_M, \overline{p}_M > \theta, \underline{p}_M > c, \overline{\phi} > 0, \overline{\nu} = 0, \overline{\eta} \neq 0, \underline{\eta} \neq 0)$ *characterized by (2.149), (2.150), and*

$$\begin{aligned}(1+\lambda)C'(K) &= \alpha(1+\lambda)(\theta - c) + \overline{\eta} + \underline{\eta} - \overline{\phi}\frac{F_m}{\overline{q}_m} \\ &\quad + \lambda[\alpha\frac{F_m}{\overline{q}_m} + (1-\alpha)(\underline{p}_M - c)]\end{aligned} \tag{2.152}$$

($C3_u$) *The policy* $(0 < K = \overline{Q}_M < \underline{Q}_M, \overline{p}_M < \theta, \underline{p}_M > c, \overline{\phi} = 0, \overline{\nu} > 0, \overline{\eta} \neq 0, \underline{\eta} \neq 0)$ *defined by*

$$\frac{\overline{p}_M - \theta}{\overline{p}_M} = \frac{\lambda}{\varepsilon(\overline{Q}_M)} + \frac{2\overline{\eta} - \alpha\overline{\nu}}{\alpha\overline{p}_M} = -\frac{\overline{\nu}}{\overline{p}_M} \tag{2.153}$$

(2.150), and

$$\begin{aligned}(1+\lambda)C'(\overline{Q}_M) &= \alpha(1+\lambda)(\theta - c) + \overline{\eta} + \underline{\eta} - \alpha\overline{\nu} \\ &\quad + \lambda[\alpha(\overline{p}_M - \theta) + (1-\alpha)(\underline{p}_M - c)]\end{aligned} \tag{2.154}$$

When there is no fixed cost, $F_m = 0$*, only policies* ($C1_u$) *and* ($C3_u$) *may arise, and policy* ($C1_u$) *is optimal when* $0 < \alpha(\theta - c) < C'(\overline{Q}_M) - \frac{1}{2}\frac{\lambda}{1+\lambda}\frac{\overline{Q}_M}{Q'_M} + \frac{(1-\alpha)(1+2\lambda)\underline{q}_m}{2(1+\lambda)Q'_M}$*, while policy* ($C3_u$) *is when the reverse inequality holds.*

When there is a fixed cost, $F_m > 0$*, only policies* ($C1_u$)*,* ($C2_u$) *may arise, and policy* ($C1_u$) *is optimal when* $0 < \alpha(\theta - c) < C'(K) - \frac{1}{2}\frac{\lambda}{1+\lambda}\frac{K}{Q'_M} + \frac{(1-\alpha)(1+2\lambda)\underline{q}_m}{2(1+\lambda)Q'_M} - \frac{\alpha(1+2\lambda)F_m}{2(1+\lambda)\overline{q}_m}$*. When this condition does not hold, policy* ($C2_u$) *is optimal.*

Proposition 2.7 shows that under policy ($C1_u$) even the θ-type firm is active and capacity is such that the social marginal cost of imports, $(1+\lambda)[c + C'(K)]$, net of the expected marginal fiscal revenue of imported gas, $\lambda[\alpha\overline{p}_M + (1-\alpha)\underline{p}_M]$, is equal to the expected marginal cost of the firm, $\alpha\theta + (1-\alpha)c$, plus the aggregate shadow cost of both types of firms' ex post profit-maximization constraints, $\overline{\eta} + \underline{\eta}$.

Under policy $(C2_u)$ the less efficient firm breaks even and capacity is such that the social marginal cost of imports net of the expected marginal fiscal revenue of imported gas equals the expected marginal cost of the firm plus the aggregate shadow cost of both types of firms' ex post profit-maximization constraints, minus the social value of the contribution of the marginal unit of the firm to the relaxation of its participation constraint, $\overline{\phi}\frac{F_m}{\overline{q}_m}$.

Under policy $(C3_u)$, the less efficient firm is shut down and capacity is such that the social marginal cost of imports (at the level that makes the less efficient firm inactive) net of the expected marginal fiscal revenue of imported gas, is equal to the expected marginal cost of the firm plus the aggregate shadow cost of both types of firms' ex post profit-maximization constraints, net of the expected shadow cost of the θ-type firm's output nonnegativity constraint $\alpha\overline{\nu}$.

Assuming the functional forms (2.22) and solving (2.141)-(2.148) yields the following policies. If the condition

$$0 \leq (\theta - c) < 2\left[\frac{\lambda + 2\omega(1+\lambda)}{1 + 4\lambda + 4\omega(1+\lambda) + \alpha(3+2\lambda)}\right](\gamma - c) \\ -2\left[\frac{1 + 4\lambda + 4\omega(1+\lambda)}{1 + 4\lambda + 4\omega(1+\lambda) + \alpha(3+2\lambda)}\right]\sqrt{F_m} \tag{2.155}$$

holds, $(C1_u)$ is optimal with

$$K = \frac{(1+2\lambda)(\gamma - c) + \alpha(3+2\lambda)(\theta - c)}{1 + 4\lambda + 4\omega(1+\lambda)} \tag{2.156}$$

$$\overline{p}_M = \frac{(\theta + c)}{2} + \left[\frac{\lambda + 2\omega(1+\lambda)}{1 + 4\lambda + 4\omega(1+\lambda)}\right](\gamma - c) \\ -\frac{\alpha}{2}\left[\frac{3+2\lambda}{1 + 4\lambda + 4\omega(1+\lambda)}\right](\theta - c) \tag{2.157}$$

$$\underline{p}_M = c + \left[\frac{\lambda + 2\omega(1+\lambda)}{1 + 4\lambda + 4\omega(1+\lambda)}\right](\gamma - c) \\ -\frac{\alpha}{2}\left[\frac{3+2\lambda}{1 + 4\lambda + 4\omega(1+\lambda)}\right](\theta - c) \tag{2.158}$$

When condition (2.155) does not hold, we obtain two cases. If $F_m > 0$, policy $(C2_u)$ is optimal with

$$K = \gamma - \theta - 2\sqrt{F_m} \tag{2.159}$$

$$\overline{p}_M = \theta + \sqrt{F_m} \tag{2.160}$$

$$\underline{p}_M = \frac{(\theta + c)}{2} + \sqrt{F_m} \tag{2.161}$$

If $F_m = 0$, policy $(C3_u)$ is optimal with

$$K = \left[\frac{1 + 2\lambda + \alpha(3 + 2\lambda)}{1 + 4\lambda + 4\omega(1 + \lambda) + \alpha(3 + 2\lambda)}\right](\gamma - c) \tag{2.162}$$

$$\overline{p}_M = c + 2\left[\frac{\lambda + 2\omega(1 + \lambda)}{1 + 4\lambda + 4\omega(1 + \lambda) + \alpha(3 + 2\lambda)}\right](\gamma - c) \tag{2.163}$$

$$\underline{p}_M = c + \left[\frac{\lambda + 2\omega(1 + \lambda)}{1 + 4\lambda + 4\omega(1 + \lambda) + \alpha(3 + 2\lambda)}\right](\gamma - c) \tag{2.164}$$

2.5.2 Regulation with uncertainty and simultaneous decisions

When the regulator sets transport capacity at the time the firm determines price, the former maximizes (2.134) with respect to K, subject to the constraints (2.135)-(2.138), while the latter maximizes its profit with respect to price subject to its output nonnegativity constraint. The first-order conditions characterizing this regulator-firm relationship are given by

$$\begin{aligned}(1 + \lambda)\left[\alpha(\theta - c) - C'(K)\right] - (\alpha\overline{\nu} + (1 - \alpha)\underline{\nu})& \\ +(\alpha\lambda - \overline{\phi})(\overline{p}_M - \theta) + ((1 - \alpha)\lambda - \underline{\phi})(\underline{p}_M - c) = 0&\end{aligned} \tag{2.165}$$

$$\overline{\phi}[(\overline{p}_M - \theta)\overline{q}_m - F_m] = 0 \tag{2.166}$$

$$\underline{\phi}[(\underline{p}_M - c)\underline{q}_m - F_m] = 0 \tag{2.167}$$

$$(\overline{p}_M - \theta + \overline{\nu})Q'_M + \overline{q}_m = 0 \tag{2.168}$$

$$(\underline{p}_M - c + \underline{\nu})Q'_M + \underline{q}_m = 0 \tag{2.169}$$

$$\overline{\nu}\ \overline{q}_m = \underline{\nu}\ \underline{q}_m = 0 \tag{2.170}$$

The solutions of these first-order conditions are characterized in the next proposition.

Proposition 2.8 *When only capacity is controlled by the regulator who sets it under uncertainty at the same time the firm determines price, the optimal policy* $(K, \overline{p}_M, \underline{p}_M, \overline{\phi}, \overline{\nu})$ *is of one of the following three types:*

$(\widehat{C1}_u)$ *The policy* $(0 < K < \overline{Q}_M < \underline{Q}_M, \overline{p}_M > \theta, \underline{p}_M > c, \overline{\phi} = 0, \overline{\nu} = 0)$ *described by*

$$\frac{\overline{p}_M - \theta}{\overline{p}_M} = \frac{\overline{q}_m}{\overline{Q}_M}\frac{1}{\varepsilon(\overline{Q}_M)} \tag{2.171}$$

$$\frac{\underline{p}_M - c}{\underline{p}_M} = \frac{\underline{q}_m}{\underline{Q}_M}\frac{1}{\varepsilon(\underline{Q}_M)} \tag{2.172}$$

$$(1+\lambda)C'(K) = \alpha(1+\lambda)(\theta - c) + \lambda[\alpha(\overline{p}_M - \theta) + (1-\alpha)(\underline{p}_M - c)] \tag{2.173}$$

$(\widehat{C2}_u)$ *The policy* $(0 < K < \overline{Q}_M < \underline{Q}_M, \overline{p}_M > \theta, \underline{p}_M > c, \overline{\phi} > 0, \overline{\nu} = 0)$ *characterized by (2.171), (2.172), and*

$$(1+\lambda)C'(K) = \alpha(1+\lambda)(\theta - c) - \overline{\phi}\frac{F_m}{\overline{q}_m} + \lambda[\alpha\frac{F_m}{\overline{q}_m} + (1-\alpha)(\underline{p}_M - c)] \tag{2.174}$$

$(\widehat{C3}_u)$ *The policy* $(0 < K = \overline{Q}_M < \underline{Q}_M, \overline{p}_M < \theta, \underline{p}_M > c, \overline{\phi} = 0, \overline{\nu} > 0)$ *defined by*

$$\frac{\overline{p}_M - \theta}{\overline{p}_M} = -\frac{\overline{\nu}}{\overline{p}_M} \tag{2.175}$$

(2.172) and

$$\begin{aligned}(1+\lambda)C'(\overline{Q}_M) = {} & \alpha(1+\lambda)(\theta - c) - \alpha\overline{\nu} \\ & +\lambda[\alpha(\overline{p}_M - \theta) + (1-\alpha)(\underline{p}_M - c)]\end{aligned} \tag{2.176}$$

When there is no fixed cost, $F_m = 0$*, only policies* $(\widehat{C1}_u)$ *and* $(\widehat{C3}_u)$ *may arise, and when* $0 < \alpha(\theta - c) < C'(\overline{Q}_M) + \frac{(1-\alpha)\lambda\underline{q}_m}{(1+\lambda)\underline{Q}'_M}$ $(\widehat{C1}_u)$ *is optimal, while policy* $(\widehat{C3}_u)$ *is when the reverse inequality holds.*

When there is a fixed cost, $F_m > 0$, only policies $(\widehat{C1}_u)$ and $(\widehat{C2}_u)$ may arise, and policy $(\widehat{C1}_u)$ is optimal when $0 < \alpha(\theta - c) < C'(K) + \frac{(1-\alpha)\lambda \underline{q}_m}{(1+\lambda)Q'_M} - \frac{\alpha\lambda}{1+\lambda}\frac{F_m}{\overline{q}_m}$. When this condition does not hold, policy $(\widehat{C2}_u)$ is optimal.

Proposition 2.8 shows that under policy $(\widehat{C1}_u)$ even the θ-type firm is active and capacity is such that the social marginal cost of imports, $(1+\lambda)[c + C'(K)]$, net of the expected marginal fiscal revenue of imported gas (evaluated at profit-maximizing prices), $\lambda[\alpha\overline{p}_M + (1-\alpha)\underline{p}_M]$, is equal to the expected marginal cost of the firm, $\alpha\theta + (1-\alpha)c$.

Under policy $(\widehat{C2}_u)$ the less efficient firm breaks even and capacity is such that the social marginal cost of imports net of the expected marginal fiscal revenue of imported gas is equal to the expected marginal cost of the firm net of the social value of the contribution of the marginal unit of the firm to the relaxation of its participation constraint, $\overline{\phi}\frac{F_m}{\overline{q}_m}$.

Under policy $(\widehat{C3}_u)$, the less efficient firm is shut down and capacity is such that the social marginal cost of imports (at the level that makes the less efficient firm inactive) net of the expected marginal fiscal revenue of imported gas, is equal to the expected marginal cost of the firm, net of the expected shadow cost of the θ-type firm's output nonnegativity constraint $\alpha\overline{\nu}$.

With functional forms (2.22), the solution to (2.165)-(2.170) yields the following policies. When the condition

$$0 \leq (\theta - c) < 2\left[\frac{\omega(1+\lambda)(\gamma - c) - [\lambda + 2\omega(1+\lambda)]\sqrt{F_m}}{\lambda + 2\omega(1+\lambda) + \alpha(2+\lambda)}\right] \tag{2.177}$$

holds, policy $(\widehat{C1}_u)$ is optimal with

$$K = \frac{\lambda(\gamma - c) + \alpha(2+\lambda)(\theta - c)}{\lambda + 2\omega(1+\lambda)} \tag{2.178}$$

$$\overline{p}_M = \frac{(\theta + c)}{2} + \frac{1}{2}\left[\frac{2\omega(1+\lambda)(\gamma - c) - \alpha(2+\lambda)(\theta - c)}{\lambda + 2\omega(1+\lambda)}\right] \tag{2.179}$$

$$\underline{p}_M = c + \frac{1}{2}\left[\frac{2\omega(1+\lambda)(\gamma - c) - \alpha(2+\lambda)(\theta - c)}{\lambda + 2\omega(1+\lambda)}\right] \tag{2.180}$$

When condition (2.177) does not hold and $F_m > 0$, (2.165)-(2.170) yield a policy $(\widehat{C2}_u)$ identical to $(C2_u)$ described by (2.159)-(2.161). When condition (2.177) does not hold and $F_m = 0$, policy $(\widehat{C3}_u)$ with

$$K = \left[\frac{\lambda + \alpha(2+\lambda)}{\lambda + 2\omega(1+\lambda) + \alpha(2+\lambda)}\right](\gamma - c) \tag{2.181}$$

$$\overline{p}_M = c + 2\left[\frac{\omega(1+\lambda)}{\lambda + 2\omega(1+\lambda) + \alpha(2+\lambda)}\right](\gamma - c) \tag{2.182}$$

$$\underline{p}_M = c + \left[\frac{\omega(1+\lambda)}{\lambda + 2\omega(1+\lambda) + \alpha(2+\lambda)}\right](\gamma - c) \tag{2.183}$$

is optimal.

2.5.3 Capacity effect of timing of decisions under scheme C

The comparison of the capacity levels achieved under control scheme C under uncertainty with sequential (K_u^C) and simultaneous $(K_{\widehat{u}}^C)$ decisions, allows us to assess the impact of timing on transport capacity. From (2.134), we have $\frac{\partial \mathrm{E}[W^C]}{\partial K} = (1+\lambda)[\alpha(\theta - c) - C'(K)] + \alpha\lambda(\overline{p}_M - \theta) + (1-\alpha)\lambda(\underline{p}_M - c)$ and $\frac{\partial^2 \mathrm{E}[W^C]}{\partial K^2} < 0$. From the first-order conditions (2.143) and (2.165), we obtain

$$\begin{aligned} sign[K_{\widehat{u}}^C - K_u^C] &= -sign\left[\left(\frac{\partial \mathrm{E}[W^C]}{\partial K_{\widehat{u}}} - \alpha\overline{\nu}_u^C\right) - \left(\frac{\partial \mathrm{E}[W^C]}{\partial K_u} - \alpha\overline{\nu}_{\widehat{u}}^C\right)\right] \\ &= -sign[(\overline{\eta}^C + \underline{\eta}^C)] \end{aligned} \tag{2.184}$$

when there is no fixed cost. When there is a fixed cost, we obtain

$$\begin{aligned} sign[K_{\widehat{u}}^C - K_u^C] &= -sign\left[\frac{\partial \mathrm{E}[W^C]}{\partial K_{\widehat{u}}} - \frac{\partial \mathrm{E}[W^C]}{\partial K_u}\right] \\ &= -sign[(\overline{\eta}^C + \underline{\eta}^C) - \overline{\phi}_u^C(\overline{p}_{M,u}^C - \theta) + \overline{\phi}_{\widehat{u}}^C(\overline{p}_{M,\widehat{u}}^C - \theta)] \end{aligned} \tag{2.185}$$

These relationships allow us to state the proposition that follows.

Proposition 2.9 *When only capacity is available as a regulatory instrument, timing of decisions has the following effect on transport capacity:*

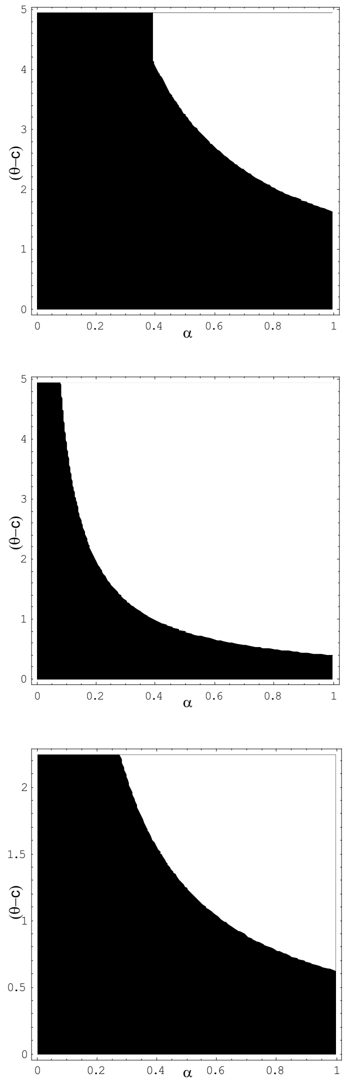
When there is no fixed cost ($F_m = 0$) *and the aggregate shadow cost of both types of firms' ex post profit-maximization constraints is positive* (*negative*)*, i.e., when* $(\overline{\eta}^C + \underline{\eta}^C) > 0$ $((\overline{\eta}^C + \underline{\eta}^C) < 0)$*, sequentiality of decisions calls for excess* (*less*) *capacity relative to simultaneity in the strict sense, i.e.,* $K_u^C > K_{\hat{u}}^C$ $(K_u^C < K_{\hat{u}}^C)$*.*

When there is a fixed cost ($F_m > 0$)*, there are three cases:*

> *When the less efficient firm earns positive profits when decisions are both sequential and simultaneous,* $\overline{\phi}_u^C = \overline{\phi}_{\hat{u}}^C = 0$*, the same conclusions as in the case where* $F_m = 0$ *can be drawn.*
>
> *When the less efficient firm just breaks even when decisions are both sequential and simultaneous,* $\overline{\phi}_u^C, \overline{\phi}_{\hat{u}}^C > 0$*, timing of decisions has no effect on transport capacity, i.e.,* $K_u^C = K_{\hat{u}}^C$*.*
>
> *When the less efficient firm just break even when decisions are either sequential or simultaneous,* $(\overline{\phi}_u^C > 0, \overline{\phi}_{\hat{u}}^C = 0)$ *or* $(\overline{\phi}_u^C = 0, \overline{\phi}_{\hat{u}}^C > 0)$*,* $(\overline{\eta}^C + \underline{\eta}^C)$ *does not allow us to rank* $K_{\hat{u}}^C$ *and* K_u^C*.*

We now verify this proposition using the functional forms given in (2.22). Comparing the capacity levels given in (2.156), (2.159), (2.162), (2.178), and (2.181) provides a preliminary verification. However, since the intervals defining the parameter space for each policy are not always compatible, we run some simulations. When $F_m = 0$, we simulate the optimal values of $(K_{\hat{u}}^C - K_u^C)$, $(\overline{\eta}^C + \underline{\eta}^C)$, $\overline{\nu}_{\hat{u}}^C$, and $\overline{\nu}_u^C$ in the $\{\alpha, (\theta - c)\}$-space for the parameter values presented in Cases 1-3 given in the verification of Proposition 2.3. When $F_m > 0$, we simulate the optimal values of $(K_{\hat{u}}^C - K_u^C)$, $(\overline{\eta}^C + \underline{\eta}^C)$, $\overline{\phi}_{\hat{u}}^C$, and $\overline{\phi}_u^C$ in the $\{F_m, (\theta - c)\}$-space for the grids of parameters in Case 1^+-3^+ presented in the verification of Proposition 2.6.

Figure 2.7 (a-b) summarizes the results of the simulated values of $(K_{\hat{u}}^C - K_u^C)$, $(\overline{\eta}^C + \underline{\eta}^C)$, $\overline{\nu}_{\hat{u}}^C$, and $\overline{\nu}_u^C$ for Cases 1, 2 and 3, respectively from the top to the bottom. Figure 2.7a shows in white and black the regions where respectively $(K_{\hat{u}}^C - K_u^C) > 0$ and $(K_{\hat{u}}^C - K_u^C) < 0$. Figure 2.7b exhibits the curves formed by the $(\alpha, (\theta - c))$ pairs such that $(\overline{\eta}^C + \underline{\eta}^C) = 0$, $\overline{\nu}_{\hat{u}}^C = 0$, and $\overline{\nu}_u^C = 0$.



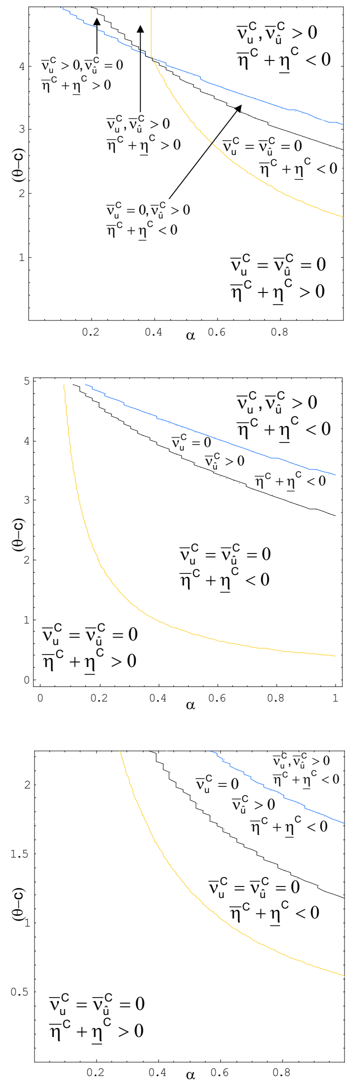


Figure 2.7a: $K_{\hat{u}}^C - K_u^C$

Figure 2.7b: $\overline{\eta}^C$, $\underline{\eta}^C$

Cross-examining Figures 2.7a and 2.7b, we see that whenever $(\overline{\eta}^C + \underline{\eta}^C) > 0$, irrespective of whether or not $\overline{\nu}_{\hat{u}}^C$ and $\overline{\nu}_u^C$ are positive $K_u^C > K_{\hat{u}}^C$. Conversely, when $(\overline{\eta}^C + \underline{\eta}^C) < 0$, $K_u^C < K_{\hat{u}}^C$ as stated in the proposition.

Figure 2.8 (a-b) summarizes the results of the simulated values of $(K_{\hat{u}}^C - K_u^C)$, $(\overline{\eta}^C + \underline{\eta}^C)$, $\overline{\phi}_{\hat{u}}^C$, and $\overline{\phi}_u^C$ for Cases 1^+, 2^+ and 3^+, respectively from the top to the bottom. Figure 2.8a shows in white, gray, and black the regions where respectively $(K^C_{\widehat{u}} - K^C_u) > 0$, $(K^C_{\widehat{u}} - K^C_u) = 0$ and $(K^C_{\widehat{u}} - K^C_u) < 0$. Figure 2.8b exhibits the curves formed by the $(\alpha, (\theta - c))$ pairs such that $(\overline{\eta}^C + \underline{\eta}^C) = 0$, $\overline{\phi}^C_{\widehat{u}} = 0$, and $\overline{\phi}^C_u = 0$.

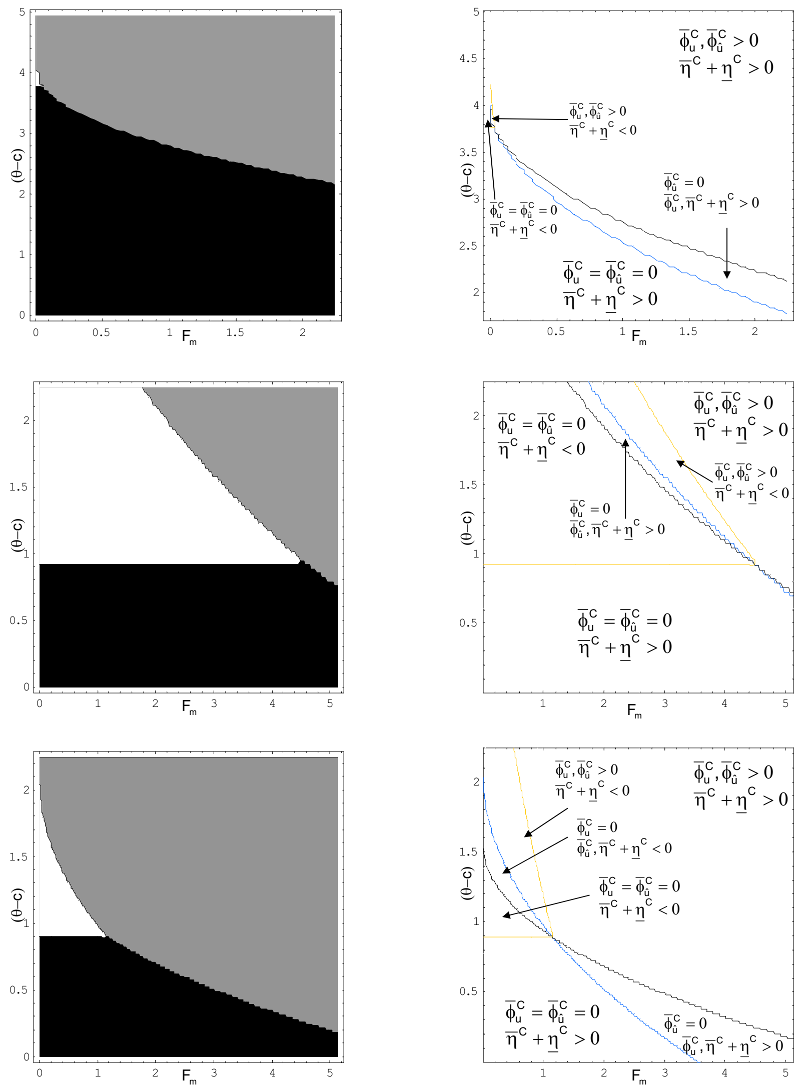


Figure 2.8a: $K^C_{\widehat{u}} - K^C_u$ **Figure 2.8b:** $\overline{\eta}^C$, $\underline{\eta}^C$

Cross-examining Figures 2.8a and 2.8b, we see that when $\overline{\phi}^C_u = \overline{\phi}^C_{\widehat{u}} = 0$, the sign of $\overline{\eta}^C + \underline{\eta}^C$ ranks the capacity gap $(K^C_{\widehat{u}} - K^C_u)$ in the same way that in the case where there is no fixed cost. Moreover, when both $\overline{\phi}^C_u, \overline{\phi}^C_{\widehat{u}} > 0$, we observe that it is always the case that $K_u^C = K_{\hat{u}}^C$. Finally, we see that when either $(\overline{\phi}_u^C > 0, \overline{\phi}_{\hat{u}}^C = 0)$ or $(\overline{\phi}_u^C = 0, \overline{\phi}_{\hat{u}}^C > 0)$, the sign of $(\overline{\eta}^C + \underline{\eta}^C)$ does not provide enough information to measure the effect of timing of decisions on transport capacity, as stated at the end of Proposition 2.9.

2.6 Conclusion

The analysis in this chapter has attempted to contribute to the literature on regulation of network industries along three dimensions. First, we derived and highlighted the economic properties of various policies based on standard regulatory instruments, namely, pricing and taxation, but most importantly on a less conventional means of market intervention, namely, investing in network capacity. As far as this first contribution is concerned, although informative, the results obtained are generally not surprising. Second, we investigated the impact on network investments of accounting for incentives in a context where private information gives the regulated firm the opportunity to earn rents. The results there suggest that this impact is not unambiguous. Finally, we explored the effect on the size of investments in transport capacity of the ability of the regulator to commit to these investments. Here again, the results support an under-investment effect, no effect, and an over-investment effect.

When the less informed regulator can use transfers and control price, a relatively over-sized transport network can be justified on normative grounds and by the need to give the informed firm proper production incentives. Indeed, by putting downward pressure on the less efficient firm's output, an important determinant of the more efficient firm's informational rent, which is the only one of concern since that of the less efficient is nil, expansion of capacity helps reducing this rent.

When transfers are not allowed, it turns out that the regulator can be concerned about the informational rent of either the more efficient firm or the less efficient one. We identify various cases. If incentive constraints are not binding, i.e., the firm behaves truthfully, capacity is neutral. When the regulator is concerned about the informational rent of the more efficient firm, capacity expansion is beneficial independently of whether or not there is a fixed cost. When it is the less efficient firm's rent that negatively affects social welfare, cases where capacity reduction is desirable might arise.

When the regulator further looses pricing as a regulatory instrument, the social cost/benefit of the firm's profit-maximizing behavior plays a role.[30] We then examine how the regulator's ability to commit to investments in capacity affects transport network sizing. When the firm's profit-maximizing behavior is socially costly (beneficial) commitment induces capacity expansion (reduction). When there is a fixed cost and the firm breaks even, the loss of the regulator's ability to commit does not affect capacity.

30. We thank C. Waddams for having suggested to us that some degree of facility-based local competition in the incumbent's market (regional market M in the framework of this chapter) would probably have to compensate for the loss of the two regulatory instruments.

Appendix

Proof of Lemma 2.1 *Consider the ex-post program under scheme A where the regulator seeks to control market power exercised by a $\widetilde{\theta}$-type firm through the maximization of the social welfare function (2.2) with respect to $p_M(\widetilde{\theta})$ and $U(\widetilde{\theta})$, for a given level of already installed transport capacity K, under the constraints (2.3) and (2.4). Differentiating with respect to $\widetilde{\theta}$ the associated system of first-order conditions yields that when $\nu(\widetilde{\theta}) = 0$, $\frac{dp_M(\widetilde{\theta})}{d\widetilde{\theta}} = \frac{1+\lambda}{1+2\lambda} > 0$ and clearly $\frac{d\nu(\widetilde{\theta})}{d\widetilde{\theta}} = 0$. When $\nu(\widetilde{\theta}) > 0$, we have $\frac{dp_M(\widetilde{\theta})}{d\widetilde{\theta}} = 0$ and $\frac{d\nu(\widetilde{\theta})}{d\widetilde{\theta}} = (1+\lambda) > 0$.* ■

Proof of Proposition 2.1 *From (2.14), we obtain that the participation constraint of the firm is always binding independently of the firm's type, i.e., $\overline{\phi} = \alpha\lambda > 0$ and $\underline{\phi} = (1-\alpha)\lambda > 0$.*

Concerning policy ($A1_u$), the condition $0 < \alpha(\theta - c) < C'(\overline{Q}_M)$ yields $\overline{\nu} = 0$. Substitute into (2.10) and use the fact that $\varepsilon(\overline{Q}_M) \equiv -Q'_M \overline{p}_M/\overline{Q}_M$ to obtain (2.17). Rewrite (2.11) using the fact that $\varepsilon(\underline{Q}_M) \equiv -Q'_M \underline{p}_M/\underline{Q}_M$ to obtain (2.18). Next, substitute $\overline{\nu} = 0$ into (2.12) to get (2.19).

For policy ($A2_u$), when $\alpha(\theta - c) > C'(\overline{Q}_M)$, the first-order condition (2.12) calls for $\overline{\nu} > 0$. Substitute this result into (2.10) to obtain (2.20). Since $\overline{\nu} > 0$ does not appear in (2.11), rewriting the later still yields (2.18). Finally, (2.12) with $\overline{\nu} > 0$ yields (2.21). ■

Proof of Proposition 2.2 *In the discussion following the system of first-order conditions (2.33)-(2.40), we obtain that in scheme A under asymmetric information $\overline{\phi} = \lambda > 0$ and $\overline{\mu} = 0$. Substituting into (2.37) yields $\underline{\mu} = (1-\alpha)\lambda$.*

Concerning policy ($A1_{ai}$), the condition $0 < (\alpha+\lambda)(\theta - c) < C'(\overline{Q}_M)$ yields $\overline{\nu} = 0$. Substitute $\underline{\mu} = (1-\alpha)\lambda > 0$ and $\overline{\nu} = 0$ into (2.33)-(2.35) to get (2.41)-(2.43).

For policy ($A2_{ai}$), when $(\alpha+\lambda)(\theta-c) > C'(\overline{Q}_M)$, the first-order condition (2.35) calls for $\overline{\nu} > 0$. Substitute $\underline{\mu} = (1-\alpha)\lambda > 0$ and $\overline{\nu} > 0$ into (2.33)-(2.35) to get (2.44)-(2.45). ■

Proof or Proposition 2.3 *We know from Propositions 2.1 and 2.2 that policy ($A1_u$) arises when $0 < (\theta - c) < \frac{C'(\overline{Q}_M^A)}{\alpha}$ whereas policy ($A1_{ai}$) happens when $0 < (\theta - c) < \frac{C'(\overline{Q}_M^A)}{\alpha+\lambda}$. It is direct then to see that whenever ($A1_{ai}$) is optimal under asymmetric information, so is ($A1_u$) under uncertainty. Thus, from (2.51) we obtain that asymmetric information induces "excess" capacity (in the strong sense), i.e., $K_{ai}^A > K_u^A$ under policy ($A1_{ai}$). When policy ($A2_{ai}$) arises, the benchmark scheme does not necessarily imply shutting down the less efficient firm. When this firm is active under uncertainty, it is easy to see that $K_u^A < \overline{Q}_{M,ai}^A$. When this firm is inactive under uncertainty, no "excess" capacity arises. In fact, the two policies are identical and hence $K_u^A = K_{ai}^A$. To see this, solve (2.21) for $\overline{\nu}$ and substitute into (2.20) to obtain $\frac{\overline{p}_M - (c + \frac{C'(\overline{Q}_M)}{\alpha})}{\overline{p}_M} = \frac{\lambda}{1+\lambda}\frac{1}{\varepsilon(\overline{Q}_M)}$. Moreover, solve (2.45) for $\overline{\nu}$ and plug into (2.44) to find the* *same markup expression. Furthermore, since (2.18) and (2.42) are identical, we conclude that price and transport capacity under policies* $(A2_u)$ *and* $(A2_{ai})$ *are the same and consequently* $(\overline{\nu}^A_{ai} - \overline{\nu}^A_u) = (1-\alpha)\lambda(\theta - c) > 0$. ■

Proof of Lemma 2.2 *To find the conditions which characterize convexity of the set associated to the constraints (2.58)-(2.61), a first step is to separately study the properties of the surface levels defined by each constraint when satisfied with equality in the* $\{\overline{p}_M, \underline{p}_M, K\}$*-space.*

When the participation constraint of the less efficient firm (2.58) is binding, it is represented by the level set $\overline{\Pi}^\star_m(\overline{p}_M, \underline{p}_M, K) = (\overline{p}_M - \theta)\overline{q}_m - F_m = 0$, *with gradient vector* $\nabla\overline{\Pi}^\star_m(\cdot) = ((\overline{p}_M - \theta)Q'_M + \overline{q}_m, 0, -(\overline{p}_M - \theta))$. *Two cases need to be considered depending on whether or not there is a fixed cost. When* $F_m > 0$, *the* θ*-type firm's output nonnegativity constraint (2.60) must hold with strict inequality,* $\overline{q}_m > 0$, *and consequently* $\overline{p}_M > \theta$. *Since in this case* $\nabla\overline{\Pi}^\star_m(\cdot) \neq 0$, $\overline{\Pi}^\star_m(\cdot)$ *is a regular surface in* $\Re^3$, *and from* $\frac{\partial\overline{\Pi}^\star_m(\cdot)}{\partial K} \neq 0$, *the level surface* $\overline{\Pi}^\star_m(\cdot)$ *can be considered as the graph of a function,* $K^\star_{\overline{\Pi}_m}$, *of* K *in terms of* $\overline{p}_M$ *and* $\underline{p}_M$ *in* $\Re^3$. *In such a case we have that* $\frac{\partial K^\star_{\overline{\Pi}_m}}{\partial \overline{p}_M} = \frac{F}{(\overline{p}_M - \theta)^2} + Q'_M$ *and* $\frac{\partial K^\star_{\overline{\Pi}_m}}{\partial \underline{p}_M} = 0$. *The leading principal minors characterizing the Hessian of the function* $K^\star_{\overline{\Pi}_m}$ *are* $\{-\frac{2F_m}{(\overline{p}_M - \theta)^3}, 0\}$. *Consequently, since* $(\overline{p}_M - \theta) > 0$, *when* $F_m > 0$ *the level surface* $\overline{\Pi}^\star_m(\cdot)$ *is concave, i.e., the set below* $\overline{\Pi}^\star_m(\cdot)$ *is convex.*

When $F_m = 0$, *the level set* $\overline{\Pi}^\star_m(\cdot)$ *is not regular everywhere. Indeed, when both* $\overline{p}_M = \theta$ *and* $K = \overline{Q}_M$ $(\overline{q}_m = 0)$ *the level set* $\overline{\Pi}^\star_m(\cdot)$ *is degenerate as* $\nabla\overline{\Pi}^\star_m(\theta, \underline{p}_M, \overline{Q}_M) = 0$. *However, two regular surfaces can be identified. First, when* $\overline{p}_M \neq \theta$, *the surface* $\overline{\Pi}^\star_m(\overline{p}_M \neq \theta, \underline{p}_M, K = \overline{Q}_M)$ *is regular. In this particular case, the* $K^\star_{\overline{\Pi}_m}$ *function has* $\frac{\partial K^\star_{\overline{\Pi}_m}}{\partial \overline{p}_M} = Q'_M$, $\frac{\partial K^\star_{\overline{\Pi}_m}}{\partial \underline{p}_M} = 0$, *and Hessian's leading minors* $\{0, 0\}$, *which define* $\overline{\Pi}^\star_m(\cdot)$ *as a plane with gradient* $\nabla\overline{\Pi}^\star_m(\cdot) = ((\overline{p}_M - \theta)Q'_M, 0, -(\overline{p}_M - \theta)) < 0$. *Second, when* $\overline{p}_M = \theta$, *and since constraint (2.60) holds,* $\overline{q}_m > 0$, *the level set* $\overline{\Pi}^\star_m(\theta, \underline{p}_M, K < \overline{Q}_M)$ *is regular and is represented by a plane with gradient* $\nabla\overline{\Pi}^\star_m(\cdot) = (\overline{q}_m, 0, 0)$, *perpendicular to the* $\overline{p}_M$*-axis. It is direct to see that these regular surfaces of* $\overline{\Pi}^\star_m(\cdot)$ *define a convex set when* $\overline{p}_M \geq \theta$.[31]

Concerning the θ*-type firm's output nonnegativity constraint (2.60), it can be binding only when*

31. A property of standard convex sets says that every two points of a convex set are visible to each other, i.e., the straight segment joining these points is contained in the set. Since $\overline{\Pi}^\star_m(\cdot)$ belongs to the set associated to the participation constraint of the less efficient firm (2.58), such set will be convex if any point lying to the straight line connecting two points in $\overline{\Pi}^\star_m(\cdot)$, yields positive profits for the θ-type firm. Let us study first the straight line lying the points $(\overline{p}_{M,1} = \theta - \epsilon, \underline{p}_M, K_1 = \overline{Q}_{M,1})$ and $(\overline{p}_{M,2} = \theta, \underline{p}_M, K_2 < \overline{Q}_{M,2} < \overline{Q}_{M,1})$. It is direct to see that $\overline{\Pi}_m(\delta\overline{p}_{M,1} + (1-\delta)\overline{p}_{M,2}, \underline{p}_M, \delta K_1 + (1-\delta)K_2) = -\delta(1-\delta)\epsilon\overline{q}_{m,2} < 0$, which is a contradiction. Let us now check the case where $(\overline{p}_{M,1} = \theta + \epsilon, \underline{p}_M, K_1 = \overline{Q}_{M,1})$ and $(\overline{p}_{M,2} = \theta, \underline{p}_M, K_2 < \overline{Q}_{M,2})$. In this latter case the profit associated to any combination of connecting points is $\overline{\Pi}_m(\cdot) = \delta(1-\delta)\epsilon\overline{q}_{m,2} > 0$, which is consistent with our convexity argument. Therefore, when $F_m = 0$ the level set $\overline{\Pi}^\star_m(\cdot)$ supports a convex set only in cases where $\overline{p}_M \geq \theta$.

$F_m = 0$. *In such a case, it is represented by the level set* $\overline{q}^\star_m(\overline{p}_M, \underline{p}_M, K) = \overline{Q}_M - K = 0$, *with gradient vector* $\nabla\overline{q}^\star_m(\cdot) = (Q'_M, 0, -1) \neq 0$. *Thus, the level surface* $\overline{q}^\star_m(\cdot)$ *is regular and defines a convex set.*[32] *Note that when* $\overline{p}_M \neq \theta$ *and* $F_m = 0$, $\nabla\overline{\Pi}^\star_m(\cdot) = (\overline{p}_M - \theta) \cdot \nabla\overline{q}^\star_m(\cdot)$, *and hence when there is no fixed cost and both (2.58) and (2.60) are effective, the gradients of these constraints are not linearly independent, i.e., the Linear Independence Constraint Qualification (LICQ) condition is violated. In order to avoid this, (2.58) is considered as a liminal constraint, i.e., an active inequality with a Lagrange multiplier equal to zero. See Horsley and Wrobel (2003) for more details.*

Similar to the analysis performed for the participation constraint of the θ*-type firm, when that of the c-type firm, i.e., (2.59), is binding, it is represented by the level set* $\underline{\Pi}^\star_m(\overline{p}_M, \underline{p}_M, K) = (\underline{p}_M - c)\underline{q}_m - F_m = 0$, *with gradient vector* $\nabla\underline{\Pi}^\star_m(\cdot) = (0, (\underline{p}_M - c)Q'_M + \overline{q}_m, -(\underline{p}_M - c))$, *and it defines a convex set. Concerning the c-type firm's output nonnegativity constraint (2.61), it is represented by the level set* $\underline{q}^\star_m(\overline{p}_M, \underline{p}_M, K) = \underline{Q}_M - K = 0$, *with gradient vector* $\nabla\underline{q}^\star_m(\cdot) = (0, Q'_M, -1) \neq 0$, *defining a convex set.*[33] *Therefore, since the intersection of convex sets is convex, the set defined by (2.58)-(2.61) is convex.*

When there is no fixed cost, $F_m = 0$, *and both nonnegativity constraints (2.60) and (2.61) are effective they are represented by the level set* $\overline{\underline{q}}^\star_m(\overline{p}_M, \underline{p}_M, K) = \underline{Q}_M - \overline{Q}_M = 0$ *with gradient vector* $\nabla\overline{\underline{q}}^\star_m(\cdot) = (-Q'_M, Q'_M, 0) \neq 0$, *and then the surface level is a plane perpendicular to the* $\overline{p}_M$*-axis which coincides with the* $45°$ *line between the* $\overline{p}_M$*- and* $\underline{p}_M$*-axes. It is then direct to see that the Jacobian* $J_{\overline{q}^\star_m, \underline{q}^\star_m} = (\nabla\overline{q}^\star_m, \nabla\underline{q}^\star_m)$ *is full rank (the maximum possible number of effective constraints), and hence the Non Degenerate Constraint Qualification (NDCQ) is satisfied.*

When $F_m > 0$ *and both participation constraints (2.58) and (2.59) are binding, they are represented by the level set* $\overline{\underline{\Pi}}^\star_m(\overline{p}_M, \underline{p}_M, K) = (\underline{p}_M - c)\underline{q}_m - (\overline{p}_M - \theta)\overline{q}_m = 0$ *with gradient vector* $\nabla\overline{\underline{\Pi}}^\star_m(\cdot) = (-(\overline{p}_M - \theta)Q'_M - \overline{q}_m, (\underline{p}_M - c)Q'_M + \underline{q}_m, (\overline{p}_M - \underline{p}_M) - (\theta - c)) \neq 0$. *Since the Jacobian* $J_{\overline{\Pi}^\star_m, \underline{\Pi}^\star_m} = (\nabla\overline{\Pi}^\star_m, \nabla\underline{\Pi}^\star_m)$ *is full rank, the (NDCQ) is again satisfied.* ■

Proof of Lemma 2.3 *Consider the ex-post program under scheme B where the regulator seeks to control market power exercised by a* $\widetilde{\theta}$*-type firm by the maximization, with respect to* $p_M(\widetilde{\theta})$, *of the social welfare function (2.54), for a given level of already installed transport capacity* K, *under the constraints (2.55) and (2.56). Differentiating the associated system of first-order conditions with respect to* $\widetilde{\theta}$ *yields that when the firm is active and makes positive profits, i.e., when* $\nu(\widetilde{\theta}) = \phi(\widetilde{\theta}) = 0$, $\frac{dp_M(\widetilde{\theta})}{d\widetilde{\theta}} = 1$, $\frac{d\Pi_m(\widetilde{\theta})}{d\widetilde{\theta}} = [(p_M(\widetilde{\theta}) - \widetilde{\theta})Q'_M + q_m(\widetilde{\theta})]\frac{dp_M(\widetilde{\theta})}{d\widetilde{\theta}} - q_m(\widetilde{\theta}) < 0$, *and clearly* $\frac{d\nu(\widetilde{\theta})}{d\widetilde{\theta}} = \frac{d\phi(\widetilde{\theta})}{d\widetilde{\theta}} = 0$. *In this case, second-order conditions are summarized by* $\lambda^2 + (1+\lambda)Q'_M C''(K) < 0$.

32. $\overline{q}^\star_m(\cdot)$ can be considered as the graph of a function, $K^\star_{\overline{q}_m}$, of K in terms of $\overline{p}_M$ and $\underline{p}_M$ in $\Re^3$ with $\frac{\partial K^\star_{\overline{q}_m}}{\partial \overline{p}_M} = Q'_M$ and $\frac{\partial K^\star_{\overline{q}_m}}{\partial \underline{p}_M} = 0$, and Hessian's leading minors $\{0, 0\}$.

33. The participation constraint (2.59) is liminal when $F_m = 0$.

When the firm is active and just breaks even, $\nu(\widetilde{\theta}) = 0$ *and* $\phi(\widetilde{\theta}) > 0$*, we obtain* $\frac{dp_M(\widetilde{\theta})}{d\widetilde{\theta}} = \frac{q_m(\widetilde{\theta})}{(p_M(\widetilde{\theta})-\widetilde{\theta})Q'_M + q_m(\widetilde{\theta})} \gtrless 0$, $\frac{d\Pi_m(\widetilde{\theta})}{d\widetilde{\theta}} = 0$, $\frac{d\nu(\widetilde{\theta})}{d\widetilde{\theta}} = 0$, *and* $\frac{d\phi(\widetilde{\theta})}{d\widetilde{\theta}} = \frac{[(1+\widetilde{\phi})(p_M(\widetilde{\theta})-\widetilde{\theta})Q'_M - \widetilde{\phi}q_m(\widetilde{\theta})]Q'_M}{[(p_M(\widetilde{\theta})-\widetilde{\theta})Q'_M+q_m(\widetilde{\theta})]^2} > 0$. *Finally, when the firm is shut down,* $\nu(\widetilde{\theta}) > 0$*, the participation constraint is trivially satisfied* $(F_m = 0)$ *and hence* $\frac{dp_M(\widetilde{\theta})}{d\widetilde{\theta}} = \frac{d\Pi_m(\widetilde{\theta})}{d\widetilde{\theta}} = \frac{d\phi(\widetilde{\theta})}{d\widetilde{\theta}} = 0$*, and* $\frac{d\nu(\widetilde{\theta})}{d\widetilde{\theta}} = 1$. ■

Proof of Proposition 2.4 *From the discussion of Lemma 2.3 in the text we know that only five combinations of Lagrange multipliers are possible.*

Concerning policy $(B1_u)$*, replace* $\overline{\phi} = \underline{\phi} = \overline{\nu} = \underline{\nu} = 0$ *in the system of first-order conditions (2.62)-(2.67) to get (2.68)-(2.70). Next, solve (2.62) and (2.63), respectively, for* $\overline{p}_M$ *and* $\underline{p}_M$ *and substitute into (2.64) to obtain* $\lambda^2 K + (1+\lambda)Q'_M C'(K) - \alpha(1+\lambda)Q'_M(\theta - c) = 0$*. For this equality to hold, it is required that* $\lambda^2 K + (1+\lambda)Q'_M C'(K) < 0$*. Moreover, second-order conditions associated with this policy are summarized by* $\lambda^2 + (1+\lambda)Q'_M C''(K) < 0$.[34]

When there is no fixed cost, $F_m = 0$*, to insure that this policy yields* $\overline{q}_m > 0$*, (2.70) should be satisfied with strict inequality when evaluated at* $\overline{q}_m = 0$*, i.e.,* $(1+\lambda)C'(\overline{Q}_M) > \alpha(1+\lambda)(\theta - c) + \lambda[\alpha(\overline{p}_M - \theta) + (1-\alpha)(\underline{p}_M - c)]$*. Replacing* $\overline{p}_M$ *and* $\underline{p}_M$ *in (2.62) and (2.63), evaluated at* $\overline{q}_m = 0$*, yields* $0 < \alpha(\theta - c) < C'(\overline{Q}_M) + \frac{\lambda^2 \overline{Q}_M}{(1+\lambda)Q'_M}$*. When there is a fixed cost to finance,* $F_m > 0$*, we need to guarantee that this solution belongs to the set defined by the participation constraints (2.58) and (2.59). From Lemma 2.3 we restrict ourselves to cases under which policy* $(B1_u)$ *satisfies* $\underline{\Pi}_m > \overline{\Pi}_m$ *and then we only need to check the participation constraint of the* θ*-type firm. First, it is necessary that (2.70) be satisfied with strict inequality when* $(\overline{p}_M - \theta) = \frac{F_m}{\overline{q}_m}$*, i.e.,* $(1+\lambda)C'(K) > \alpha(1+\lambda)(\theta - c) + \lambda[\alpha\frac{F_m}{\overline{q}_m} + (1-\alpha)(\underline{p}_M - c)]$*, which can be rewritten as* $0 < \alpha(\theta - c) < C'(K) + \frac{\lambda^2 K}{Q'_M} - \alpha\lambda(\frac{\lambda K\overline{q}_m + Q'_M F_m}{\overline{q}_m Q'_M})$*. Second, the pricing rule associated with* $(B1_u)$ *should satisfy (2.58), i.e.,* $\lambda K\overline{q}_m + Q'_M F_m > 0$.

To obtain policy $(B2_u)$*, replace* $\overline{\nu} = \underline{\nu} = \underline{\phi} = 0$ *and* $F_m > 0$ *in the system of first-order conditions (2.62)-(2.67) to get (2.71), (2.69), and (2.72). Since* $F_m > 0$*, it is necessary that (2.72) be satisfied with strict inequality when* $(\underline{p}_M - c) = \frac{F_m}{\underline{q}_m}$*, i.e.,* $(1+\lambda)C'(K) > \alpha(1+\lambda)(\theta - c) + \lambda[\alpha\frac{F_m}{\overline{q}_m} + (1-\alpha)\frac{F_m}{\underline{q}_m}]$*, which can be rewritten as* $\alpha(\theta - c) < C'(K) - \frac{\lambda F_m}{1+\lambda}[\frac{\overline{q}_m + \alpha(\underline{q}_m - \overline{q}_m)}{\overline{q}_m \underline{q}_m}]$*. Second-order conditions for this policy are summarized by* $\alpha^2\lambda^2(\alpha^2 K + (\overline{q}_m + \lambda K((1-\alpha)\overline{q}_m - K(\lambda - \alpha(2+\lambda))))) - 2\alpha^2\lambda\overline{\phi}\overline{q}_m(\overline{q}_m - (2+\lambda)K) + \alpha\overline{\phi}^2\overline{q}_m(3\overline{q}_m + 2\lambda K) + 2\overline{\phi}^3\overline{q}_m{}^2 - \alpha^2(1+\lambda)(\overline{q}_m - \lambda K)^2 Q'_M C''(K) > 0$.

To obtain policy $(B3_u)$*, replace* $\overline{\phi} = \underline{\phi} = \underline{\nu} = 0$ *and* $F_m = 0$ *in the system of first-order conditions (2.62)-(2.67) to get (2.73), (2.69), and (2.74). Next, solve (2.62) and (2.63), respectively, for* $\overline{p}_M$ *and* $\underline{p}_M$ *and substitute into (2.64) to obtain* $\lambda^2 K + (1+\lambda)Q'_M C'(K) + (1+\lambda)Q'_M[\overline{\nu} - \alpha(\theta - c)] = 0$*. We now prove that* $[\overline{\nu} - \alpha(\theta - c)] < 0$*. Since* $\overline{\nu} > 0$ *and* $\underline{\nu} = 0$*, from Lemma 2.3 we know that* $\underline{q}_m > \overline{q}_m = 0$ *and hence* $\underline{p}_M < \overline{p}_M$*. From (2.62),* $\overline{\nu} = \alpha(-(\overline{p}_M - \theta) - \frac{\lambda K}{Q'_M}) > 0$*, and from (2.63),*

34. Note that when $\frac{C'(K)}{K} - C''(K) \leq 0$, when $\lambda^2 K + (1+\lambda)Q'_M C'(K) < 0$ holds, second-order conditions are always satisfied.

$-\frac{\lambda K}{Q'_M} = (\underline{p}_M - c)$, *which results in* $\overline{\nu} - \alpha(\theta - c) = -\alpha(\overline{p}_M - \underline{p}_M) < 0$. *Consequently, policy* $(B3_u)$ *arises when* $F_m = 0$ *and* $\lambda^2 K + (1+\lambda)Q'_M C'(K) < 0$. *Second-order conditions associated with this policy are summarized by* $\lambda^2 + (1+\lambda)Q'_M C''(K) < \alpha(1+\lambda)^2$.[35]

To obtain policy $(B4_u)$, *replace* $\overline{\nu} = \underline{\nu} = 0$ *in the system of first-order conditions (2.62)-(2.67) to get (2.71), (2.75), and (2.76). Second-order conditions for this policy are always satisfied.*

Finally, to obtain policy $(B5_u)$, *replace* $\overline{\phi} = \underline{\phi} = 0$ *in the system of first-order conditions (2.62)-(2.67) to get (2.73), (2.77), and (2.78). Next, solve (2.62) and (2.63), respectively, for* $\overline{p}_M$ *and* $\underline{p}_M$ *and plug into (2.64) to obtain* $\lambda^2 K + (1+\lambda)Q'_M C'(K) + (1+\lambda)Q'_M[(\overline{\nu} + \underline{\nu}) - \alpha(\theta - c)] = 0$. *We next prove that* $[(\overline{\nu} + \underline{\nu}) - \alpha(\theta - c)] > 0$. *Since* $\overline{\nu} > 0$ *and* $\underline{\nu} > 0$, *from Lemma 2.3 we know that* $\underline{p}_M = \overline{p}_M$. *From (2.62),* $\overline{\nu} > 0$ *necessitates* $-\frac{\lambda K}{Q'_M} > (\overline{p}_M - \theta)$, *and from (2.63),* $\underline{\nu} > 0$ *calls for* $-\frac{\lambda K}{Q'_M} > (\overline{p}_M - c)$. *Therefore, when* $\overline{p}_M - c + \frac{\lambda K}{Q'_M} < 0$, *both* $\overline{\nu}$ *and* $\underline{\nu}$ *are strictly positive. Now, solve (2.62) and (2.63), respectively, for* $\overline{\nu}$ *and* $\underline{\nu}$ *and obtain* $(\overline{\nu} + \underline{\nu}) - \alpha(\theta - c) = -[\overline{p}_M - c + \frac{\lambda K}{Q'_M}] > 0$. *Thus, for* $(B5_u)$ *to arise as the optimal policy, it is necessary that* $F_m = 0$ *and* $\lambda^2 K + (1+\lambda)Q'_M C'(K) > 0$. *Second-order conditions for this policy are always satisfied.* ■

Proof of Lemma 2.4 *From Lemma 2.2, the constraint set defined by (2.58)-(2.61) is convex. It then remains to analyze the properties of the sets defined by the incentive constraints (2.89) and (2.90).*

The incentive constraint of the less efficient firm (2.89) satisfied with equality is represented by the level set $\overline{\Upsilon}^\star(\overline{p}_M, \underline{p}_M, K) = (\overline{p}_M - \theta)\overline{q}_m - (\underline{p}_M - \theta)\underline{q}_m = 0$, *with gradient vector* $\nabla\overline{\Upsilon}^\star(\cdot) = ((\overline{p}_M - \theta)Q'_M + \overline{q}_m, -(\underline{p}_M - \theta)Q'_M - \underline{q}_m, -(\overline{p}_M - \underline{p}_M))$. *Since adding up the incentive constraints (2.89) and (2.90) yields* $\underline{p}_M \leq \overline{p}_M$, *two cases should be analyzed depending on whether or not this inequality holds in the strict sense. When* $\underline{p}_M < \overline{p}_M$ *and (2.89) is satisfied with equality, it can be easily verified that (2.90) holds with strict inequality. Moreover, linearity of demand implies* $(\overline{q}_m - \underline{q}_m) = (\overline{p}_M - \underline{p}_M)Q'_M$, *which allows to rewrite* $\overline{\Upsilon}^\star(\cdot)$ *as* $\overline{\Upsilon}^\star(\overline{p}_M, \underline{p}_M, K) = (\overline{p}_M - \theta)Q'_M + \underline{q}_m = 0$. *Hence, we obtain that* $\nabla\overline{\Upsilon}^\star(\cdot) < 0$, *and since* $\frac{\partial\overline{\Upsilon}^\star(\cdot)}{\partial K} < 0$, $\overline{\Upsilon}^\star(\cdot)$ *can be considered as the graph of a function* $K^\star_{\overline{\Upsilon}}$, *of* K, *in terms of* $\overline{p}_M$ *and* $\underline{p}_M$ *with* $\frac{\partial K^\star_{\overline{\Upsilon}}}{\partial \overline{p}_M} = \frac{\partial K^\star_{\overline{\Upsilon}}}{\partial \underline{p}_M} = Q'_M$.[36] *Consequently, when* $\underline{p}_M < \overline{p}_M$ *the level surface* $\overline{\Upsilon}^\star(\cdot)$ *is a plane with* $\nabla\overline{\Upsilon}^\star(\cdot) < 0$ *and hence the set below it is convex. When* $\underline{p}_M = \overline{p}_M$, *the level set* $\overline{\Upsilon}^\star(\cdot)$ *cannot be represented through the* $K^\star_{\overline{\Upsilon}}$ *function since* $\frac{\partial\overline{\Upsilon}^\star(\cdot)}{\partial K} = 0$. *However, since in this case the gradient vector is* $\nabla\overline{\Upsilon}^\star(\overline{p}_M, \overline{p}_M, K) = \frac{\partial\overline{\Pi}_M}{\partial\overline{p}_M} \cdot (1, -1, 0)$,

35. Note that this inequality is less stringent than the one summarizing second-order conditions of policy $(B1_u)$. Furthermore, when $\frac{C'(K)}{K} - C''(K) \leq -\frac{\alpha(1+\lambda)}{Q'_M}$, second-order conditions of policy $(B3_u)$ are always satisfied.

36. For a general demand function $\frac{\partial K^\star_{\overline{\Upsilon}}}{\partial \overline{p}_M} = \frac{(\overline{p}_M - \underline{p}_M)(\overline{p}_M - \theta)\overline{Q}'_M - (\overline{q}_m - \underline{q}_m)(\underline{p}_M - \theta)}{(\overline{p}_M - \underline{p}_M)^2} \gtreqless 0$ and $\frac{\partial K^\star_{\overline{\Upsilon}}}{\partial \underline{p}_M} = -\frac{(\overline{p}_M - \underline{p}_M)(\underline{p}_M - \theta)\underline{Q}'_M - (\overline{q}_m - \underline{q}_m)(\overline{p}_M - \theta)}{(\overline{p}_M - \underline{p}_M)^2} \gtreqless 0$. The assumption of linearity of market demand helps not only to simplify these expressions but also to sign them.

the surface level is a plane perpendicular to the $\overline{p}_M$-axis which coincides with the 45°-line between the $\overline{p}_M$- and $\underline{p}_M$-axes.[37]

Let us now check that $\overline{\Upsilon}^\star(\cdot)$ defines a convex set when both incentive constraints (2.89) and (2.90) hold, hence when $\underline{p}_M \leq \overline{p}_M$. To see this, we verify if the points $(\overline{p}_{M,1} = p_M, \underline{p}_{M,1} = p_M, K_1 = K < \overline{Q}_{M,1} = \underline{Q}_{M,1} = Q_M)$ and $(\overline{p}_{M,2} = p_M, \underline{p}_{M,2} = p_M - \epsilon, K_2 = K < \overline{Q}_M = Q_M < \underline{Q}_{M,2})$, each belonging to one of the two regular surfaces defined for the level set $\overline{\Upsilon}^\star(\cdot)$, are "visible" to each other. For the set defined by $\overline{\Upsilon}^\star(\cdot)$ to be convex, it must be the case that any point which lies on the connection between these two points should satisfy the incentive constraint (2.89). With linear demand, $\underline{q}_{m2} = \underline{q}_{m,1} - \epsilon Q'_M$. Hence, $(\delta\overline{p}_{M,1} + (1-\delta)\overline{p}_{M,2} - \theta)(\delta\overline{q}_{m,1} + (1-\delta)\overline{q}_{m,2}) - (\delta\underline{p}_{M,1} + (1-\delta)\underline{p}_{M,2} - \theta)(\delta\underline{q}_{m,1} + (1-\delta)\underline{q}_{m,2}) = \delta(1-\delta)\epsilon^2 Q'_M < 0$, which violates (2.89). Thus, to guarantee convexity of the set defined by the level set $\overline{\Upsilon}^\star(\cdot)$, $\underline{p}_M < \overline{p}_M$ should be imposed.

Similarly, when the incentive constraint of the more efficient firm, (2.90), is binding, it is represented by the level set $\underline{\Upsilon}^\star(\overline{p}_M, \underline{p}_M, K) = (\underline{p}_M - c)\underline{q}_m - (\overline{p}_M - c)\overline{q}_m = 0$ with gradient vector $\nabla\underline{\Upsilon}^\star(\cdot) = (-(\overline{p}_M - c)Q'_M - \overline{q}_m, (\underline{p}_M - c)Q'_M + \underline{q}_m, (\overline{p}_M - \underline{p}_M))$. When $(\underline{p}_M - c)\underline{q}_m - (\overline{p}_M - c)\overline{q}_m = 0$ holds, so does $(\overline{p}_M - c)Q'_M + \underline{q}_m = 0$ and hence $\nabla\underline{\Upsilon}^\star(\cdot) > 0$. Therefore, when $\underline{p}_M < \overline{p}_M$ the level surface $\underline{\Upsilon}^\star(\cdot)$ is a plane and the set above it is convex.[38] *Again, as shown for the level set $\overline{\Upsilon}^\star(\cdot)$, to insure convexity of the set defined by $\underline{\Upsilon}^\star(\cdot)$, $\underline{p}_M < \overline{p}_M$ should be imposed.*

Summing up, when $F_m > 0$ the relevant level sets defining the constraint set of the regulator's optimization program under asymmetric information are $\overline{\Pi}^\star_m(\cdot)$, $\overline{\Upsilon}^\star(\cdot)$, and $\underline{\Upsilon}^\star(\cdot)$. Since the intersection of convex sets is convex, the constraint set defined by (2.58)-(2.61) and (2.89)-(2.90) is convex only when $\underline{p}_M < \overline{p}_M$. When $F_m = 0$ the relevant level sets defining this constraint set are $\overline{q}^\star_m(\cdot)$, $\overline{\Upsilon}^\star(\cdot)$, and $\underline{\Upsilon}^\star(\cdot)$. Again, since the intersection of convex sets is convex, we should still impose the restriction $\underline{p}_M < \overline{p}_M$ in order to obtain convexity.

Before proceeding in the proof, let us illustrate our results in the case where $F_m = 0$, $Q_M(p_M(\widetilde{\theta})) = 10 - p_M(\widetilde{\theta})$, $\theta = 4$, and $c = 2$. When $\underline{p}_M < \overline{p}_M$, Figure 2.A1a shows that the set defined by (2.58)-(2.61) and (2.89)-(2.90) is convex in the $\{\overline{p}_M, \underline{p}_M, K\}$-space. When $\underline{p}_M = \overline{p}_M$, the incentive constraints (2.89)-(2.90) are trivially satisfied, and hence the relevant constraint set is defined by (2.58)-(2.61). In this case, Figure 2.A1b shows that the constraint set is also convex (see the trapezoidal region defined by bold lines).

37. Note that the level set $\overline{\Upsilon}^\star(\cdot)$, given that $\underline{p}_M = \overline{p}_M$, is degenerate when $\frac{\partial\overline{\Pi}_M}{\partial\overline{p}_M} = 0$, i.e., when profits of the less efficient firm are maximized.

38. When $\underline{p}_M = \overline{p}_M$, we have $\underline{\Upsilon}^\star(\overline{p}_M, \overline{p}_M, K) = \overline{\Upsilon}^\star(\overline{p}_M, \overline{p}_M, K)$ and $\nabla\underline{\Upsilon}^\star(\overline{p}_M, \overline{p}_M, K) = -\nabla\overline{\Upsilon}^\star(\overline{p}_M, \overline{p}_M, K)$. Hence, in this case, the two incentive constraints are trivially satisfied.

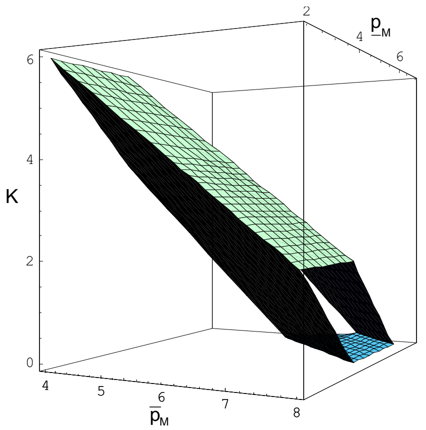


Figure 2.A1a: *Constraint set with* $\underline{p}_M < \overline{p}_M$

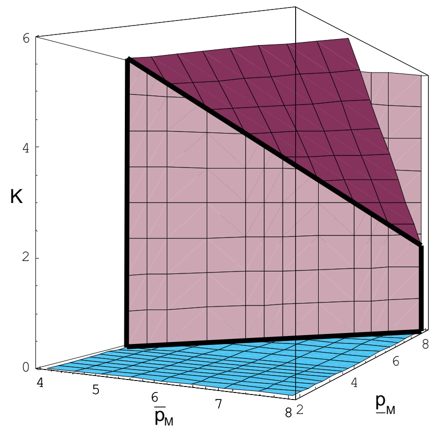


Figure 2.A1b: *Constraint set with* $\underline{p}_M = \overline{p}_M$

However, in the general case where $\underline{p}_M \leq \overline{p}_M$*, the constraint set found by superposing the constraint sets in Figures 2.A1a and 2.A1b is not convex, as shown in Figure 2.A2.*

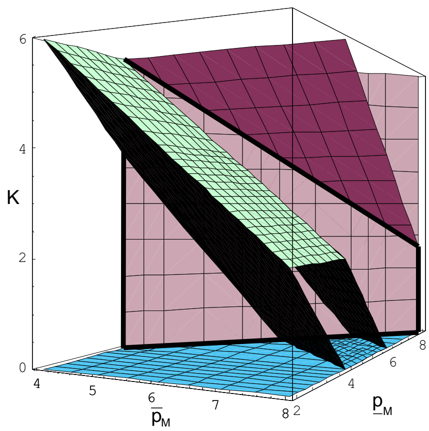


Figure 2.A2: *Constraint set with* $\underline{p}_M \leq \overline{p}_M$

Let us now verify the regularity of the constraint set under asymmetric information. When $F_m = 0$ *and both (2.60) and (2.89) are binding, they are represented by the level set* $\overline{\overline{\Upsilon}}^{\star}(\overline{p}_M, \underline{p}_M, K) = -(\underline{p}_M - \theta)\underline{q}_m = 0$ *with gradient vector* $\nabla\overline{\overline{\Upsilon}}^{\star}(\cdot) = ((\underline{p}_M - \theta)Q'_M, -(\underline{p}_M - \theta) - \underline{q}_m, 0)$ *with* $\underline{p}_M = \theta$*, i.e.,* $\nabla\overline{\overline{\Upsilon}}^{\star}(\cdot) = (0, -\underline{q}_m, 0) \neq 0$ *since* $\underline{q}_m > 0$*. In such a case, the Jacobian* $J_{\overline{\Upsilon}^{\star}, \overline{q}_m^{\star}}$ *is full rank. When* $F_m > 0$*, and both (2.58) and (2.89) are binding, they are represented by the level set* $\overline{\overline{\Upsilon}}^{\star\star}(\overline{p}_M, \underline{p}_M, K) = F - (\underline{p}_M - \theta)\underline{q}_m = 0$ *with gradient vector* $\nabla\overline{\overline{\Upsilon}}^{\star\star}(\cdot) = (0, -(\underline{p}_M - \theta)Q'_M -$

$\underline{q}_m, (\underline{p}_M - \theta))$ *with* $\underline{p}_M = \theta + \frac{F_m}{\underline{q}_m}$. *Then, the Jacobian* $J_{\overline{\Upsilon}^\star, \overline{\Pi}_m^\star}$ *is again full rank.*[39]

Finally, concerning the local concavity of the welfare function (2.57), we know that $\frac{\partial^2 E[W]}{\partial \overline{p}_M^2} = \alpha Q'_M < 0$, $\frac{\partial^2 E[W]}{\partial K \partial \overline{p}_M} = \alpha\lambda > 0$, $\frac{\partial^2 E[W]}{\partial \overline{p}_M \partial \underline{p}_M} = 0$, $\frac{\partial^2 E[W]}{\partial K \partial \underline{p}_M} = (1-\alpha)\lambda > 0$, $\frac{\partial^2 E[W]}{\partial \underline{p}_M^2} = (1-\alpha)Q'_M < 0$, *and* $\frac{\partial^2 E[W]}{\partial K^2} = -(1+\lambda)C''(K) < 0$. *The leading principal minors of the Hessian of the welfare function (2.57) are* $\{\alpha Q'_M, \alpha(1-\alpha){Q'_M}^2, -(1-\alpha)Q'_M[\lambda^2 + (1+\lambda)Q'_M C''(K)]\}$. *Local concavity of the welfare function requires that the last minor be negative, i.e., the condition stated in the lemma.* ■

Proof of Proposition 2.5 *Let us then start assuming that the incentive constraints (2.89) and (2.90) are satisfied with strict inequality. In such a case, we come back to the regulator's optimization program under uncertainty. We should now check which of the five policies* $(B1_u)$*-*$(B5_u)$ *can arise under asymmetric information. When* $F_m = 0$, *since under asymmetric information* $\underline{p}_M < \overline{p}_M$, *only policies* $(B1_u)$ *and* $(B3_u)$ *can arise, renamed as* $(B1_{ai})$ *and* $(B3_{ai})$. *When* $F_m > 0$, *since the less efficient firm cannot be shut down* ($\overline{q}_m > 0$), *from the incentive constraint (2.90), rewritten as* $\underline{\Pi}_m \geq \overline{\Pi}_m + (\theta - c)\overline{q}_m$, *we obtain* $\underline{\Pi}_m > \overline{\Pi}_m$. *Therefore, from Proposition 2.4 only policy* $(B2_u)$ *can arise, renamed here as* $(B2_{ai})$.

When the incentive constraint (2.90) is binding, ($\underline{\mu} > 0$, $\overline{\mu} = 0$), *and there is no fixed cost, only the case where* $\overline{\nu} = 0$ *may arise. Indeed, replace for* $\overline{\nu} > 0$ *into set of constraints (2.58)-(2.61) and (2.89)-(2.90) to obtain* $\underline{p}_M = c$. *Substituting this into (2.92) yields* $(1-\alpha)\lambda K + \underline{\mu}\underline{q}_m = 0$. *Since* $\underline{q}_m > 0$, *this equality requires* $\underline{\mu} < 0$, *which is a contradiction. Then, replacing for* $\overline{\phi} = \overline{\nu} = \overline{\mu} = 0$, *and* $\underline{\mu} > 0$ *into (2.91)-(2.93), yields (2.98)-(2.100) which characterize policy* $(B4_{ai})$.

When there is a fixed cost, in addition to policy $(B4_{ai})$, *there is the possibility to make the less efficient firm just break even,* $\overline{\phi} > 0$. *Replacing* $\overline{\nu} = \overline{\mu} = 0$, $\overline{\phi} > 0$ $\underline{\mu} > 0$ *into (2.91)-(2.93), yields (2.101), (2.99), and (2.102) which describe policy* $(B5_{ai})$.

Let us now study the case where the incentive constraint (2.89) is binding, ($\underline{\mu} = 0$, $\overline{\mu} > 0$) *three cases might arise. First substitute for* $\overline{\nu} = \overline{\phi} = \underline{\mu} = 0$ *into (2.91)-(2.93), to obtain (2.103)-(2.105) which describe policy* $(B6_{ai})$.

When there is fixed cost, $F_m > 0$, *and replacing for* $\overline{\nu} = \underline{\mu} = 0$ *into (2.91)-(2.93), yields (2.106), (2.104), and (2.107) characterizing policy* $(B7_{ai})$. *When there is no fixed cost,* $F_m = 0$, *and replacing for* $\overline{\phi} = \underline{\mu} = 0$ *into the constraint set (2.58)-(2.60) and (2.89)-(2.90) yields* $\underline{p}_M = \theta$. *Moreover, replacing for* $\underline{\phi} = \underline{\mu} = 0$ *into (2.91)-(2.93), we get (2.108) and (2.109) describing policy* $(B8_{ai})$. ■

Derivation of optimal regulatory policies under asymmetric information assuming

39. A similar approach can be applied in the two remaining cases, i.e., when both (2.60) and (2.90) are binding, and when both (2.58) and (2.90) are tight.

(2.22) *Solving the system of first-order conditions (2.91)-(2.97) when we assume* $F_m = 0$ $(\overline{\phi} = \underline{\phi} = \underline{\nu} = 0)$ *with the functional forms (2.22), yields the following solutions:*

Solution 1: *described by* $\overline{\nu} = 0$, $\overline{p}_M = \theta + \frac{\alpha(\theta-c)\lambda(1+\lambda)}{\omega+\lambda(-\lambda+\omega)}$, $\underline{p}_M = c + \frac{\alpha(\theta-c)\lambda(1+\lambda)}{\omega+\lambda(-\lambda+\omega)}$, $K = \frac{\alpha(\theta-c)(1+\lambda)}{\omega+\lambda(-\lambda+\omega)}$, $\overline{\mu} = 0$, *and* $\underline{\mu} = 0$. *Second-order conditions are satisfied provided* $\Psi \equiv \omega(1+\lambda) - \lambda^2 > 0$. *In such a case, it is clear to see that* $\underline{p}_M > c$, $\overline{p}_M > \theta$, $K > 0$. *For* $\overline{q}_m > 0$, *it is required that* $\Psi(\gamma - c) > [\Psi + \alpha(1+\lambda)^2](\theta - c)$. *Moreover, this solution makes both incentive constraints (2.89) and (2.90) inactive. Hence, we need to check for which values of* $(\theta - c)$ *they are jointly satisfied. As to (2.89) it requires that* $\Psi(\gamma - c) > \alpha(1+\lambda)(1+2\lambda)(\theta - c)$. *For (2.90), it is necessary that* $\Psi(\gamma - c) < [\Psi + \alpha(1+\lambda)(1+2\lambda)](\theta - c)$. *It can be seen that this last condition is compatible with those establishing that the incentive constraint (2.89) holds and* $\overline{q}_m > 0$. *Now, we should check which of these conditions is the more stringent one. After some calculations, we obtain that when the condition* $\Psi \geq \alpha\lambda(1+\lambda)$ *holds, the final interval for this solution is* $[\frac{\Psi}{\Psi+\alpha(1+\lambda)(1+2\lambda)}](\gamma - c) \leq (\theta - c) < [\frac{\Psi}{\Psi+\alpha(1+\lambda)^2}](\gamma - c)$. *Otherwise, when* $0 < \Psi < \alpha\lambda(1+\lambda)$, *the final interval for this solution is* $[\frac{\Psi}{\Psi+\alpha(1+\lambda)(1+2\lambda)}](\gamma - c) < (\theta - c) < [\frac{\Psi}{\alpha(1+\lambda)(1+2\lambda)}](\gamma - c)$. *This solution constitutes policy* $(B1_{ai})$.

Solution 2: *described by* $\overline{\nu} = 0$, $\overline{p}_M = \underline{p}_M = c + \alpha(\theta - c) + \frac{\alpha(\theta-c)\lambda(1+\lambda)}{\omega+\lambda(-\lambda+\omega)}$, $K = \frac{\alpha(\theta-c)(1+\lambda)}{\omega+\lambda(-\lambda+\omega)}$, $\underline{\mu} = 0$, *and* $\overline{\mu} = \frac{(-1+\alpha)\alpha(\theta-c)(\lambda^2-(1+\lambda)\omega)}{((\gamma-c)+(\theta-c))(\lambda^2-(1+\lambda)\omega)+\alpha(\theta-c)(1+3\lambda+2(1+\lambda)\omega)}$. *In this case, second-order conditions,* $\overline{p}_M = \underline{p}_M > c$, *and* $K > 0$ *necessitate* $\Psi > 0$. *For* $\overline{p}_M \geq \theta$ *it is necessary that* $\Psi \leq \frac{\alpha\lambda(1+\lambda)}{(1-\alpha)}$. $\overline{q}_m$ *requires* $\Psi(\gamma - c) > \alpha[\Psi + (1+\lambda)^2](\theta - c)$. *This solution makes both incentive constraints (2.89) and (2.90) binding. To get this result, however, only* $\overline{\mu} > 0$ *which calls for* $\Psi(\gamma - c) < [\alpha(1+\lambda)(1+2\lambda) - (1-2\alpha)\Psi](\theta - c)$. *Hence, the defining interval for this solution, provided* $\Psi \leq \frac{\alpha\lambda(1+\lambda)}{(1-\alpha)}$ *holds, is given by* $[\frac{\Psi}{[\alpha(1+\lambda)(1+2\lambda)-(1-2\alpha)\Psi]}](\gamma - c) \leq (\theta - c) < [\frac{\Psi}{\alpha[\Psi+(1+\lambda)^2]}](\gamma - c)$. *However, from Lemma* 2.4 *this solution is neglected.*

Solution 3: *described by* $\overline{\nu} = 0$, $\overline{p}_M = \underline{p}_M = c + \alpha(\theta - c) + \frac{\alpha(\theta-c)\lambda(1+\lambda)}{\omega+\lambda(-\lambda+\omega)}$, $K = \frac{\alpha(\theta-c)(1+\lambda)}{\omega+\lambda(-\lambda+\omega)}$, $\overline{\mu} = 0$, *and* $\underline{\mu} = -\frac{(-1+\alpha)\alpha(\theta-c)(\lambda^2-(1+\lambda)\omega)}{(\gamma-c)(\lambda^2-(1+\lambda)\omega)+\alpha(\theta-c)(1+3\lambda+2(1+\lambda)\omega)}$. *In this case, second-order conditions,* $\overline{p}_M = \underline{p}_M > c$, *and* $K > 0$ *necessitate* $\Psi > 0$. *For* $\overline{p}_M \geq \theta$, $\Psi \leq \frac{\alpha\lambda(1+\lambda)}{(1-\alpha)}$, *and for* $\overline{q}_m$, $\Psi(\gamma - c) > \alpha[\Psi + (1+\lambda)^2](\theta - c)$. *This solution makes both incentive constraints (2.89) and (2.90) binding. To get this result, however, only* $\underline{\mu} > 0$ *which calls for* $\Psi(\gamma - c) > \alpha[(1+\lambda)(1+2\lambda) + 2\Psi](\theta - c)$. *Therefore, the defining interval for this solution, provided* $\Psi \leq \frac{\alpha\lambda(1+\lambda)}{(1-\alpha)}$ *holds, is given by* $0 \leq (\theta - c) < [\frac{\Psi}{\alpha[(1+\lambda)(1+2\lambda)+2\Psi]}](\gamma - c)$. *However, from Lemma* 2.4 *this solution is neglected.*

Solution 4: *described by* $\overline{\nu} = 0$, $K = \frac{\alpha((-1+\alpha)(\gamma-c)(1+2\lambda)+(\theta-c)(\lambda-\alpha(1+2\lambda)))}{\lambda^2-\alpha(1+2\lambda)^2+(\alpha+2\alpha\lambda)^2-(1+\lambda)\omega}$, $\overline{\mu} = 0$,

$$\overline{p}_M = \frac{\lambda((\gamma-c)\lambda+\alpha^2((\gamma-c)+2(\gamma-c)\lambda)-\alpha((\gamma-c)+(\theta-c)+3(\gamma-c)\lambda))}{\lambda^2-\alpha(1+2\lambda)^2+(\alpha+2\alpha\lambda)^2-(1+\lambda)\omega}$$
$$+ \frac{((-1+\alpha)(\gamma-c)-\alpha(\theta-c))(1+\lambda)\omega+c(\lambda^2-\alpha(1+2\lambda)^2+(\alpha+2\alpha\lambda)^2-(1+\lambda)\omega)}{\lambda^2-\alpha(1+2\lambda)^2+(\alpha+2\alpha\lambda)^2-(1+\lambda)\omega},$$
$$\underline{p}_M = \frac{c(-1+\alpha)(\alpha(1+\lambda)(1+2\lambda)+\omega+\lambda(-\lambda+\omega))}{\lambda^2-\alpha(1+2\lambda)^2+(\alpha+2\alpha\lambda)^2-(1+\lambda)\omega}$$
$$+ \frac{\alpha(\alpha(1+2\lambda)((\theta-c)+(c+(\gamma-c))\lambda)-(1+\lambda)(-(\theta-c)\omega+(c+(\gamma-c))(\lambda+\omega)))}{\lambda^2-\alpha(1+2\lambda)^2+(\alpha+2\alpha\lambda)^2-(1+\lambda)\omega}, \text{ and}$$
$$\underline{\mu} = \frac{(-1+\alpha)\alpha(\alpha(\theta-c)(1+\lambda)(1+2\lambda)+((\gamma-c)-(\theta-c))(\lambda^2-(1+\lambda)\omega))}{\alpha\lambda((\theta-c)+2(\gamma-c)\lambda)+\alpha^2((\theta-c)+2(\theta-c)\lambda)+2\alpha(-(\gamma-c)+(\theta-c))(1+\lambda)\omega+(\gamma-c)(\omega+\lambda(-\lambda+\omega))}.$$

Second-order conditions are satisfied when $\Psi + \alpha(1-\alpha)(1+2\lambda)^2 > 0$*, which is always true since from Lemma 2.4, we restrict ourselves to cases where* $\Psi > 0$*. To obtain that* $\overline{q}_m > 0$ *the condition* $[(1-\alpha)\lambda(1+2\lambda)+\Psi](\gamma-c) > [\Psi+\alpha(1+2\lambda)+\lambda^2](\theta-c)$ *should hold. For* $\underline{q}_m > 0$, $-(1-\alpha)[\alpha\lambda(1+2\lambda)+\Psi](\gamma-c) < \alpha[\Psi+\lambda(1+\lambda)](\theta-c)$*. As to the incentive constraint (2.89), it is satisfied provided that* $(1-2\alpha)\Psi(\gamma-c)+\alpha[(\alpha+\lambda)(1+2\lambda)+2\Psi](\theta-c) > 0$*. Note that the denominator of* $\underline{\mu}$ *is positive whenever the incentive constraint is (2.89) satisfied. Therefore,* $\underline{\mu} > 0$ *requires* $\Psi(\gamma-c) > [\alpha(1+\lambda)(1+2\lambda)+\Psi](\theta-c)$*. Solving the former inequality in* Ψ *we obtain* $\Psi^* > \frac{\alpha(1+\lambda)(1+2\lambda)(\theta-c)}{(\gamma-\theta)} > 0$*, and then this solution requires* $\Psi > 0$*.*[40] *Now we have to check which of the constraints determining that* $\overline{q}_m > 0$ *and* $\underline{\mu} > 0$ *is more stringent. After some calculations, we get that the most stringent constraint is that establishing* $\underline{\mu} > 0$*. This solution illustrates policy* $(B4_{ai})$*.*

Solution 5*: described by* $\overline{\nu} = 0$*,* $K = \frac{\alpha(-(\theta-c)(1+\lambda)+(-1+\alpha)(\gamma-c)(1+2\lambda))}{\lambda^2-\alpha(1+2\lambda)^2+(\alpha+2\alpha\lambda)^2-(1+\lambda)\omega}$*,* $\underline{\mu} = 0$*,*

$$\overline{p}_M = \frac{\lambda(\alpha((-1+\alpha)(\gamma-c)+(-2+\alpha)(\theta-c))+(-1+\alpha)(-1+2\alpha)((\gamma-c)+(\theta-c))\lambda)}{\lambda^2-\alpha(1+2\lambda)^2+(\alpha+2\alpha\lambda)^2-(1+\lambda)\omega} + \frac{((-1+\alpha)(\gamma-c)-(\theta-c))(1+\lambda)\omega+c(\lambda^2-\alpha(1+2\lambda)^2+(\alpha+2\alpha\lambda)^2-(1+\lambda)\omega)}{\lambda^2-\alpha(1+2\lambda)^2+(\alpha+2\alpha\lambda)^2-(1+\lambda)\omega},$$

$$\underline{p}_M = \frac{c(-1+\alpha)(\alpha(1+\lambda)(1+2\lambda)+\omega+\lambda(-\lambda+\omega))}{\lambda^2-\alpha(1+2\lambda)^2+(\alpha+2\alpha\lambda)^2-(1+\lambda)\omega} + \frac{\alpha(\alpha(1+2\lambda)((\theta-c)+(c+(\gamma-c)+(\theta-c))\lambda)-(1+\lambda)((c+(\gamma-c)+(\theta-c))\lambda+(c+(\gamma-c))\omega))}{\lambda^2-\alpha(1+2\lambda)^2+(\alpha+2\alpha\lambda)^2-(1+\lambda)\omega},$$ *and*

$$\overline{\mu} = -\frac{(-1+\alpha)\alpha(\alpha(\theta-c)(1+\lambda)(1+2\lambda)+(\gamma-c)(\lambda^2-(1+\lambda)\omega))}{\alpha^2((\theta-c)+2(\theta-c)\lambda)+\alpha\lambda((\theta-c)+2((\gamma-c)+(\theta-c))\lambda)-2\alpha(\gamma-c)(1+\lambda)\omega+((\gamma-c)+(\theta-c))(\omega+\lambda(-\lambda+\omega))}.$$

Second order conditions are satisfied when $\Psi + \alpha(1-\alpha)(1+2\lambda)^2 > 0$*, which is always true. For* $\overline{q}_m > 0$, $\alpha[(1-\alpha)\lambda(1+2\lambda)+\Psi](\gamma-c) > [\Psi+\alpha(1-\alpha)\lambda(1+2\lambda)+\alpha(1+\lambda)^2](\theta-c)$*. Concerning the incentive constraint (2.90), it is satisfied when* $(1-2\alpha)\Psi(\gamma-c)+[\Psi+\alpha(\alpha+\lambda)(1+2\lambda)](\theta-c) > 0$*. When both* $\overline{q}_m > 0$ *and (2.90) hold,* $\underline{p}_m > c$*. Furthermore, for* $\overline{\mu} > 0$*, both* $(1-2\alpha)\Psi(\gamma-c)+[\Psi+\alpha(\alpha+\lambda)(1+2\lambda)](\theta-c) > 0$ *and* $\Psi(\gamma-c) < \alpha(1+\lambda)(1+2\lambda)(\theta-c)$ *should hold.*[41]*. After some calculations we obtain that when* $\Psi < \alpha\lambda(1+\lambda)$*, the incentive constraint (2.90) is always satisfied and hence the defining interval of this solution is given by those establishing that* $\overline{q}_m > 0$ *and* $\overline{\mu} > 0$*. This solution represents policy* $(B6_{ai})$*.*

Solution 6*: described by* $\overline{\nu} = -(\gamma-c)+\alpha(\theta-c)+\frac{(\gamma-c)(1+\lambda)^2}{1+\omega+\lambda(2+\omega)}$*,* $\overline{p}_M = \underline{p}_M = c + \frac{(\gamma-c)(\lambda+\omega+\lambda\omega)}{1+\omega+\lambda(2+\omega)}$*,* $\overline{\mu} = \frac{(-1+\alpha)(\gamma-c)(\lambda^2-(1+\lambda)\omega)}{(\gamma-c)(\lambda+\omega+\lambda\omega)-(\theta-c)(1+\omega+\lambda(2+\omega))}$*,* $K = \frac{(\gamma-c)(1+\lambda)}{1+\omega+\lambda(2+\omega)}$*, and* $\underline{\mu} = 0$*. Second-order conditions are always satisfied. This solution is characterized by* $\overline{q}_m = \underline{q}_m = 0$*, and makes both incentive constraints (2.89) and (2.90) binding by setting* $\overline{\mu} > 0$ *and* $\underline{\mu} = 0$*. Shutting down is obtained by setting* $\overline{\nu} > 0$*, which calls for* $0 < \Psi < \frac{\alpha\lambda(1+\lambda)}{(1-\alpha)}$ *and* $\frac{\Psi}{\alpha}(\gamma-c) < [\Psi+(1+\lambda)^2](\theta-c) < [\Psi+\lambda(1+\lambda)](\gamma-c)$*. However, from Lemma* 2.4 *this solution is neglected.*

Solution 7*: described by* $\overline{\nu} = -(\gamma-c)+\alpha(\theta-c)+\frac{(\gamma-c)(1+\lambda)^2}{1+\omega+\lambda(2+\omega)}$*,* $\overline{p}_M = \underline{p}_M = c + \frac{(\gamma-c)(\lambda+\omega+\lambda\omega)}{1+\omega+\lambda(2+\omega)}$*,* $\underline{\mu} = -\frac{(-1+\alpha)(\lambda^2-(1+\lambda)\omega)}{\lambda+\omega+\lambda\omega}$*,* $K = \frac{(\gamma-c)(1+\lambda)}{1+\omega+\lambda(2+\omega)}$*, and* $\overline{\mu} = 0$*. Second-order conditions are always satisfied. This solution is characterized by* $\overline{q}_m = \underline{q}_m = 0$*, and makes both incentive constraints*

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40. Given that $\Psi > 0$, $\underline{q}_m > 0$ and (2.89) are always satisfied.

41. Note that the former inequality provides an upper bound for Ψ which allows for the possibility of $\Psi \lesseqgtr 0$. However, from Lemma 2.4, we restrict to cases with $\Psi > 0$

(2.89) and (2.90) binding by setting $\overline{\mu} = 0$ *and* $\underline{\mu} > 0$*, which requires that* $\Psi < 0$*. Since, from Lemma 2.4 we must restrict to cases where* $\Psi > 0$ *and* $\underline{p}_M < \overline{p_M}$*, this solution is ignored.*

Solution 8: *described by* $\overline{p}_M = c + \frac{-(\theta-c)\lambda+\alpha((\gamma-c)+(\theta-c))\lambda+(\gamma-c)(1+\lambda)\omega}{\alpha+2\alpha\lambda+\omega+\lambda\omega}$, $\underline{p}_M = \theta$, $\underline{\mu} = 0$, $\overline{\nu} = \frac{\alpha^2((\gamma-c)-(\theta-c))\lambda(1+2\lambda)+(\theta-c)(\omega+\lambda(-\lambda+\omega))+\alpha((\theta-c)(1+3\lambda(1+\lambda))-(\gamma-c)(1+\lambda)(\lambda+\omega))}{\alpha+2\alpha\lambda+\omega+\lambda\omega}$, $\overline{\mu} = -\frac{(-1+\alpha)(\alpha(1+\lambda)((\theta-c)-(\gamma-c)\lambda+(\theta-c)\lambda)+(\theta-c)(\omega+\lambda(-\lambda+\omega)))}{(\theta-c)\lambda+\alpha((\theta-c)-(\gamma-c)\lambda+(\theta-c)\lambda)+(-(\gamma-c)+(\theta-c))(1+\lambda)\omega}$, $K = \frac{(\theta-c)\lambda+\alpha((\gamma-c)+(\gamma-c)\lambda-(\theta-c)\lambda)}{\alpha+2\alpha\lambda+\omega+\lambda\omega}$. *Second order conditions are always satisfied. This solution is characterized by* $\underline{p}_M > c$ *and* $\overline{q}_m = 0$*. For the incentive constraint (2.90) to hold,* $[\Psi+\lambda(\alpha+\lambda)](\gamma-c) > [\Psi+(1+\lambda)(\alpha+\lambda)](\theta-c)$*. Provided that this latter condition holds, for* $\overline{\mu} > 0$, $\alpha\lambda(1+\lambda)(\gamma-c) > [\Psi+\alpha(1+\lambda)^2](\theta-c)$*. Furthermore,* $\overline{\nu} > 0$ *calls for* $\alpha[(1-\alpha)\lambda(1+2\lambda)+\Psi](\gamma-c) < [\Psi+\alpha(1-\alpha)\lambda(1+2\lambda)+\alpha(1+\lambda)^2](\theta-c)$*. After some calculations, we obtain that when* $\Psi < \alpha\lambda(1+\lambda)$*, the conditions which define the optimality of this solution are those guaranteeing that* $\overline{\nu} > 0$ *and* $\overline{\mu} > 0$*. This solution illustrates policy* $(B8_{ai})$*.*

Solution 9: *described by* $\overline{\nu} = \frac{\alpha(\alpha(\theta-c)(1+\lambda)^2+((\gamma-c)-(\theta-c))(\lambda^2-(1+\lambda)\omega))}{\alpha(1+\lambda)^2+\omega+\lambda(-\lambda+\omega)}$, $\overline{p}_M = c + (\gamma-c) - \frac{\alpha(\gamma-c)(1+\lambda)}{\alpha(1+\lambda)^2+\omega+\lambda(-\lambda+\omega)}$, $\underline{p}_M = c + \frac{\alpha(\gamma-c)\lambda(1+\lambda)}{\alpha(1+\lambda)^2+\omega+\lambda(-\lambda+\omega)}$, $\overline{\mu} = 0$, $K = \frac{\alpha(\gamma-c)(1+\lambda)}{\alpha(1+\lambda)^2+\omega+\lambda(-\lambda+\omega)}$, *and* $\underline{\mu} = 0$*. Second-order conditions are satisfied when* $\Psi + \alpha(1+\lambda)^2 > 0$*, which is always true in our case. This solution is characterized by* $\overline{q}_m = 0$*. For the incentive constraint (2.89) to hold,* $\alpha\lambda(1+\lambda)(\gamma-c) < [\alpha(1+\lambda)^2+\Psi](\theta-c)$*. Provided that this latter condition holds, for* $\overline{\nu} > 0$*, it is required that* $\Psi(\gamma-c) < [\alpha(1+\lambda)^2+\Psi](\theta-c)$*. Concluding, two cases might arise: If* $\Psi \geq \alpha\lambda(1+\lambda)$*, this solution is chosen when* $[\frac{\Psi}{\Psi+\alpha(1+\lambda)^2}](\gamma-c) < (\theta-c) < (\gamma-c)$*. If* $0 < \Psi < \alpha\lambda(1+\lambda)$*, this solution is chosen when* $[\frac{\alpha\lambda(1+\lambda)}{\Psi+\alpha(1+\lambda)^2}](\gamma-c) < (\theta-c) < (\gamma-c)$*. This solution illustrates policy* $(B3_{ai})$*.* ■

Proof of Proposition 2.6 *The first-order conditions of the regulator's optimization program under uncertainty, (2.62)-(2.64), can be expressed as*[42]

$$\frac{\partial E[W^B]}{\partial \overline{p}_M} + \overline{\phi}_u^B \frac{\partial \overline{\Pi}_m^B}{\partial \overline{p}_M} + \overline{\nu}_u^B Q'_M = 0 \tag{2.A1}$$

$$\frac{\partial E[W^B]}{\partial \underline{p}_M} + \underline{\phi}_u^B \frac{\partial \underline{\Pi}_m^B}{\partial \underline{p}_M} + \underline{\nu}_u^B Q'_M = 0 \tag{2.A2}$$

$$\frac{\partial E[W^B]}{\partial K} - \overline{\phi}_u^B(\overline{p}_M^B - \theta) - \underline{\phi}_u^B(\underline{p}_M - c) - \overline{\nu}_u^B = 0 \tag{2.A3}$$

Those of the regulator's optimization program under asymmetric information, (2.91)-(2.93), can be written as

$$\frac{\partial E[W^B]}{\partial \overline{p}_M} + (\overline{\phi}_{ai}^B + \overline{\mu}^B - \underline{\mu}^B)\frac{\partial \overline{\Pi}_m^B}{\partial \overline{p}_M} - \underline{\mu}^B(\theta-c)Q'_M + \overline{\nu}_{ai}^B Q'_M = 0 \tag{2.A4}$$

42. Note that following Lemma 2.4 we should exclude the case where both $\overline{\nu}_u^B > 0$ and $\underline{\nu}_u^B > 0$, and hence $\underline{\nu}_u^B = 0$.

$$\frac{\partial E[W^B]}{\partial \underline{p}_M} - (\overline{\mu}^B - \underline{\mu}^B)\frac{\partial \underline{\Pi}_m^B}{\partial \underline{p}_M} + \overline{\mu}^B(\theta - c)Q'_M = 0 \tag{2.A5}$$

$$\frac{\partial E[W^B]}{\partial K} - \overline{\phi}_{ai}^B(\overline{p}_M^B - \theta) - (\overline{\mu}^B - \underline{\mu}^B)(\overline{p}_M^B - \underline{p}_M^B) - \overline{\nu}_{ai}^B = 0 \tag{2.A6}$$

We know from Propositions 2.4 and 2.5 that when there is no fixed cost, $\overline{\phi}_u^B = \underline{\phi}_u^B = 0$ *and* $\underline{\phi}_{ai}^B = 0$. *When there is a positive fixed cost, these propositions yield that* $\overline{\nu}_u^B = 0$ *and* $\underline{\nu}_{ai}^B = 0$. *Moreover, from the definition of the firm's profit function (2.52) and the expected welfare function (2.57),* $\frac{\partial^2 \overline{\Pi}_m}{\partial \overline{p}_M^2}, \frac{\partial^2 \underline{\Pi}_m}{\partial \underline{p}_M^2} < 0$ *and* $\frac{\partial^2 E[W^B]}{\partial \overline{p}_M^2}, \frac{\partial^2 E[W^B]}{\partial \underline{p}_M^2}, \frac{\partial^2 E[W^B]}{\partial K^2} < 0$. *Let us now separately study two cases according to whether or not there is a fixed cost.*

The no-fixed-cost case. *When* $F_m = 0$, *we see from (2.128) that the effect of accounting for incentives is closely related to the behavior of* $\overline{\mu}^B$, $\underline{\mu}^B$, $\overline{\nu}_{ai}^B$, *and* $\overline{\nu}_u^B$. *As a consequence of Lemma 2.4 only three cases should be discussed. First, we study the case where* $\overline{\mu}^B = \underline{\mu}^B = 0$. *Second, we consider the effect of accounting for incentives when the regulator is constrained to minimize the information rent of the more efficient type, i.e., it makes the incentive constraint of the c-type firm binding,* $\underline{\mu}^B > 0$. *Finally, we analyze the role of incentives when the regulator targets on the information rent of the less efficient firm by setting* $\overline{\mu}^B > 0$.

It is direct to see that when the incentive constraints (2.89) and (2.90) are satisfied with strict inequality, i.e., $\overline{\mu}^B = \underline{\mu}^B = 0$, *the outcome of the regulatory scheme under asymmetric information coincides with that under uncertainty and hence* $K_{ai}^B = K_u^B$.

When $\overline{\mu}^B = 0$ *and* $\underline{\mu}^B > 0$, *the only possibility is to have* $\overline{\nu}_{ai}^B = 0$.[43] *Since* $\underline{\mu}^B > 0$, *constraint (2.90), rewritten as (2.127), implies that* $(\frac{\partial \overline{\Pi}_m}{\partial \overline{p}_{M,ai}} + (\theta - c)Q'_M) < 0$. *Then, from* (2.A4) *we obtain* $\frac{\partial E[W]}{\partial \overline{p}_{M,ai}} < 0$, *while from* (2.A1) $\frac{\partial E[W]}{\partial \overline{p}_{M,u}} \geq 0$, *which implies that* $\overline{p}_{M,ai}^B > \overline{p}_{M,u}^B$. *Similarly, (2.127) satisfied with equality yields* $\frac{\partial \underline{\Pi}_m}{\partial \underline{p}_{M,ai}} > 0$. *Then, from* (2.A5) *we obtain* $\frac{\partial E[W]}{\partial \underline{p}_{M,ai}} < 0$, *while from* (2.A2), $\frac{\partial E[W]}{\partial \underline{p}_{M,u}} = 0$ *which implies that* $\underline{p}_{M,ai}^B > \underline{p}_{M,u}^B$. *Plugging all these results into (2.128) yields that when* $F_m = 0$ *and* $\underline{\mu}^B > 0$, $K_{ai}^B > K_u^B$

When $\overline{\mu}^B > 0$ *and* $\underline{\mu}^B = 0$, *constraint (2.89), rewritten as (2.126), implies* $\frac{\partial \overline{\Pi}_m}{\partial \overline{p}_{M,ai}} < 0$ *and* $(\frac{\partial \underline{\Pi}_m}{\partial \underline{p}_{M,ai}} - (\theta - c)Q'_M) > 0$. *Now, two cases should be analyzed depending of whether or not the less efficient firm is shut down under asymmetric information.*

When $\overline{\nu}_{ai}^B = 0$ *we obtain* $[\frac{\partial E[W]}{\partial \overline{p}_{M,ai}} - (\frac{\partial E[W]}{\partial \overline{p}_{M,u}} + \overline{\nu}_u^B Q'_M)] = -\overline{\mu}^B \frac{\partial \overline{\Pi}_m}{\partial \overline{p}_{M,ai}} > 0$ *and then it is direct to see that* $\overline{p}_{M,ai}^B < \overline{p}_{M,u}^B$. *From* (2.A5) *we obtain* $\frac{\partial E[W]}{\partial \underline{p}_{M,ai}} > 0$, *while from* (2.A2), $\frac{\partial E[W]}{\partial \underline{p}_{M,u}} = 0$ *which implies that* $\underline{p}_{M,ai}^B < \underline{p}_{M,u}^B$. *Now, from conditions* (2.A3) *and* (2.A6) *we obtain* $sign[K_{ai}^B - K_u^B] = -sign[\frac{\partial E[W^B]}{\partial K_{ai}} - (\frac{\partial E[W^B]}{\partial K_u} - \overline{\nu}_u^B)] = -sign[\overline{\mu}(\overline{p}_{M,ai}^B - \underline{p}_{M,ai}^B)] < 0$, *i.e.,* $K_{ai}^B < K_u^B$.[44]

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43. See the proof of Proposition 2.5 in the Appendix.

44. If the regulator is allowed to set $\overline{\mu}^B > 0$ without shutting down the firm, $\overline{\nu}_{ai}^B = 0$, when it

When $\overline{\nu}_{ai}^B > 0$ we again obtain that $\overline{p}_{M,ai}^B < \overline{p}_{M,u}^B$ and $\underline{p}_{M,ai}^B < \underline{p}_{M,u}^B$. Two subcases should be analyzed depending of the value of $\overline{\nu}_u^B$. When $\overline{\nu}_u^B = 0$, it is direct to see from (2.128) that when $\overline{\mu}^B > 0$, $\overline{\nu}_{ai}^B > 0$, and $\overline{\nu}_u^B = 0$, $K_{ai}^B < K_u^B$. When $\overline{\nu}_u^B > 0$, $sign[K_{ai}^B - K_u^B] = -sign[(\frac{\partial E[W^B]}{\partial K_{ai}} - \overline{\nu}_{ai}^B)) - (\frac{\partial E[W^B]}{\partial K_u} - \overline{\nu}_u^B)] = -sign[\overline{\mu}(\overline{p}_{M,ai}^B - \underline{p}_{M,ai}^B)] < 0$, i.e., $K_{ai}^B < K_u^B$[45]

The with-fixed-cost case. *When $F_m > 0$, we see from (2.A1)-(2.A6), and (2.129) that the effect of accounting for incentives is closely related to the behavior of $\overline{\mu}^B$, $\underline{\mu}^B$, $\overline{\phi}_{ai}^B$, $\overline{\phi}_u^B$, and $\underline{\phi}_u^B$. Again, three cases should be studied. First, we study the case where $\overline{\mu}^B = \underline{\mu}^B = 0$. Second, we consider the case where $\overline{\mu}^B = 0$ and $\underline{\mu}^B > 0$. Next, we analyze the role of incentives when $\overline{\mu}^B > 0$ and $\underline{\mu}^B = 0$.*

As in the no-fixed-cost case, we see that when $\overline{\mu}^B = \underline{\mu}^B = 0$, $K_{ai}^B = K_u^B$.

When $\overline{\mu}^B = 0$ and $\underline{\mu}^B > 0$, constraint (2.90), rewritten as (2.127), implies that $(\frac{\partial \overline{\Pi}_m}{\partial \overline{p}_{M,ai}} + (\theta - c)Q'_M) < 0$ and $\frac{\partial \underline{\Pi}_m}{\partial \underline{p}_{M,ai}} > 0$. Two cases should be studied depending of whether or not $\overline{\phi}_{ai}^B = 0$.

When $\overline{\phi}_{ai}^B = 0$, from (2.A1) and (2.A4) we obtain that $\frac{\partial E[W]}{\partial \overline{p}_{M,ai}} < 0$, and $[\frac{\partial E[W]}{\partial \overline{p}_{M,ai}} - (\frac{\partial E[W]}{\partial \overline{p}_{M,u}} + \overline{\phi}_u^B \frac{\partial \overline{\Pi}_m}{\partial \overline{p}_{M,u}})] = \underline{\mu}^B(\frac{\partial \overline{\Pi}_m}{\partial \overline{p}_{M,ai}} + (\theta - c)Q'_M) < 0$, and hence $\overline{p}_{M,ai}^B > \overline{p}_{M,u}^B$. Similarly, from (2.A2) and (2.A5) we obtain that $\frac{\partial E[W]}{\partial \underline{p}_{M,ai}} < 0$, and $[\frac{\partial E[W]}{\partial \underline{p}_{M,ai}} - (\frac{\partial E[W]}{\partial \underline{p}_{M,u}} + \underline{\phi}_u^B \frac{\partial \underline{\Pi}_m}{\partial \underline{p}_{M,u}})] = -\underline{\mu}^B \frac{\partial \underline{\Pi}_m}{\partial \underline{p}_{M,ai}} < 0$, and hence $\underline{p}_{M,ai}^B > \underline{p}_{M,u}^B$. Plugging all these results into (2.129) yields that when $F_m > 0$, $\underline{\mu}^B > 0$, and $\overline{\phi}_{ai}^B = 0$, disregarding of whether or not $\overline{\phi}_u^B$ and/or $\underline{\phi}_u^B$ are equal to zero, $K_{ai}^B > K_u^B$.

When $\overline{\phi}_{ai}^B > 0$, we see that when the regulator is allowed to set $\underline{\mu}^B > 0$ and still makes the less efficient firm just break even, $\overline{\phi}_{ai}^B > 0$, while would have only been necessary to let it earn zero profits under uncertainty, i.e., $\overline{\phi}_u^B, \underline{\phi}_u^B > 0$, clearly $\underline{\mu}^B(\overline{p}_{M,ai}^B - \underline{p}_{M,ai}^B) > \overline{\phi}_{ai}^B(\overline{p}_{M,ai}^B - \theta) - \overline{\phi}_u^B(\overline{p}_{M,u}^B - \theta) - \underline{\phi}_u^B(\underline{p}_{M,u}^B - c)$. Plugging all these results into (2.129) yields that when $F_m > 0$, $\underline{\mu}^B > 0$, and $\overline{\phi}_{ai}^B > 0$, $K_{ai}^B > K_u^B$.

When $\overline{\mu}^B > 0$ and $\underline{\mu}^B = 0$, constraint (2.89), rewritten as (2.126), implies $\frac{\partial \overline{\Pi}_m}{\partial \overline{p}_{M,ai}} < 0$ and $(\frac{\partial \underline{\Pi}_m}{\partial \underline{p}_{M,ai}} - (\theta - c)Q'_M) > 0$. Now, two cases should be analyzed depending of whether or not the less efficient firm is constrained to break even under asymmetric information.

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would have been necessary to do so in the case where incentives are not taken into account, i.e., $\overline{q}_{m,u} = 0$, it should be the case that $\overline{\mu}^B(\overline{p}_{M,ai}^B - \underline{p}_{M,ai}^B) > \overline{\nu}_u^B$. Plugging this into (2.128) yields that when $F_m = 0$, $\overline{\mu}^B > 0$, and $\overline{\nu}_{ai}^B = 0$, $K_{ai}^B < K_u^B$

45. Indeed, consistency between (2.A3) and (2.A6) necessitates that $-(\overline{\nu}_{ai}^B - \overline{\nu}_u^B) < \overline{\mu}^B(\overline{p}_{M,ai}^B - \underline{p}_{M,ai}^B) < \overline{\nu}_u^B$. Plugging this result into (2.128) yields that when $F_m = 0$, $\overline{\mu}^B > 0$, $\overline{\nu}_{ai}^B > 0$, $K_{ai}^B < K_u^B$.

When $\overline{\phi}_{ai}^{B} = 0$*, from* (2.*A*1) *and* (2.*A*4) *we obtain that* $\frac{\partial E[W]}{\partial \overline{p}_{M,ai}} > 0$*, and* $[\frac{\partial E[W]}{\partial \overline{p}_{M,ai}} - (\frac{\partial E[W]}{\partial \overline{p}_{M,u}} + \overline{\phi}_{u}^{B} \frac{\partial \overline{\Pi}_m}{\partial \overline{p}_{M,u}})] = -\overline{\mu}^B \frac{\partial \overline{\Pi}_m}{\partial \overline{p}_{M,ai}} > 0$*, and hence* $\overline{p}_{M,ai}^{B} < \overline{p}_{M,u}^{B}$*. Similarly, from* (2.*A*2) *and* (2.*A*5) *we obtain that* $\frac{\partial E[W]}{\partial \underline{p}_{M,ai}} > 0$*, and* $[\frac{\partial E[W]}{\partial \underline{p}_{M,ai}} - (\frac{\partial E[W]}{\partial \underline{p}_{M,u}} + \underline{\phi}_{u}^{B} \frac{\partial \underline{\Pi}_m}{\partial \underline{p}_{M,u}})] = \overline{\mu}^B (\frac{\partial \underline{\Pi}_m}{\partial \underline{p}_{M,ai}} - (\theta - c) Q'_M) > 0$*, and hence* $\underline{p}_{M,ai}^{B} < \underline{p}_{M,u}^{B}$*. Now, from conditions* (2.*A*3) *and* (2.*A*6) *we see that when the regulator is allowed to set* $\overline{\mu}^B > 0$ *without making binding the participation constraint of the less efficient firm,* $\overline{\phi}_{ai}^{B} = 0$*, while it would have been necessary to do so in the case where incentives are not taken into account, i.e.,* $\overline{\phi}_{u}^{B} > 0$*, it clear that* $\overline{\mu}^B (\overline{p}_{M,ai}^{B} - \underline{p}_{M,ai}^{B}) > \overline{\phi}_{u}^{B} (\overline{p}_{M,u}^{B} - \theta) + \underline{\phi}_{u}^{B} (\underline{p}_{M,u}^{B} - c)$*. Hence, substituting into (2.128) implies that when* $F_m > 0$*,* $\overline{\mu}^B > 0$*, and* $\overline{\phi}_{ai}^{B} = 0$*,* $K_{ai}^B < K_u^B$*.*

When $\overline{\phi}_{ai}^{B} > 0$ *we again obtain that* $\overline{p}_{M,ai}^{B} < \overline{p}_{M,u}^{B}$ *and* $\underline{p}_{M,ai}^{B} < \underline{p}_{M,u}^{B}$*. Two subcases should be analyzed depending of the value of* $\overline{\phi}_{u}^{B}$ *and/or* $\underline{\phi}_{u}^{B}$*. When* $\overline{\phi}_{u}^{B} = \underline{\phi}_{u}^{B} = 0$*, it is direct to see from (2.129) that* $K_{ai}^B < K_u^B$*. When either* $\overline{\phi}_{u}^{B} > 0$ *or both* $\overline{\phi}_{u}^{B} > 0$ *and* $\underline{\phi}_{u}^{B} > 0$*,* $\overline{\mu}^B > 0$ *does not unambiguously imply the sign of* $(K_{ai}^B - K_u^B)$*.* ■

Proof of Lemma 2.5 *Let us first summarize the main implications of Lemma 2.2. This lemma states that the set defined by the participation and output nonnegativity constraints of both the θ- and c-type firms is convex and constraint qualified, i.e., the NDCQ and LICQ conditions are satisfied. Moreover, this lemma yields that whenever there is no fixed cost,* $F_m = 0$*, the firms' participation constraints should be considered as liminal constraints, i.e, constraints that whenever active their Lagrange multiplier is still equal to zero. Conversely, when there is a fixed cost,* $F_m > 0$*, the firm's nonnegativity constraints should be ignored. A straight applications of the results in Lemma 2.2 allows us to study now the properties of the constraint set associated with (2.135)-(2.138).*

First, when there is no fixed cost, the participation constraints are liminal constraints and hence (2.135) and (2.136) can be ignored. In this case the constraint set is defined by (2.137) and (2.138). We study two cases according to whether or not $\overline{\nu}$ *and* $\underline{\nu}$ *are equal to zero. When* $\overline{\nu} = 0$ *(*$\underline{\nu} = 0$*), the constraint (2.137) ((2.138)) is trivially satisfied. When* $\overline{\nu} > 0$*, the constraint (2.137) is represented in the* $\{\overline{p}_M, \underline{p}_M, K\}$*-space by the level set* $\overline{\nu}\ \overline{q}_m^{\star}(\overline{p}_M, \underline{p}_M, K) = \overline{\nu}(\overline{Q}_M - K) = 0$ *which is a linear combination of the level set* $\overline{q}_m^{\star}(\cdot)$*, defined in the proof of Lemma 2.2, which represents the θ-type firm's output nonnegativity constraint (2.60) when being binding. Thus, since the constraint (2.137) is a linear combination of (2.60), the convexity property still holds. Second, when there is fixed cost, the firms' nonnegativity constraints are always satisfied with strict inequality, i.e.,* $\overline{\nu} = \underline{\nu} = 0$*. In such a case the participation constraints (2.135)-(2.136) are identical to (2.58)-(2.59), and hence convex and qualified.*

It then remains to show that the constraint set C associated with the regulator's optimization-aanalyze the properties of the sets defined by the profit-maximization constraints (2.139) and (2.140). When the less efficient firm is active, $\overline{q}_m > 0$*, its profit-maximization constraint*

(2.139) is represented by the level set $\overline{\Omega}^{\star}_m(\overline{p}_M, \underline{p}_M, K) = (\overline{p}_M - \theta)Q'_M + \overline{q}_m = 0$, *with gradient vector* $\nabla\overline{\Omega}^{\star}_m(\cdot) = (2Q'_M, 0, -1) \leq 0$. *Thus, the level surface* $\overline{\Omega}^{\star}_m(\cdot)$ *is regular plane and defines a convex set.*[46] *When the* θ*-type firm is shut down, its profit maximization constraint consists in the intersection of the level set* $\overline{q}^{\star}_m(\cdot)$ *with gradient* $\nabla\overline{q}^{\star}_m(\cdot) = (Q'_M, 0, -1)$ *and the one defined by the less efficient firm's profit-maximization constraint when it is shut down, i.e.,* $\overline{\Omega}^{\circ}_m(\overline{p}_M, \underline{p}_M, K) = (\overline{p}_M - \theta + \overline{\nu})Q'_M = 0$ *with gradient* $\nabla\overline{\Omega}^{\circ}_m(\cdot) = (Q'_M, 0, 0)$. *In such a case, the set defined by the less efficient firm's profit-maximization constraint is still convex and regular, i.e., meets the NDCQ and LICQ conditions.*

Similarly, when the more efficient firm is active, its profit-maximization constraint (2.140) is represented by the level set $\underline{\Omega}^{\star}_m(\overline{p}_M, \underline{p}_M, K) = (\underline{p}_M - c)Q'_M + \underline{q}_m = 0$, *with gradient vector* $\nabla\underline{\Omega}^{\star}_m(\cdot) = (0, 2Q'_M, -1) \leq 0$. *Thus, the level surface* $\overline{\Omega}^{\star}_m(\cdot)$ *is also a regular plane and defines a convex set. When it is shut down, the more efficient firm's profit maximization constraint consists in the intersection of the level set* $\underline{q}^{\star}_m(\cdot)$ *and the one defined by* $\underline{\Omega}^{\circ}_m(\overline{p}_M, \underline{p}_M, K) = (\underline{p}_M - c + \underline{\nu})Q'_M = 0$. *Again, the set associated to the c-type firm's profit-maximization constraint is convex and qualified.*

Finally, since the intersection of convex sets is convex, it is direct to see than the set defined by the constraints (2.135)-(2.138) and (2.139)-(2.140) is convex and qualified. ■

Proof of Lemma 2.6 *Consider the ex-post program under scheme C where the regulator seeks to control market power exercised by a* $\widetilde{\theta}$*-type firm trough the maximization of the social welfare function (2.54) with respect to* $p_M(\widetilde{\theta})$*, given a level of capacity K under the participation constraint of the* $\widetilde{\theta}$*-type firm, and the first-order conditions of its profit maximization program (2.132) and (2.133). Differentiate the associated system of first-order conditions with respect to* $\widetilde{\theta}$ *yields that when the firm is active and makes positive profits, i.e., when* $\nu(\widetilde{\theta}) = \phi(\widetilde{\theta}) = 0$, $\frac{dp_M(\widetilde{\theta})}{d\widetilde{\theta}} = \frac{1}{2} > 0$, $\frac{d\Pi_m(\widetilde{\theta})}{d\widetilde{\theta}} = (p_M(\widetilde{\theta}) - \widetilde{\theta})Q'_M - \frac{q_m(\widetilde{\theta})}{2} < 0$, $\frac{d\eta(\widetilde{\theta})}{d\widetilde{\theta}} = -\frac{1}{4} < 0$, *and clearly* $\frac{d\nu(\widetilde{\theta})}{d\widetilde{\theta}} = \frac{d\phi(\widetilde{\theta})}{d\widetilde{\theta}} = 0$. *When the firm is active and just breaks even,* $\nu(\widetilde{\theta}) = 0$ *and* $\phi(\widetilde{\theta}) > 0$, *we obtain* $\frac{dp_M(\widetilde{\theta})}{d\widetilde{\theta}} = 12$, $\frac{d\Pi_m(\widetilde{\theta})}{d\widetilde{\theta}} = 0$, $\frac{d\phi(\widetilde{\theta})}{d\widetilde{\theta}} \to \infty$, *and* $\frac{d\eta(\widetilde{\theta})}{d\widetilde{\theta}} \to -\frac{1}{4} < 0$. *Finally, when the firm is shut down,* $\nu(\widetilde{\theta}) > 0$, *the participation constraint is trivially satisfied* ($F_m = 0$) *and hence ignored,* $\phi(\widetilde{\theta}) = 0$. *In such a situation we obtain* $\frac{dp_M(\widetilde{\theta})}{d\widetilde{\theta}} = \frac{d\Pi_m(\widetilde{\theta})}{d\widetilde{\theta}} = \frac{d\phi(\widetilde{\theta})}{d\widetilde{\theta}} = \frac{d\eta(\widetilde{\theta})}{d\widetilde{\theta}} = 0$ *and* $\frac{d\nu(\widetilde{\theta})}{d\widetilde{\theta}} = 1$. ■

Proof of Proposition 2.7 *From Lemma 2.6 and the discussion that follows its statement we conclude that solutions with* $(\overline{\phi} = 0, \underline{\phi} = 0, \overline{\nu} = 0, \underline{\nu} > 0)$, $(\overline{\phi} = 0, \underline{\phi} > 0, \overline{\nu} = 0, \underline{\nu} = 0)$, $(\overline{\phi} = 0, \underline{\phi} = 0, \overline{\nu} > 0, \underline{\nu} > 0)$, *and* $(\overline{\phi} > 0, \underline{\phi} > 0, \overline{\nu} = 0, \underline{\nu} = 0)$ *cannot arise. Thus, only three combinations of Lagrange multipliers associated to the regulator's optimization program are possible.*

46. $\overline{\Omega}^{\star}_m(\cdot)$ can be considered as the graph of a function ,$K^{\star}_{\overline{q}_m}$, of K in terms of $\overline{p}_M$ and $\underline{p}_M$ in $\Re^3$ with $\frac{\partial K^{\star}_{\overline{\Omega}_m}}{\partial \overline{p}_M} = 2Q'_M$ and $\frac{\partial K^{\star}_{\overline{\Omega}_m}}{\partial \underline{p}_M} = 0$, and Hessian's leading minors $\{0, 0\}$.

Concerning policy $(C1_u)$*, replace for* $\overline{\phi} = \underline{\phi} = \overline{\nu} = \underline{\nu} = 0$ *in the system of first order conditions (2.141)-(2.148) to get (2.149)-(2.151). Next, solve (2.141) and (2.142), respectively, for* $\overline{\eta}$ *and* $\underline{\eta}$ *and substitute into (2.143). Similarly, solve (2.147) and (2.148), respectively, for* $\overline{p}_M$ *and* $\underline{p}_M$*. Now, substitute these values into (2.143) and obtain* $\lambda K-(1+2\lambda)[\alpha\overline{q}_m+(1-\alpha)\underline{q}_m]+2(1+\lambda)[\alpha(\theta-c)-C'(K)]Q'_M = 0$*. When there is no fixed cost,* $F_m = 0$*, the left-hand side of the latter inequality should be strictly positive, when evaluated* $K = \overline{Q}_M$ $(\overline{q}_m = 0)$*. This results in the condition* $0 < \alpha(\theta-c) < C'(\overline{Q}_M) - \frac{1}{2}\frac{\lambda}{1+\lambda}\frac{\overline{Q}_M}{Q'_M} + \frac{(1-\alpha)(1+2\lambda)\underline{q}_m}{2(1+\lambda)Q'_M}$*. When there is a positive fixed cost,* $F_m > 0$*, the left-hand side of the condition* $\lambda K-(1+2\lambda)[\alpha\overline{q}_m+(1-\alpha)\underline{q}_m]+2(1+\lambda)[\alpha(\theta-c)-C'(K)]Q'_M = 0$ *should be strictly positive, when evaluated* $\overline{q}_m^2 = -F_m Q'_M$*, which yields condition* $0 < \alpha(\theta-c) < C'(K) - \frac{1}{2}\frac{\lambda}{1+\lambda}\frac{K}{Q'_M} + \frac{(1-\alpha)(1+2\lambda)\underline{q}_m}{2(1+\lambda)Q'_M} - \frac{\alpha(1+2\lambda)F_m}{2(1+\lambda)\overline{q}_m}$*.*[47]

To obtain policy $(C2_u)$*, replace for* $\overline{\nu} = \underline{\nu} = \underline{\phi} = 0$ *and* $F_m > 0$ *in the system of first order conditions (2.141)-(2.148) to get (2.149), (2.150), and (2.152). Second-order conditions for this policy are always satisfied.*

To obtain policy $(C3_u)$*, replace for* $\overline{\phi} = \underline{\phi} = \underline{\nu} = 0$ *and* $F_m = 0$ *in the system of first order conditions (2.141)-(2.148) to obtain (2.153), (2.150), and (2.154). Second-order conditions for this policy are always satisfied.* ■

Proof of Proposition 2.8 *A straight application of the proof of Lemma 2.6 to the first-order conditions (2.165)-(2.170) yields that when the firm is active and makes positive profits, i.e., when* $\nu(\widetilde{\theta}) = \phi(\widetilde{\theta}) = 0$*,* $\frac{dp_M(\widetilde{\theta})}{d\widetilde{\theta}} = \frac{1}{2} > 0$*,* $\frac{d\Pi_m(\widetilde{\theta})}{d\widetilde{\theta}} = (p_M(\widetilde{\theta})-\widetilde{\theta})Q'_M - \frac{q_m(\widetilde{\theta})}{2} < 0$ *and clearly* $\frac{d\nu(\widetilde{\theta})}{d\widetilde{\theta}} = \frac{d\phi(\widetilde{\theta})}{d\widetilde{\theta}} = 0$*. When the firm is active and just breaks even, we obtain* $\frac{dp_M(\widetilde{\theta})}{d\widetilde{\theta}} = 12$*,* $\frac{d\Pi_m(\widetilde{\theta})}{d\widetilde{\theta}} = 0$*, and* $\frac{d\phi(\widetilde{\theta})}{d\widetilde{\theta}} \to \infty$*. Finally, when the firm is shut down,* $\nu(\widetilde{\theta}) > 0$*,* $\frac{dp_M(\widetilde{\theta})}{d\widetilde{\theta}} = \frac{d\Pi_m(\widetilde{\theta})}{d\widetilde{\theta}} = \frac{d\phi(\widetilde{\theta})}{d\widetilde{\theta}} = 0$ *and* $\frac{d\nu(\widetilde{\theta})}{d\widetilde{\theta}} = 1$*. Thus, we can conclude that under control scheme* C *with uncertainty and simultaneous decisions, at the optimum, we have* $\underline{p}_M \leq \overline{p}_M$*,* $\underline{\Pi}_m \geq \overline{\Pi}_m$*,* $\underline{\phi} \leq \overline{\phi}$*,* $\underline{\nu} \leq \overline{\nu}$*, and* $\underline{\eta} > \overline{\eta}$*.*

We see that solutions with $(\overline{\phi} = 0, \underline{\phi} = 0, \overline{\nu} = 0, \underline{\nu} > 0)$ *and* $(\overline{\phi} = 0, \underline{\phi} > 0, \overline{\nu} = 0, \underline{\nu} = 0)$ *are ruled out for the type of regulator-firm relationship established by the system of first-order conditions (2.165)-(2.170). Moreover, applying the same strategy that in the discussion that follows the statement of Lemma 2.6 we are able to obtain that solutions with either* $(\overline{\phi} = 0, \underline{\phi} = 0, \overline{\nu} > 0, \underline{\nu} > 0)$ *or* $(\overline{\phi} > 0, \underline{\phi} > 0, \overline{\nu} = 0, \underline{\nu} = 0)$ *cannot arise. Consequently, onle three combinations of Lagrange multipliers are possible according to whether or not they are equal to zero.*

Concerning policy $(\widehat{C1}_u)$*, replace for* $\overline{\phi} = \underline{\phi} = \overline{\nu} = \underline{\nu} = 0$ *in the system of first order conditions (2.165)-(2.170) to get (2.171)-(2.173). Next, solve (2.168) and (2.169), respectively, for* $\overline{p}_M$ *and* $\underline{p}_M$*. Now, substitute these values into (2.165) and obtain that when* $F_m = 0$*, this policy arises when* $0 < \alpha(\theta-c) < C'(\overline{Q}_M) + \frac{(1-\alpha)\lambda\underline{q}_m}{(1+\lambda)Q'_M}$*, and when* $F_m > 0$*, is emerges when* $0 < \alpha(\theta-c) <$

47. Second-order conditions are always satisfied for policy $(C1_u)$.

$C'(K) + \frac{(1-\alpha)\lambda \underline{q}_m}{(1+\lambda)Q'_M} - \frac{\alpha\lambda}{1+\lambda}\frac{F_m}{\overline{q}_m}$.[48]

To obtain policy $(\widehat{C2}_u)$, *replace for* $\overline{\nu} = \underline{\nu} = \underline{\phi} = 0$ *and* $F_m > 0$ *in the system of first order conditions (2.165)-(2.170) to get (2.171), (2.172), and (2.174). Second-order conditions for this policy are always satisfied.*

As to policy $(\widehat{C3}_u)$, *replace for* $\overline{\phi} = \underline{\phi} = \underline{\nu} = 0$ *and* $F_m = 0$ *in (2.165)-(2.170) to obtain (2.175), (2.172), and (2.176). Second-order conditions for this policy are always satisfied.* ■

Proof of Proposition 2.9 *We separately study the case where there is no fixed cost, and that where there is one.*

The no-fixed-cost case. *When* $F_m = 0$, *direct observation of (2.184) yields that* $sign[K^C_{\widehat{u}} - K^C_u] = -sign[\overline{\eta}^C + \underline{\eta}^C]$.[49]

The with-fixed-cost case. *When* $F_m > 0$, *we see from (2.185) that the effect of timing of decision is closely related to the behavior of* $\overline{\eta}^C$, $\underline{\eta}^C$, $\overline{\phi}^C_u$, *and* $\overline{\phi}^C_{\widehat{u}}$. *When the firm earns strictly positive profits in both a sequential or a simultaneous decision scheme,* $\overline{\phi}^C_u = \overline{\phi}^C_{\widehat{u}} = 0$, $sign[K^C_{\widehat{u}} - K^C_u] = -sign[\overline{\eta}^C + \underline{\eta}^C]$.

When the less efficient firm just breaks even in both the sequential and the simultaneous case, i.e., when $\overline{\phi}^C_u > 0$ *and* $\overline{\phi}^C_{\widehat{u}} > 0$, *we know from the proof of Lemma 2.2 that the level set* $\overline{\Pi}^\star_m(\overline{p}_M, \underline{p}_M, K)$ *is associated to the participation constraint of the* θ*-type firm, with gradient vector* $\nabla\overline{\Pi}^\star_m(\cdot) = ((\overline{p}_M - \theta)Q'_M + \overline{q}_m, 0, -(\overline{p}_M - \theta))$. *Note that when the profit-maximization constraint of this firm is effective,* $\nabla\overline{\Pi}^\star_m(\cdot) = (0, 0, -\frac{F_m}{\overline{q}_{m,u}})$ *and hence the function* $K^\star_{\overline{\Pi}_m}$, *of* K *in terms of* $\overline{p}_M$ *and* $\underline{p}_M$ *in* $\Re^3$ *meets its maximum. When decisions are taken simultaneously, given the nature of this optimization program we arrive to the same point obtained when decision are sequential. Consequently, when* $\overline{\phi}^C_u > 0$ *and* $\overline{\phi}^C_{\widehat{u}} > 0$, $\{\overline{p}^C_{M,u}, \underline{p}^C_{M,u}, K^C_u\} = \{\overline{p}^C_{M,\widehat{u}}, \underline{p}^C_{M,\widehat{u}}, K^C_{\widehat{u}}\}$.

In the remaining cases, i.e., when either $(\overline{\phi}^C_u > 0, \overline{\phi}^C_{\widehat{u}} = 0)$ *or* $(\overline{\phi}^C_u = 0, \overline{\phi}^C_{\widehat{u}} > 0)$, *gap* $K_{\widehat{u}} - K_u$ *cannot be unambiguously defined from the sign of the sum of shadow costs of the profit maximization constraints,* $\overline{\eta}^C + \underline{\eta}^C$. ■

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48. Second-order conditions are always satisfied for policy $(\widehat{C1}_u)$.

49. From Lemma 2.6, $\underline{\eta}^C > \overline{\eta}^C$. Therefore, whenever $\overline{\eta} > 0$, $\underline{\eta} > 0$, and then $K^C_{\widehat{u}} < K^C_u$. Conversely, whenever $\underline{\eta}^C < 0$, $\overline{\eta}^C < 0$, and then $K^C_{\widehat{u}} > K^C_u$.

Chapter 3

Transport capacity and competition in gas markets

3.1 Introduction

Traditionally, regulation and competition have been viewed as substitutes for improving the efficiency of markets. Regulation has been typically applied to industries where competition is not sustainable; the so called *natural monopolies.* This was, and still is to some extent, the case of public utilities for decades, most notably the telecommunications, electricity and natural gas industries. More recently, however, following major changes in technology and industry structure, these two mechanisms have come to complement each other. These industries have moved from what essentially was a vertically integrated structure subject to heavy regulation to one in which the natural monopoly portion is separated from segments deemed ready for competition. In gas, transport remains largely under a regulated monopoly while commodity supply is progressively open to competition.[1] This chapter attempts to assess the relative merits of policies that combine upstream regulation with alternative approaches to downstream competition.

While a great number of papers has analyzed the way upstream transport

1. The experience of the UK gas industry provides a good illustration of this interaction between regulation and competition (Waddams Price, 1997).

networks affect the working of downstream markets (De Vany and Walls, 1994, Doane and Spulber, 1994 in gas, Borenstein et al., 2000, Léautier, 2001 in electricity, among others), to the best of our knowledge, the major part of this literature has taken as given the capacity of the transport network and the charge applied for its use.[2] Both of these factors are considered as endogenous in this chapter. In the next section, we develop a model of an upstream firm providing a marketer with transport capacity at a regulated price. The regulator sets the transport charge taking as given competition in output between an incumbent and the marketer in a downstream gas commodity market. The outcome of the downstream firms' interaction is synthesized by generic equilibrium output responses to changes in the transport charge.[3] Section 3.3 applies this general setting to specific forms of market conduct with a varying degree of competition. Section 3.4 performs a comparative analysis of the various regulatory policies considered, in particular, an attempt to assess their relative welfare performance is made. The last section summarizes the main lessons to be drawn from the analysis and gives some directions for further research. The appendix gives technical proofs.

3.2 Transport regulation: general setting

Consider a regional natural gas commodity market, market B, in which an incumbent firm, firm I, produces gas with a technology described by a cost function $C_I(q_I)$ where q_I is output. We assume that the institutional framework allows a marketer M to import gas from an alternative market, market A, at a constant unit commodity price c and a regulated transport charge p_K paid to a transporter T that builds a pipeline of capacity K linking the two markets at cost $C_T(K)+F_T$.[4] Consumption takes place in market B according to inverse demand $p(\cdot)$ assumed

2. We should also mention Breton and Zaccour, 2001 who analyze competition in the downstream market using the Cournot and Stackelberg models.

3. In this chapter, we abstract away from information problems.

4. The incumbent's cost function is assumed to be increasing, strictly convex, and twice continuously differentiable with $C_I^{'''} = 0$. The transporter's cost function is increasing convex.

to be linear. Figure 3.1 pictures this simple industry structure.[5]

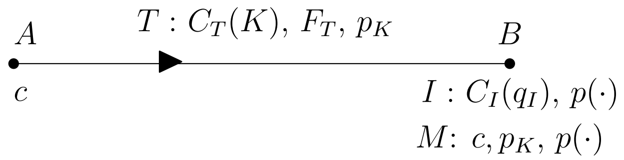


Figure 3.1: Industry configuration

We assume that the transporter is regulated. More specifically, the regulator determines the transport charge p_K subject to equilibrium behavior in the downstream gas commodity market B. Our main objective then is to investigate the relationship between the transport charge p_K (and the associated social welfare) and firms' conduct in this market.

Let us analyze the regulator's problem of setting the price of transport capacity p_K. Total supply in the downstream gas commodity market Q, composed of q_I units produced locally by the incumbent and K units imported by the marketer, brings consumers a net surplus CS given by

$$CS = \quad S(q_I + K) - p(q_I + K)[q_I + K] \tag{3.1}$$

where $S(\cdot)$ represents gross consumer surplus. The profit function of the upstream firm T, the transporter, is given by[6]

$$\Pi_T = p_K K - C_T(K) - F_T \tag{3.2}$$

5. Although this framework shares some features with that typically used to study access to an essential facility such as the local loop in telecommunications, two important aspects specific to the case of natural gas considered here are worth mentioning. First, the essential facility (the pipeline) is used only by the entrant (the marketer). Second, the incumbent supplier of the final good (natural gas) is completed separated from the owner of the essential facility (the capacity builder).

6. The cost structure of this upstream firm reflects the fact that natural gas transportation is highly capital-intensive and typically considered as a natural monopoly.

In the downstream market, firms I and M compete in output and their profit functions are respectively given by[7]

$$\Pi_I = \quad p(q_I + K)q_I - C_I(q_I) \tag{3.3}$$

$$\Pi_M = \quad [p(q_I + K) - p_K - c]K \tag{3.4}$$

Since capacity is an input for the marketer, equilibrium levels of output (and hence price) in this downstream market are going to depend on the level of the transport charge set by the regulator. This is formalized by writing downstream levels of output as functions $q_I(p_K)$ and $K(p_K)$, where the specific forms of these functions will be determined by the precise nature of the interaction between firms. So, as far as timing, first the regulator sets p_K, second the transporter builds K, and third the marketer uses K to compete with the incumbent.

Using (3.1)-(3.4), the utilitarian social welfare function W is given by[8]

$$W(p_K) = S(q_I(p_K) + K(p_K)) - C_I(q_I(p_K)) - cK(p_K) - C_T(K(p_K)) - F_T \tag{3.5}$$

The regulator's program consists in maximizing (3.5) under the participation constraint of the transporter[9]

$$\Pi_T(p_K) = p_K K(p_K) - C(K(p_K)) - F_T \geq 0 \tag{3.6}$$

Letting ϕ_T designate the Lagrange multiplier associated with (3.6) and using the fact that $\frac{\partial S(\cdot)}{\partial q_I} = \frac{\partial S(\cdot)}{\partial K} = p(\cdot)$, we obtain the following first-order conditions:

$$(p - C_I')\frac{dq_I}{dp_K} + (p - c - C_T')\frac{dK}{dp_K} + \phi_T\left[K + (p_K - C_T')\frac{dK}{dp_K}\right] = 0 \tag{3.7}$$

$$\phi_T[p_K K - C_T(K) - F_T] = 0 \tag{3.8}$$

7. We assume that in equilibrium both firms are active.

8. This social welfare is merely the unweighted sum of net consumer surplus and firms' profits.

9. We assume that the set defined by this participation constraint is convex which insures that the regulatory program is concave. A sufficient condition is concavity of the profit function (3.2), obtained if $2\frac{dK}{dp_K} + (p_K - C_T')\frac{d^2K}{dp_K^2} - C_T''(\frac{dK}{dp_K})^2 \leq 0$.

When the transporter's participation constraint is not binding, ($\phi_T = 0$), second-order conditions, necessary and sufficient for a unique local maximum, require

$$(p - c - C'_T)\frac{d^2K}{dp_K^2} + (p - C'_I)\frac{d^2q_I}{dp_K^2} + (p' - C''_T)\left(\frac{dK}{dp_K}\right)^2 + (p' - C''_I)\left(\frac{dq_I}{dp_K}\right)^2 < 0 \tag{3.9}$$

When it is binding ($\phi_T > 0$), second-order conditions are always satisfied. Rewriting the first-order conditions (3.7)-(3.8), we obtain:

Proposition 3.1 *For a given equilibrium in the downstream market described by the six-tuple* $(K(p_K), q_I(p_K), \frac{dK}{dp_K}, \frac{dq_I}{dp_K}, \frac{d^2K}{dp_K}, \frac{d^2q_I}{dp_K})$*, at the optimum, transport charge, outputs, price and shadow cost of the transporter's participation constraint satisfy the following condition:*

$$(1 + \phi_T)(p_K - C'_T)\frac{dK(p_K)}{dp_K} + \phi_T K(p_K) = -\left((p - p_K - c)\frac{dK(p_K)}{dp_K} + (p - C'_I)\frac{dq_I(p_K)}{dp_K}\right) \tag{3.10}$$

When the transporter's participation constraint is binding, $\phi_T > 0$, we obtain standard average-cost transport pricing $p_K = \frac{C_T(\cdot)+F_T}{K(\cdot)}$ satisfying (3.10). When this constraint is not binding, $\phi_T = 0$, we obtain that transport charge is distorted away from marginal cost with a bounded distortion, $p_K - C'_T(\cdot) \leq (p - C'_I)(-\frac{dq_I/dp_K}{dK/dp_K})$. The interpretation of this distortion becomes easier if one assumes that $|\frac{dK}{dp_K}| > |\frac{dq_I}{dp_K}|$, in which case an interior solution satisfies $C'_I < c + C'_T$, i.e., the cost of a marginal unit produced by the incumbent is less than the net cost of a marginal imported unit, $(c + p_K) - (p_K - C'_T)$.[10]

The equation stated in Proposition 3.1 shows at the left-hand side the social marginal effect in the upstream market of an increase in the transport charge.

10. The condition $|\frac{dK}{dp_K}| > |\frac{dq_I}{dp_K}|$ holds in all of our formal representations of downstream competition.

More precisely, this is the impact on both the marginal and infra marginal units of capacity built by the regulated transporter. At the right-hand side, it shows the effect of this increase in p_K on the downstream market, namely, on the marginal profitability of both the marketer and the incumbent. At the optimum, these two effects should be balanced. Clearly, their respective magnitude will depend on the specific nature of the downstream firms' interaction. The next section considers capacity pricing policies under various assumptions about this interaction.

3.3 Transport regulation and downstream competition

We consider four scenarios of downstream firms' behavior with a decreasing degree of competition, namely, no competition between firms I and M, Stackelberg competition, Cournot competition, and the case in which the incumbent faces a competitive fringe represented by firm M.

3.3.1 No downstream competition

In this section, we consider the polar case where there is no competition in the downstream market, i.e., the incumbent and the marketer behave as if they were a single entity.[11] These firms maximize then joint profits given by

$$\Pi_I + \Pi_M = p(q_I + K)(q_I + K) - C_I(q_I) - (p_K + c)K \tag{3.11}$$

For a given transport charge p_K, solving the joint profit-maximization problem yields the following first-order conditions:[12]

$$[p(q_I + K) - p_K - c] + (q_I + K)p' = 0 \tag{3.12}$$

11. Alternatively, one can think of the marketer as being an affiliate of the incumbent, but, although the firms maximize joint profits, they have to comply with some strict accounting separation rule.

12. The second-order condition is $2p'C_I'' < 0$, which is true given our linear demand and convex cost function.

$$[p(q_I + K) - C_I'] + (q_I + K)p' \quad = 0 \tag{3.13}$$

The profit-maximizing levels of output $(K^m(p_K), q_I^m(p_K))$ in this market are found by solving the system of first-order conditions (3.12)-(3.13).[13] How these outputs respond to changes in the transport charge p_K set by the regulator can be seen from the formulas provided in the next lemma.

Lemma 3.1 *The no downstream competition profit-maximizing outputs* $(K^m(p_K), q_I^m(p_K))$*, satisfy:*

$$\begin{aligned} \frac{dK^m}{dp_K} &= \frac{1}{2p'} - \frac{1}{C_I''} & \frac{d^2K^m}{dp_K^2} &= \frac{C_I'''}{C_I''}\left(\frac{dq_I^m}{dp_K}\right)^2 \\ \frac{dq_I^m}{dp_K} &= \frac{1}{C_I''} & \frac{d^2q_I^m}{dp_K^2} &= -\frac{C_I'''}{C_I''}\left(\frac{dq_I^m}{dp_K}\right)^2 \end{aligned} \tag{3.14}$$

An increase in the transport charge leads to a decrease in transport capacity and an increase in incumbent's output. However, the reduction in transport capacity dominates the increase in incumbent's volume, and the net effect is a reduction of total output and hence an increase in market price. Substituting $\frac{dK^m}{dp_K}$ and $\frac{dq_I^m}{dp_K}$ from this lemma into Proposition 3.1 allows us to characterize the optimum when there is no competition in the downstream gas commodity market.[14]

Proposition 3.2 *Assuming no competition in the downstream market, at the optimum, transport charge, outputs, price and shadow cost of the transporter's par-*

13. Note that (3.12) and (3.13) imply $p_K = C_I' - c$. Existence and uniqueness of the maximum of the joint profit function for $K, q_I > 0$ is guaranteed in our industry configuration by the strict convexity of the incumbent's cost function.

14. The regulator's maximization program is well behaved since the participation constraint of the transporter when there is no downstream competition defines a convex set. Indeed, replacing the results shown in Lemma 3.1 into the condition guaranteeing the concavity of the transporter's profit function (see footnote 9) yields that it is always true since we assume $C_I''' = 0$.

ticipation constraint satisfy the following conditions:

$$-\frac{(1+\phi_T^m)(p_K^m - C_T^{\prime m})(2p' - C_I^{\prime\prime m})}{2p' C_I^{\prime\prime m}} + \phi_T^m K^m =$$
$$\left(\frac{(p^m - p_K^m - c)(2p' - C_I^{\prime\prime m}) - 2(p^s - C_I^{\prime m})p'}{2p' C_I^{\prime\prime m}}\right) \quad (3.15)$$
$$[p^m - p_K^m - c] + (q_I^m + K^m)p' = 0 \quad (3.16)$$
$$\left[p^m - C_I^{\prime m}\right] + (q_I^m + K^m)p' = 0 \quad (3.17)$$

When the transporter's participation constraint is binding, we obtain standard average-cost transport pricing $p_K^m = \frac{C_T(\cdot)+F_T}{K^m}$ satisfying (3.15)-(3.17). When this constraint is not binding, $\phi_T^m = 0$, we obtain that $p_K^m < C_T^{\prime m}(\cdot) + \frac{2(p^m - C_I^{\prime m})p'}{(2p' - C_I^{\prime\prime m})}$ and $C_I^{\prime m} < c + C_T^{\prime m}$.[15] The detailed argument behind the existence of this bound is presented at the end of the proof of Proposition 3.2 in the appendix.[16] Let us now study transport capacity policies when downstream competition prevails.

3.3.2 Stackelberg downstream competition

In this section, we assume that competition in the downstream market is à la Stackelberg where the incumbent and the marketer are respectively the leader and the follower. For a given transport charge p_K, solving the marketer's profit-maximization problem yields the following first-order condition:[17]

$$[p(q_I + K) - p_K - c] + Kp' = 0 \quad (3.18)$$

15. From Lemma 3.1, $|\frac{dK^m}{dp_K}| > |\frac{dq_I^m}{dp_K}|$, which as discussed in section 3.2, implies $C_I^{\prime m} < c + C_T^{\prime m}$. Given this condition, second-order conditions are always satisfied. Indeed, when $\phi_T = 0$, replacing the results obtained in this lemma into condition (3.9), yields $-C_T'' C_I''^3 + p' C_I''^2 [4C_T'' + C_I''] - 4p'^2 C_I'' [C_T'' + C_I''] - 4p'^2 C_I''' [c + C_T' - C_I'] < 0$, which is true.

16. This is done for all of the other propositions corresponding to the competitive scenarios considered in this chapter.

17. The second-order condition is $2p' < 0$, which is true given our linear demand. It is well known that log-concavity of demand and convexity of the cost function of the incumbent imply that the best response function of the marketer is monotone and decreasing with slope belonging to the interval (-1,0). In our case, since demand is linear this slope is equal to $-\frac{1}{2}$.

This first-order condition is solved for K to yield the marketer's reaction function. The latter is substituted into the incumbent's profit function which is then maximized with respect to q_I. The first-order condition of this maximization problem is

$$[p - C_I'] + \frac{q_I p'}{2} \quad = 0 \tag{3.19}$$

The equilibrium $(K^s(p_K), q_I^s(p_K))$ of this Stackelberg game is obtained as the solution to the system of first-order conditions (3.18) and (3.19).[18] Some formulas that allow us to see how these equilibrium outputs vary with the regulated transport charge p_K are presented in the next Lemma.

Lemma 3.2 *The Stackelberg equilibrium (with the incumbent as a leader) in the downstream market, $(K^{s_I}(p_K), q_I^{s_I}(p_K))$, satisfies:*

$$\begin{aligned} \frac{dK^{s_I}}{dp_K} &= \frac{1}{2}\left[\frac{1}{p'} + \frac{1}{2(p' - C_I'')}\right] & \frac{d^2K^{s_I}}{dp_K^2} &= -\frac{C_I'''}{2(p' - C_I'')}\left(\frac{dq_I^{s_I}}{dp_K}\right)^2 \\ \frac{dq_I^{s_I}}{dp_K} &= -\frac{1}{2(p' - C_I'')} & \frac{d^2q_I^{s_I}}{dp_K^2} &= \frac{C_I'''}{(p' - C_I'')}\left(\frac{dq_I^{s_I}}{dp_K}\right)^2 \end{aligned} \tag{3.20}$$

Lemma 3.2 shows that under Stackelberg competition, an increase in the transport charge leads to a decrease in transport capacity and an increase in incumbent's output. However, the reduction in transport capacity more than offsets the increase in incumbent's volume, yielding a reduction of total output and hence an increase in market price. Substituting $\frac{dK^{s_I}}{dp_K}$ and $\frac{dq_I^{s_I}}{dp_K}$ from this lemma into Proposition 3.1 allows us to characterize the optimum when there is downstream Stackelberg competition with the incumbent as a leader.

Proposition 3.3 *Assuming downstream Stackelberg competition with the incumbent as a leader, at the optimum, transport charge, outputs, price and shadow cost*

18. Existence and uniqueness of this equilibrium is guaranteed by our assumptions on demand and incumbent's cost function. It corresponds to the tangency point between the marketer's reaction function and a level curve of the incumbent's profit function in the positive quadrant.

of the transporter's participation constraint satisfy the following conditions:

$$\frac{(1+\phi_T^{s_I})(p_K^s - C_T^{'s_I})(3p' - 2C_I^{''s_I})}{4p'(p' - C_I^{''s_I})} + \phi_T^{s_I} K^s = - \left(\frac{(p^{s_I} - p_K^{s_I} - c)(3p' - 2C_I^{''s_I}) - 2(p^s - C_I^{'s_I})p'}{4p'(p' - C_I^{''s_I})} \right) \tag{3.21}$$

$$[p^{s_I} - p_K^{s_I} - c] + K^{s_I} p' = 0 \tag{3.22}$$

$$[p^{s_I} - C_I^{'s_I}] + \frac{q_I^{s_I} p'}{2} = 0 \tag{3.23}$$

When the transporter's participation constraint is binding, we obtain standard average-cost transport pricing $p_K^{s_I} = \frac{C_T(\cdot)+F_T}{K^{s_I}}$ satisfying (3.21)-(3.23). When this constraint is not binding, we obtain that $p_K^{s_I} < C_T^{'s_I}(\cdot) + \frac{2(p^{s_I} - C_I^{'s_I})p'}{(3p' - 2C_I^{''s_I})}$ and $C_I^{'s_I} < c + C_T^{'s_I}$.

The case with the marketer as a leader is treated as follows. The Stackelberg equilibrium $(K^{s_M}(p_K),\, q_I^{S_M}(p_K))$ is obtained by solving the first-order conditions

$$[p(q_I + K) - C_I'] + q_I p' = 0 \tag{3.24}$$

$$[p(q_I + K) - p_K - c] + K\left(1 - \frac{p'}{2p' - C_I''}\right) p' = 0 \tag{3.25}$$

The next lemma provides useful information on the relationship between this equilibrium and the transport charge.

Lemma 3.2' *The Stackelberg equilibrium (with the marketer as a leader) in the downstream market, $(K^{s_M}(p_K), q_I^{s_M}(p_K))$, satisfies:*

$$\begin{aligned} \frac{dK^{s_M}}{dp_K} &= \frac{1}{2}\left[\frac{1}{p'} + \frac{1}{(p' - C_I'')}\right] & \frac{d^2K^{s_M}}{dp_K^2} &= 0 \\ \frac{dq_I^{s_M}}{dp_K} &= -\frac{1}{2(p' - C_I'')} & \frac{d^2 q_I^{s_M}}{dp_K^2} &= 0 \end{aligned} \tag{3.26}$$

Cross-examining Lemmas 3.2 and 3.2', we see that when leadership is transferred to the marketer, the slope of the incumbent's equilibrium output function remains unchanged. This is because the transport charge has only a second-order effect on the incumbent's profits which is zero given our assumption of linear demand. As to the marketer, because the transport charge has a first-order effect on its profits, switching from the role of a follower to that of a leader, it sees the slope of its equilibrium output (capacity) function increased in absolute value.

Lemma 3.2' shows that an increase in transport charge has opposite effects on capacity and incumbent's output but the net effect on aggregate output is negative. Substituting $\frac{dK^{s_M}}{dp_K}$ and $\frac{dq_I^{s_M}}{dp_K}$ from this lemma into Proposition 3.1 allows us to characterize the optimum when there is downstream Stackelberg competition with the marketer as a leader.

Proposition 3.3' *Assuming downstream Stackelberg competition with the marketer as a leader, at the optimum, transport charge, outputs, price and shadow cost of the transporter's participation constraint satisfy the following conditions:*

$$\frac{(1+\phi_T^{s_M})(p_K^{s_M} - C_T'^{s_M})(2p' - C_I''^{s_M})}{2p'(p' - C_I''^{s_M})} + \phi_T^{s_M} K^{s_M} = -\left(\frac{(p^{s_M} - p_K^{s_M} - c)(2p' - C_I''^{s_M}) - (p^{s_M} - C_I'^{s_M})p'}{4p'(p' - C_I''^{s_M})}\right) \quad (3.27)$$

$$[p^{s_M} - p_K^{s_M} - c] + K^{s_M}\left(1 - \frac{p'}{2p' - C_I''^{s_M}}\right)p' = 0 \quad (3.28)$$

$$[p^{s_M} - C_I'^{s_M}] + q_I^{s_M} p' = 0 \quad (3.29)$$

When the transporter's participation constraint is binding, we obtain standard average-cost transport pricing $p_K^{s_M} = \frac{C_T(\cdot)+F_T}{K^{s_M}}$ satisfying (3.27)-(3.29). When this constraint is not binding, we obtain that $p_K^{s_M} < C_T'^{s_M}(\cdot) + \frac{(p^{s_M} - C_I'^{s_M})p'}{(2p' - C_I''^{s_M})}$ and $C_I'^{s_M} < c + C_T'^{s_M}$.

3.3.3 Cournot downstream competition

In this section, we assume that competition in the downstream market is à la Cournot. For a given transport charge p_K, the marketer and the incumbent simultaneously maximize own profits yielding the following first-order conditions:[19]

$$[p(q_I + K) - p_K - c] + Kp' = 0 \tag{3.30}$$

$$[p(q_I + K) - C_I'] + q_I p' = 0 \tag{3.31}$$

Solving these first-order conditions yields the Cournot equilibrium $(K^c(p_K), q_I^c(p_K))$ and the next lemma provides useful information on the relationship between this equilibrium and the transport charge.[20]

Lemma 3.3 *The Cournot equilibrium* $(K^c(p_K), q_I^c(p_K))$ *in the downstream market, satisfies:*

$$\begin{aligned} \frac{dK^c}{dp_K} &= \frac{1}{2}\left[\frac{1}{p'} + \frac{1}{3p' - 2C_I''}\right] & \frac{d^2K^c}{dp_K^2} &= -\frac{C_I'''}{3p' - 2C_I''}\left(\frac{dq_I^c}{dp_K}\right)^2 \\ \frac{dq_I^c}{dp_K} &= -\frac{1}{3p' - 2C_I''} & \frac{d^2q_I^c}{dp_K^2} &= \frac{2C_I'''}{3p' - 2C_I''}\left(\frac{dq_I^c}{dp_K}\right)^2 \end{aligned} \tag{3.32}$$

Assuming Cournot competition, an increase in the transport charge leads to a decrease in transport capacity and an increase in incumbent's output with a net negative effect on aggregate output.[21] Substituting $\frac{dK^c}{dp_K}$ and $\frac{dq_I^c}{dp_K}$ from this lemma

19. The second-order conditions for the marketer's and incumbent's problem are respectively $2p' < 0$ and $2p' - C_I'' < 0$, which are always satisfied under our demand and cost assumptions.

20. Existence and uniqueness of this equilibrium is guaranteed by our assumptions on demand and incumbent's cost function. It corresponds to the crossing point of the firm's reaction functions derived from (3.30) and (3.31).

21. This corresponds to the general result in IO saying that with strategic substitutes and a unique Cournot equilibrium, a firm's output decreases with its marginal cost and increases with its competitor's (Tirole, 1988, p. 220). In this chapter, we find that this result also holds for the other forms of imperfect competition considered. Moreover, we find that an increase in one firm's marginal cost decreases industry output.

into Proposition 3.1 allows us to characterize the optimum when there is downstream Cournot competition.

Proposition 3.4 *With Cournot competition in the downstream market, at the optimum, transport charge, outputs, price and shadow cost of the transporter's participation constraint satisfy the following conditions:*

$$\frac{(1+\phi_T^c)(p_K^c - C_T'^c)(2p' - C_I''^c)}{p'(3p' - 2C_I''^c)} + \phi_T^c K^c = -\left(\frac{(p^c - p_K^c - c)(2p' - C_I''^c) - (p^c - C_I'^c)p'}{p'(3p' - 2C_I''^c)}\right) \tag{3.33}$$

$$[p^c - p_K^c - c] + K^c p' = 0 \tag{3.34}$$

$$[p^c - C_I'^c] + q_I^c p' = 0 \tag{3.35}$$

When the transporter's participation constraint is binding, we obtain standard average-cost transport pricing $p_K^c = \frac{C_T(\cdot)+F_T}{K^c}$ satisfying (3.33)-(3.35). When this constraint is not binding, we obtain that $p_K^c < C_T'^c(\cdot) + \frac{(p^c - C_I'^c)p'}{(2p' - C_I''^c)}$ and $C_I'^c < c + C_T'^c$.

3.3.4 Downstream competitive fringe

Now, assume that the incumbent faces a competitive fringe of gas traders represented by the marketer M. For a given transport charge p_K, this competitive fringe maximizes profits taking market price as given by ordering from the transporter capacity K such that its marginal cost is equal to market price:

$$p(q_I + K) - p_K - c \quad = 0 \tag{3.36}$$

The incumbent maximizes own profits over the residual demand and hence sets its marginal revenue equal to its marginal cost:

$$[p(q_I + K) - C_I'] + q_I p' \quad = 0 \tag{3.37}$$

The market equilibrium $(K^f(p_K), q_I^f(p_K))$ is obtained by solving (3.30) and (3.31) and useful information on this equilibrium are provided in the next Lemma.

Lemma 3.4 *The equilibrium $(K^f(p_K), q_I^f(p_K))$ obtained when the incumbent faces a competitive fringe in the downstream market satisfies:*

$$\begin{aligned} \frac{dK^f}{dp_K} &= \frac{1}{p'} + \frac{1}{p' - C_I''} & \frac{d^2K^f}{dp_K^2} &= -\frac{C_I'''}{p' - C_I''}\left(\frac{dq_I^f}{dp_K}\right)^2 \\ \frac{dq_I^f}{dp_K} &= -\frac{1}{p' - C_I''} & \frac{d^2q_I^f}{dp_K^2} &= \frac{C_I'''}{(p' - C_I'')}\left(\frac{dq_I^f}{dp_K}\right)^2 \end{aligned} \tag{3.38}$$

Again, we see from this lemma that an increase in transport charge has opposite effects on capacity and incumbent's output but the net effect on aggregate output is negative. Substituting $\frac{dK^f}{dp_K}$ and $\frac{dq_I^f}{dp_K}$ from this lemma into Proposition 3.1 allows us to characterize the optimum when there is a competitive fringe of gas traders in the downstream market.

Proposition 3.5 *when the incumbent faces a competitive fringe, at the optimum, transport charge, outputs, price and shadow cost of the transporter's participation constraint satisfy the following conditions:*

$$\frac{(1+\phi_T^f)(p_K^f - C_T'^f)(2p' - C_I''^f)}{p'(p' - C_I''^f)} + \phi_T^f K^f = -\left(\frac{(p^f - p_K^f - c)(2p' - C_I''^f) - (p^f - C_I'^f)p'}{p'(p' - C_I''^f)}\right) \tag{3.39}$$

$$p^f - p_K^f - c = 0 \tag{3.40}$$

$$[p^f - C_I'^f] + q_I^f p' = 0 \tag{3.41}$$

When the transporter's participation constraint is binding, we obtain standard average-cost transport pricing $p_K^f = \frac{C_T(\cdot)+F_T}{K^f}$ satisfying (3.39)-(3.41). When this constraint is not binding, we obtain that $p_K^f = C_T'^f(\cdot) + \frac{(p^f - C_I'^f)p'}{(2p' - C_I''^f)}$ and $C_I'^f < c + C_T'^f$.

3.4 Comparative analysis

So far, we have characterized individual transport charge policies associated with various assumptions about the competitive behavior of firms in the downstream market. Our purpose now is to attempt to compare these policies. While the complete analytical comparison of these second-best policies is beyond the scope of this chapter, this is however possible with specific functional forms and simulations. Let us then assume that

$$p(q_I + K) = \gamma - (q_I + K), \quad C_I(q_I) = \frac{\theta}{2}q_I^2, \quad C_T(K) = \omega K + F_T \qquad (3.42)$$

A straight application of Lemmas 1-5 allows us to derive the slopes of the equilibrium output functions under the corresponding assumptions about downstream competition. The results are shown in Table 3.1 where the indices m, s_I, s_M, c, and f refer to the five forms of competition considered is subsections 3.3.1-3.3.4 respectively.

Table 3.1: Slopes of equilibrium output functions

Market Assumption	$\frac{dK}{dp_K}$	$\frac{dq_I}{dp_K}$	$\frac{dQ}{dp_K}$
m	$-\frac{2+\theta}{2\theta}$	$\frac{1}{\theta}$	$-\frac{1}{2}$
s_I	$-\frac{3+2\theta}{4(1+\theta)}$	$\frac{1}{2(1+\theta)}$	$-\frac{1+2\theta}{4(1+\theta)}$
s_M	$-\frac{2+\theta}{2(1+\theta)}$	$\frac{1}{2(1+\theta)}$	$-\frac{1}{2}$
c	$-\frac{2+\theta}{3+2\theta}$	$\frac{1}{3+2\theta}$	-$\frac{1+\theta}{3+2\theta}$
f	$-\frac{2+\theta}{1+\theta}$	$\frac{1}{1+\theta}$	-1

These slopes convey information on the downstream firms' output responses to changes in p_K. The magnitude of these responses are ranked as follows: For $0 < \theta < 1$, we have

$$\left|\frac{dK^c}{dp_K}\right| < \left|\frac{dK^{s_I}}{dp_K}\right| < \left|\frac{dK^{s_M}}{dp_K}\right| < \left|\frac{dK^f}{dp_K}\right| < \left|\frac{dK^m}{dp_K}\right| \tag{3.43}$$

and for $\theta > 1$, we have

$$\left|\frac{dK^c}{dp_K}\right| < \left|\frac{dK^{s_I}}{dp_K}\right| < \left|\frac{dK^{s_M}}{dp_K}\right| < \left|\frac{dK^m}{dp_K}\right| < \left|\frac{dK^f}{dp_K}\right| \tag{3.44}$$

Whereas for any θ, we obtain

$$\left|\frac{dq_I^c}{dp_K}\right| < \left|\frac{dq_I^{s_I}}{dp_K}\right| = \left|\frac{dq_I^{s_M}}{dp_K}\right| < \left|\frac{dq_I^f}{dp_K}\right| < \left|\frac{dq_I^m}{dp_K}\right| \tag{3.45}$$

$$\left|\frac{dQ^{s_I}}{dp_K}\right| < \left|\frac{dQ^c}{dp_K}\right| < \left|\frac{dQ^{s_M}}{dp_K}\right| = \left|\frac{dQ^m}{dp_K}\right| < \left|\frac{dQ^f}{dp_K}\right| \tag{3.46}$$

With the functional forms described in (3.42), we see from Table 3.1 that the equilibrium output functions are linear in the transport charge. The equilibrium capacity functions are negatively sloped across the five forms of competition considered while those of the incumbent's output are positively sloped. However, as stated in section 3.3, the net effect on aggregate output is always negative, i.e., an increase in p_K will be accompanied by an unambiguous increase in gas commodity price.

From (3.43) and (3.44) we see that irrespective of the degree of convexity of the incumbent's cost function, θ, when competition prevails, i.e., under market assumptions s_I, c, s_M, and f, the response of equilibrium capacity to an increase in p_K are unambiguously ranked as $|\frac{dK^c}{dp_K}| < |\frac{dK^{s_I}}{dp_K}| < |\frac{dK^{s_M}}{dp_K}| < |\frac{dK^f}{dp_K}|$. This says that the more rigorous the level of competition is in the downstream market, the more responsive capacity is to changes in p_K.[22] As mentioned above, since this (negative) capacity effect dominates the (positive) effect on the incumbent's output, aggregate output decreases. From (3.46), we see that under market assumptions m (no

22. We view Stackelberg leadership by the marketer as representing more rigorous competition than Stackelberg leadership by the incumbent.

competition) and s_M (marketer as a Stackelberg leader), an increase in p_K leads to decreases in aggregate output of the same magnitude. This is related to the fact that p_K has a direct effect on the marketer's profits (it directly affects its marginal cost) and our demand and cost assumptions.[23]

While these slopes of the equilibrium outputs are instructive by themselves, recall from the theory presented in the previous sections that they feed the regulator's decision. More specifically, these slopes need to be substituted into the conditions that characterize the optimal capacity pricing rules derived in Propositions 2-5. Let us state next these rules for each of the five forms of downstream competition in turn.

$$p_K^m - \omega = \left(\frac{\phi_T^m}{1+\phi_T^m}\right)\frac{2\theta K^m}{(2+\theta)} - \left(\frac{1}{1+\phi_T^m}\right)\frac{\theta Q^m}{(2+\theta)} \tag{3.47}$$

$$p_K^{s_I} - \omega = \left(\frac{\phi_T^{s_I}}{1+\phi_T^{s_I}}\right)\frac{4(1+\theta)K^{s_I}}{(3+2\theta)} + \left(\frac{1}{1+\phi_T^{s_I}}\right)\frac{[q_I^{s_I} - (3+2\theta)K^{s_I}]}{(3+2\theta)} \tag{3.48}$$

$$p_K^{s_M} - \omega = \left(\frac{\phi_T^{s_M}}{1+\phi_T^{s_M}}\right)\frac{2(1+\theta)K^{s_M}}{2+\theta} + \left(\frac{1}{1+\phi_T^{s_M}}\right)\frac{[q_I^{s_M} - (1+\theta)K^{s_M}]}{(2+\theta)} \tag{3.49}$$

$$p_K^c - \omega = \left(\frac{\phi_T^c}{1+\phi_T^c}\right)\frac{(3+2\theta)K^c}{(2+\theta)} + \left(\frac{1}{1+\phi_T^c}\right)\frac{[q_I^c - (2+\theta)K^c]}{(2+\theta)} \tag{3.50}$$

$$p_K^f - \omega = \left(\frac{\phi_T^f}{1+\phi_T^f}\right)\frac{(1+\theta)K^f}{(2+\theta)} + \left(\frac{1}{1+\phi_T^f}\right)\frac{q_I^f}{(2+\theta)} \tag{3.51}$$

In order to compare the performance of these five policies we ran simulations with the following parameters values: $\gamma = 1$, $\theta = 0.67$, c normalized to zero, ω and F_T continuously varying in $[0, 0.13]$ and $[0, 0.012]$ respectively. Figures 3.2(a-b), 3.3, 3.4(a-b), and 3.5(a-b) exhibit the regions with different ranking of K, q_I, p_K, Π_I, Π_M, CS, $\Pi_I+\Pi_M$, and W, and the corresponding regions in the $\{F_T, \omega\}$-space. The region with dashed lines contours represents the (F_T, ω) pairs for which there does not exist a real root to the regulator's maximization program when there is no competition in the downstream market.

23. The indirect effect corresponds to the impact of p_K on equilibrium output levels and the subsequent effect on profits.

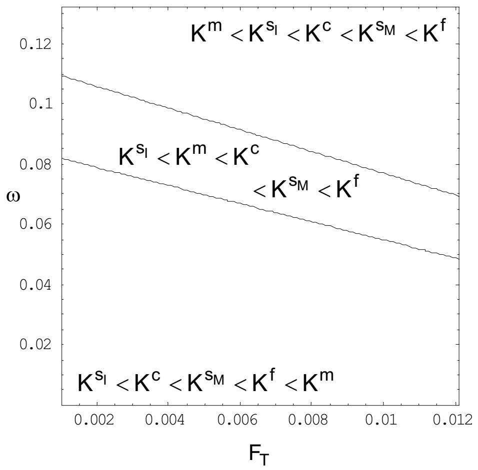


Figure 3.2a: Ranking of K

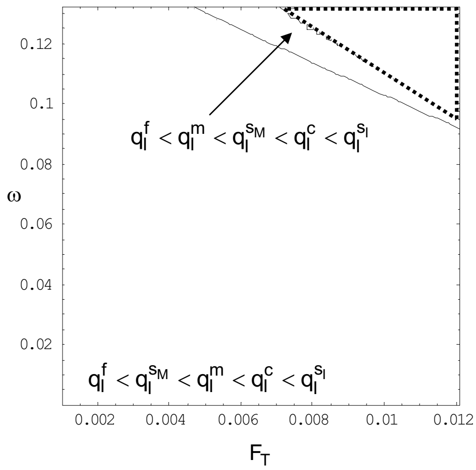
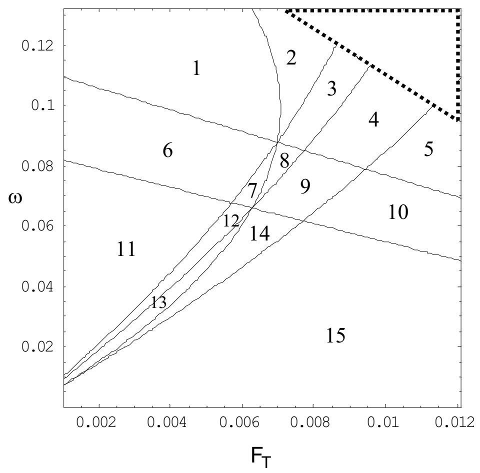


Figure 3.2b: Ranking of q_I



1 : $p_K^{s_M} < p_K^c < p_K^{s_I} < p_K^m < p_K^f$
2 : $p_K^{s_M} < p_K^c < p_K^{s_I} < p_K^f < p_K^m$
3 : $p_K^{s_M} < p_K^c < p_K^f < p_K^{s_I} < p_K^m$
4 : $p_K^{s_M} < p_K^f < p_K^c < p_K^{s_I} < p_K^m$
5 : $p_K^f < p_K^{s_M} < p_K^c < p_K^{s_I} < p_K^m$
6 : $p_K^{s_M} < p_K^c < p_K^m < p_K^{s_I} < p_K^f$
7 : $p_K^{s_M} < p_K^c < p_K^m < p_K^f < p_K^{s_I}$
8 : $p_K^{s_M} < p_K^c < p_K^f < p_K^m < p_K^{s_I}$
9 : $p_K^{s_M} < p_K^f < p_K^c < p_K^m < p_K^{s_I}$
10 : $p_K^f < p_K^{s_M} < p_K^c < p_K^m < p_K^{s_I}$
11 : $p_K^{s_M} < p_K^m < p_K^c < p_K^{s_I} < p_K^f$
12 : $p_K^{s_M} < p_K^m < p_K^c < p_K^f < p_K^{s_I}$
13 : $p_K^{s_M} < p_K^m < p_K^f < p_K^c < p_K^{s_I}$
14 : $p_K^{s_M} < p_K^f < p_K^m < p_K^c < p_K^{s_I}$
15 : $p_K^f < p_K^{s_M} < p_K^m < p_K^c < p_K^{s_I}$

Figure 3.3: Ranking of p_K in regions 1-15

Figures 3.2a and 3.2b show the ranking of optimal capacity and incumbent's output, respectively, in the $\{F_T, \omega\}$-space. We see that when the downstream market is competitive, the more rigorous the level of competition, the higher (the lower) the capacity (the incumbent's output). The capacity levels without downstream competition cannot be unambiguously ranked relative to those achieved with downstream competition. As to the incumbent's output, an unambiguous ranking is obtained when we restrict ourselves to market assumptions f, m, and c. In such a case, going from either no competition or Cournot competition to a competitive fringe market structure lowers the incumbent's output. However, moving from no competition to Cournot competition increases incumbent's output.

Figure 3.3 shows that if there is competition in the downstream market but it is not excessive (this excludes market assumptions m and f), the transport charge decreases as the marketer plays a more important role in the downstream market, $p_K^{s_I} > p_K^c > p_K^{s_M}$. This result is consistent with the unambiguous ordering $K^{s_I} < K^c < K^{s_M}$ of marketer's output. When the two excluded market structures are put back as possible options, the optimal transport charges achieved cannot be unambiguously ranked between them and relative to market assumptions s_I, c, and s_M.[24] Despite this somewhat unstable behavior of the optimal transport charge and corresponding output levels across the various assumptions about the downstream market structure, it turns out that the ordering of social welfare and its components, i.e., consumer surplus and firms' profits, is much less surprising as we now show.

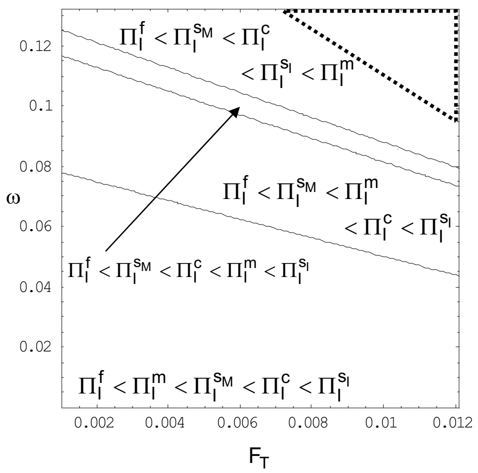


Figure 3.4a: Ranking of Π_I

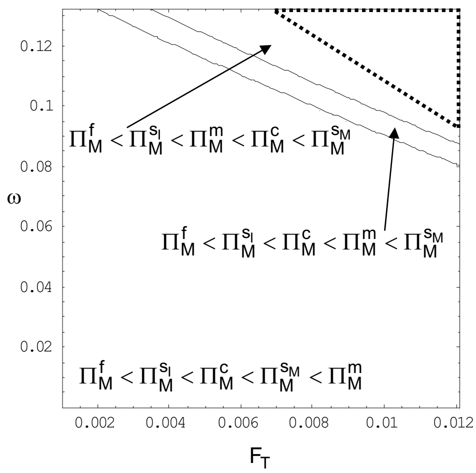


Figure 3.4b: Ranking of Π_M

24. One would have expected that as competition becomes more agressive, the optimal transport charge would be lower. Our simulations do not, however, support this conjecture. Even more surprising is the result that p_K^f and p_K^m cannot be unambiguously ordered.

Figure 3.4a shows that when there is competition, the incumbent is always better off under a Stackelberg market structure in which it is the leader than under Cournot competition, Stackelberg competition with the marketer as a leader, or a competitive fringe market structure, its least preferred option ($\Pi_I^f < \Pi_I^{s_M} < \Pi_I^c < \Pi_I^{s_I}$). Between excessive competition and no competition at all, the choice is obvious since $\Pi_I^f < \Pi_I^m$ is always true. As to the marketer, Figure 3.4b shows that when the marketer is not merely a price taker and it is independent from the incumbent (this excludes f and m), its profits become larger as one moves from s_I to c to s_M. When a merger with the incumbent is a possibility, the marketer prefers it to a situation where it is an independent follower ($\Pi_M^m > \Pi_M^{s_I}$).

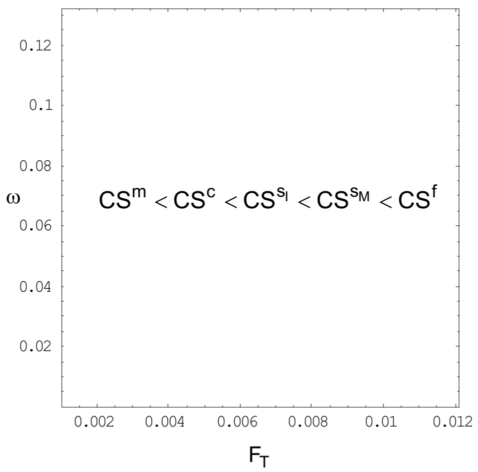


Figure 3.5a: Ranking of CS

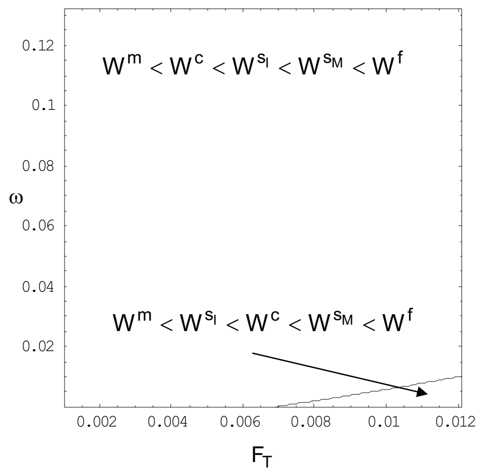


Figure 3.5b: Ranking of W

Figures 3.5a and 3.5b confirm the basic economic principle that more competition should benefit consumers and society as a whole ($CS^m < CS^c < CS^{s_I} < CS^{s_M} < CS^f$ and ($W^m < W^c < W^{s_I} < W^{s_M} < W^f$), although we find in our simulations a small region where, because the capacity building technology is characterized by high fixed cost and very low marginal cost, society is better off under Cournot competition than under Stackelberg leadership of the incumbent. In fact, given that the welfare levels achieved are available, we now examine the preferences of the agents over the different scenarios.[25] Table 3.2 shows the outcome of

25. Note that the transporter is indifferent among scenarios as regulation always bind its partic-

pairwise contests based on these welfare levels. Each cell of this table shows the choice of the agent indicated in the column in the contest indicated in the row.[26]

Table 3.2: Pairwise contests

Contest	Consumers	Incumbent	Marketer	Society
m vs. s_I	s_I	m, s_I	m	s_I
m vs. s_M	s_M	m, s_M	m, s_M	s_M
m vs. c	c	m, c	m, c	c
m vs. f	f	m	m	f
s_I vs. s_M	s_M	s_I	s_M	s_M
s_I vs. c	s_I	s_I	c	s_I, c
s_I vs. f	f	s_I	s_I	f
s_M vs. c	s_M	c	s_M	s_M
s_M vs. f	f	s_M	s_M	f
c vs. f	f	c	c	f

Three implications of this table are worth mentioning.[27] First, it appears that having the marketer as a follower is a “poor” policy. Second, a close examination of the regions of the parameter space indicates that there is no room for a Pareto-improvement, i.e., a move that will make all agents better off. Third, there is a conflict between consumers (and society) and the downstream firms in the choice between no or some competition (m, s_I, c, s_M) and strong competition (f). Indeed, downstream firms will always oppose an extreme strengthening of competition in the downstream market.

ipation constraint.

26. A cell showing two choices corresponds to a case where the agent's welfare ordering is not unambiguous.

27. The reader should realize that before drawing conclusions from this table, compatibility among the regions of the parameter space over which the choice(s) is (are) made should be checked.

3.5 Conclusion

This chapter has considered the relationship between the regulated portion of the gas industry (transport) and the segment that has been subject to liberalization (commodity supply). We model the role of pricing of transport capacity in the determination of the equilibrium in the commodity market served by an incumbent and a marketer . We first characterize the optimal capacity pricing rule assuming a "generic" form of downstream competition. We find that the regulator should balance the impact of the transport charge between the marginal and infra marginal units of capacity built by the transporter (upstream), on the one hand, and the marginal profitability of the marketer and the incumbent (downstream), on the other hand. We then proceed to specify this policy under alternative assumptions about the behavior of firms in the downstream market. In order to compare these second-best policies we rely on simulations.

While the simulations confirm the general wisdom that more competition is preferred to less from the consumers and the social welfare points of view, they also show some less expected results about the ordering of key policy variables, such as the capacity of pipelines and its price, across different competitive scenarios that reveal some redistribution conflicts. In particular, a reform that will support high entry in the gas trading segment, although socially desirable, is found to be opposed by both the existing marketer and the incumbent. The comparative analysis has also shown the important role played by the transporter's technology which here is assumed to be perfectly known by the regulator. Hence, there is clearly room for an extension of this work that relaxes the assumption of complete information about the capacity building technology.[28] Another extension that is feasible under the framework developed in this chapter is to analyze the role of measures of *gas-release* that occupy a large part of the current debate in the industry. Both of these extensions are in our future research agenda.

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28. Chapter 2 of this dissertation has explored the impact on transport capacity of asymmetric information on technology of gas commodity supply when the downstream market is a monopoly.

Appendix

Proof of Proposition 3.1 *Condition (3.1) in the proposition is just the first-order condition (3.7) rewritten in such a way that at the left-hand side we obtain the terms that show the impact of p_K on the profitability of the transporter, and at the right-hand side the terms that show the impact on the incumbent and the marketer.* ■

Proof of Lemma 3.1 *Differentiate the first-order conditions (3.12) and (3.13) with respect to p_K to obtain $\frac{dK(\cdot)}{dp_K} = \frac{1}{2p'} - \frac{dq_I}{dp_K}$, $\frac{dq_I(\cdot)}{dp_K} = (\frac{2p'}{C_I''-2p'})\frac{dK}{dp_K}$, and $\frac{d^2K(\cdot)}{dp_K^2} = -\frac{d^2q_I}{dp_K^2} = \Omega^m[2\frac{d^2K}{dp_K^2}p' - 2(\frac{dq_I}{dp_K})^2C_I''']$, where $\Omega^m \equiv [(2p' - C_I'')]^{-1}$. Then solve the system of equations composed of the first-order derivatives to obtain $\frac{dK^m}{dp_K} = \frac{1}{2p'} - \frac{1}{C_I''} < 0$ and $\frac{dq_I^m}{dp_K} = \frac{1}{C_I''} > 0$ which are rewritten as shown in the first column of (3.14). Solve the system of equations composed of the second-order derivatives to obtain $\frac{d^2K^m}{dp_K^2} = \frac{C_I'''}{C_I''}(\frac{dq_I^m}{dp_K})^2$ and $\frac{d^2K^m}{dp_K^2} = -\frac{C_I'''}{C_I''}(\frac{dq_I^m}{dp_K})^2$ which are rewritten as shown in the second column of (3.14).* ■

Proof of Proposition 3.2 *First, substitute the results (3.14) from Lemma 3.1 into condition (3.10) from Proposition 3.1, to obtain (3.15). Next, rewrite the first-order conditions (3.12) and (3.13) evaluated at the optimum. This yields (3.16) and (3.17).*

When $\phi_T^m > 0$, the capacity pricing rule described by (3.15) is equivalent to standard average-cost pricing. When $\phi_T^m = 0$, from (3.15) we obtain that $p_K^m = C_T'^m(\cdot) + (p^m - p_K^m - c) + \frac{2(p^m - C_I'^m)p'}{(2p' - C_I''^m)}$. From (3.16) we obtain $(p^m - p_K^m - c) > 0$ which implies $p_K^m < C_T'^m(\cdot) + \frac{2(p^m - C_I'^m)p'}{(2p' - C_I''^m)}$ and $C_I'^m < c + C_T'^m$. ■

Proof of Lemma 3.2 *The slopes and the convexity of the incumbent's and marketer's equilibrium outputs, K^s and q_I^s, under Stackelberg competition are obtained in a similar way to those under the assumption of no downstream competition. Differentiate the first-order condition (3.18) with respect to p_K to obtain $\frac{dK(\cdot)}{dp_K} = \frac{1}{2}(\frac{1}{p'} - \frac{dq_I}{dp_K})$ and $\frac{d^2K(\cdot)}{dp_K^2} = -\frac{1}{2}\frac{d^2q_I}{dp_K^2}$. Similarly, differentiate (3.19) to get $\frac{dq_I(\cdot)}{dp_K} = (\frac{2p'}{2C_I''-3p'})\frac{dK}{dp_K}$ and $\frac{d^2q_I(\cdot)}{dp_K^2} = -\Omega_1^s[2\frac{d^2K}{dp_K^2}p' - 2(\frac{dq_I}{dp_K})^2C_I''']$, where $\Omega_1^{s_I} \equiv [(3p' - 2C_I'')]^{-1}$. Solve the system of equations given by the first-order derivatives to obtain $\frac{dK^{s_I}}{dp_K} = \frac{1}{2p'} + \frac{1}{4(p'-C_I'')} < 0$ and $\frac{dq_I^{s_I}}{dp_K} = -\frac{1}{2(p'-C_I'')} > 0$ which are rewritten as shown in the first column of (3.20). Next, solve the system of second-order derivatives and obtain $\frac{d^2K^{s_I}}{dp_K^2} = -\frac{\Omega_2^{s_I}}{2}[\frac{dq_I}{dp_K}C_I''']\frac{dq_I}{dp_K}$ and $\frac{d^2q_I^{s_I}}{dp_K^2} = \Omega_2^{s_I}[\frac{dq_I}{dp_K}C_I''']\frac{dq_I}{dp_K}$, where $\Omega_2^{s_I} \equiv [(p' - C_I'')]^{-1}$, which are rewritten as shown in the second column of (3.20).* ■

Proof of Proposition 3.3 *First, substitute the results (3.20) from Lemma 3.2 into condition*

(3.10) from Proposition 3.1, to obtain (3.21). Next, rewrite the first-order conditions (3.18) and (3.19) evaluated at the optimum. This gives (3.22) and (3.23).

When $\phi_T^{s_I} > 0$*, the capacity pricing rule described by (3.21) is equivalent to standard average-cost pricing. When* $\phi_T^{s_I} = 0$*, from (3.21) we obtain that* $p_K^{s_I} = C_T'^{s_I}(\cdot) + (p^{s_I} - p_K^{s_I} - c) + \frac{2(p^{s_I} - C_I'^{s_I})p'}{(3p' - 2C_I''^{s_I})}$*. From (3.22) we get* $(p^{s_I} - p_K^{s_I} - c) > 0$ *which implies* $p_K^{s_I} < C_T'^{s_I}(\cdot) + \frac{2(p^{s_I} - C_I'^{s_I})p'}{(3p' - 2C_I''^{s_I})}$ *and* $C_I'^{s_I} < c + C_T'^{s_I}$*.* ■

Proof of Lemma 3.2' *Differentiate the first-order conditions (3.24) and (3.25) with respect to* p_K*, which since* $C_I''' = 0$ *imply* $\frac{dq_I(\cdot)}{dp_K} = (\frac{p'}{C_I'' - 2p'})\frac{dK}{dp_K}$*,* $\frac{dK(\cdot)}{dp_K} = \frac{2p' - C_I''}{p'(2C_I'' - 3p')}[p'\frac{dq_m}{dp_K} - 1]$*, and* $\frac{d^2K(\cdot)}{dp_K^2} = \frac{d^2q_I}{dp_K^2} = 0$*. Solve the system of first-order derivatives to get* $\frac{dK^{sM}}{dp_K} = \frac{1}{2p'} + \frac{1}{2(p' - C_I'')} < 0$ *and* $\frac{dq_I^{sM}}{dp_K} = -\frac{1}{2(p' - C_I'')} > 0$ *which are rewritten as shown in the first column of (3.26).* ■

Proof of Proposition 3.3' *Substituting the results (3.26) from Lemma 3.2' into condition (3.10) from Proposition 3.1, we obtain (3.27). Next, rewrite the first-order conditions (3.24) and (3.25) evaluated at the optimum,. This yields (3.28) and (3.29). The rest of the proof is omitted as it closely follows the proof of Proposition 3.3.* ■

Proof of Lemma 3.3 *Differentiate the first-order condition (3.30) with respect to* p_K *to obtain* $\frac{dK(\cdot)}{dp_K} = \frac{1}{2}(\frac{1}{p'} - \frac{dq_I}{dp_K})$ *and* $\frac{d^2K(\cdot)}{dp_K^2} = -\frac{1}{2}\frac{d^2q_I}{dp_K^2}$ *(see the proof of Lemma 3.2). Next, differentiate (3.31) with respect to* p_K *to get* $\frac{dq_I(\cdot)}{dp_K} = (\frac{p'}{C_I'' - 2p'})\frac{dK}{dp_K}$ *and* $\frac{d^2q_I(\cdot)}{dp_K^2} = -\Omega_1^c[\frac{d^2K}{dp_K^2}p' - (\frac{dq_I}{dp_K})^2 C_I''']$*, where* $\Omega_1^c \equiv [(2p' - C_I'')]^{-1}$*. Solve the system of first-order derivatives to get* $\frac{dK^c}{dp_K} = \frac{1}{2p'} + \frac{1}{(3p' - 2C_I'')} < 0$ *and* $\frac{dq_I^c}{dp_K} = -\frac{1}{(3p' - 2C_I'')} > 0$ *which are rewritten as shown in the first column of (3.32). Solve the system of second-order derivatives to obtain* $\frac{d^2K^c}{dp_K^2} = -\Omega_2^c[\frac{dq_I}{dp_K}C_I''']\frac{dq_I}{dp_K}$ *and* $\frac{d^2q_I^c}{dp_K^2} = 2\Omega_2^c[\frac{dq_I}{dp_K}C_I''']\frac{dq_I}{dp_K}$*, where* $\Omega_2^c \equiv [(3p' - 2C_I'')]^{-1}$*, which are rewritten as shown in the second column of (3.32).* ■

Proof of Proposition 3.4 *Substitute the results (3.32) from Lemma 3.3 into condition (3.10) from Proposition 3.1, to obtain (3.33). Next, rewrite the first-order conditions (3.30) and (3.31) evaluated at the optimum. This yields (3.34) and (3.35).*

When $\phi_T^c > 0$*, the capacity pricing rule described by (3.33) is equivalent to standard average-cost pricing. When* $\phi_T^c = 0$*, from (3.33) we obtain that* $p_K^c = C_T'^c(\cdot) + (p^c - p_K^c - c) + \frac{(p^c - C_I'^c)p'}{(2p' - C_I''^c)}$*. From condition (3.34) we get* $(p^c - p_K^c - c) > 0$ *which implies* $p_K^c < C_T'^c(\cdot) + \frac{(p^c - C_I'^c)p'}{(2p' - C_I''^c)}$ *and* $C_I'^c < c + C_T'^c$*.* ■

Proof of Lemma 3.4 *Differentiate the first-order condition (3.36) with respect to* p_K *to get*

$\frac{dK(\cdot)}{dp_K} = (\frac{1}{p'} - \frac{dq_I}{dp_K})$ *and* $\frac{d^2K(\cdot)}{dp_K^2} = -\frac{d^2q_I}{dp_K^2}$. *Next, from the proof of Lemma 3.3 we know the values of* $\frac{dq_I(\cdot)}{dp_K}$ *and* $\frac{d^2q_I(\cdot)}{dp_K^2}$. *Solve the system of first-order derivatives to obtain* $\frac{dK^f}{dp_K} = \frac{1}{p'} + \frac{1}{(p'-C_I'')} < 0$ *and* $\frac{dq_I^f}{dp_K} = -\frac{1}{(p'-C_I'')} > 0$ *which are rewritten as shown in in the first column of (3.38). Next, solve the system of second-order derivatives to get* $\frac{d^2K^f}{dp_K^2} = -\frac{d^2q_I^f}{dp_K^2} = -\Omega_2^f[\frac{dq_I}{dp_K}C_I'''] \frac{dq_I}{dp_K}$, *where* $\Omega_2^f \equiv [(p' - C_I'')]^{-1}$ *which are rewritten as shown in in the second column of (3.38).* ■

Proof of Proposition 3.5 *Substitute the results (3.38) from Lemma 3.4 into condition (3.10) from Proposition 3.1, to obtain (3.39). Next, rewrite the first-order conditions (3.36) and (3.37) evaluated at the optimum. This yields (3.40) and (3.41).*

When $\phi_T^f > 0$, *the capacity pricing rule described by (3.39) is equivalent to standard average-cost pricing. When* $\phi_T^f = 0$, *from (3.39) we get* $p_K^f = C_T^{'f}(\cdot) + (p^f - p_K^f - c) + \frac{(p^f - C_I^{'f})p'}{(2p' - C_I^{''f})}$. *From condition (3.40), we obtain* $(p^f - p_K^f - c) = 0$ *which implies* $p_K^f = C_T^{'f}(\cdot) + \frac{(p^f - C_I^{'f})p'}{(2p' - C_I^{''f})}$ *and* $C_I^{'f} < c + C_T^{'f}$. ■

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