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ABSTRACT

Models of Imperfect Competition in Deregulated Wholesale Electricity Markets

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In this dissertation we analyze, using standard formal imperfect competition models from the literature, two central public policy issues in the deregulated wholesale electricity markets. The first issue is the regulatory rules around generator ownership of transmission companies or transmission rights in general. The second issue we look into is the extent to which publicly owned generation assets should be privatized and what the objective function of the remaining assets should be in a market where a private generator also competes. Furthermore, before going into these formal analyses, we discuss the theory behind restructuring and deregulation, the practices of the United States, Britain and some Latin American countries, and the applicable lessons for the restructuring of the Turkish electricity industry from the theory and these experiences.

On the first issue, we find that allowing generators to partially own transmission companies is not necessarily detrimental to consumer interests, depending on the transmission network configuration and the resulting congestion patterns. On the second issue, our finding is that, except in a few limiting cases, the optimal choice of objective function for the public (or regulated) firm for total surplus maximization is never pure profit maximization or pure welfare (or consumers' surplus) maximization, but a strictly convex combination of the two. Both results differ from the conventional wisdom

and the previous findings of the relevant literatures, due to the special characteristics of the electricity markets and the electric transmission networks that are not observed in any other standard industry structure.

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Table of Contents

List of Figures

List of Tables

Chapter I: **Introduction**

With the wave of restructuring, privatization and deregulation of electricity industries that began in the 1980s and spread all over the world in the 1990s, a variety of interesting market structures and institutions arose, along with accompanying regulatory and public policy issues that did not exist before. This dissertation identifies a few of those issues and offers some insights using standard formal models from the microeconomics and industrial organization literatures.

The second chapter begins with a review of the theory behind electricity sector restructuring and deregulation, continues with the discussion of the restructuring experiences of United States, Britain, Argentina, Brazil, Uruguay and Chile, and concludes with the description of the history and current state of the Turkish electricity industry and the lessons offered by the theory and global restructuring practices so far for the restructuring of the Turkish electricity sector going forward.

The experiences of developed countries (United States and Britain) offer lessons different from the experiences of the developing countries (Argentina, Brazil, Uruguay and Chile). Our discussion about the American and British experiences focuses mostly on their initial market structures, generation concentration levels, existing regulatory structures and regimes and the details of their regulatory mechanisms. On the other hand, for the developing countries, overall economic, legal and regulatory environments, as well as the private property safeguarding institutions and the stability of the political and regulatory regimes are the centerpieces of the discussion. As a developing country, Turkey has lessons to draw from the successful and failed restructuring attempts of both groups of countries.

The third chapter develops a model and an equilibrium concept in a Cournot-style imperfectly competitive wholesale electricity market with loops flows and binding transmission constraints. There are two separate but interdependent markets within the model: electricity and transmission congestion rights. Through the explicit pricing of transmission rights, we develop a market-based congestion management mechanism where reliability of the system is maintained by the price signals, rather than ad hoc intervention of the Independent System Operator. As expected, equilibrium levels of prices, outputs and line flows as well as the congestion patterns are determined by the relative capacities of the individual transmission lines.

The third chapter next examines the policy issues surrounding generator ownership interests in the transmission company, or of transmission congestion rights in general. Despite the popular opinion that entitling a generator to congestion rents collected by the grid operator would lead to increased market power and lower consumers' surplus, we find in most (but not all) cases within our model that such ownership interest leads to higher output, lower prices and thus higher consumers' surplus. The conclusion we reach is that there is no single regulatory rule applicable to any market and transmission system configuration that would improve consumers' surplus.

The fourth chapter examines the equilibrium in a mixed Cournot-style imperfectly competitive wholesale electricity market where a private generator competes with a public or regulated generator. The private generator's objective is to maximize own profits, whereas the regulated generator's objective is determined by the regulator, and it is a weighted average of own profits and total welfare. We analyze a two-node network (where there are no loop flows) as well as a three-node network (characterized by loop flows).

Given the equilibrium of the Cournot rivalry between the two generators for each objective function chosen by the regulator, Chapter 4 next analyzes the optimal (total surplus maximizing) choice of the regulator. Except in a few limiting cases, we find that the optimal choice of objective function is never pure profit maximization or pure welfare maximization, but a strictly convex combination of the two. This result differs from the general understanding in the literature due to the special properties of the electricity industry and electric transmission networks, which are not displayed by any other standard industry.

The fifth chapter examines the same problem as the fourth chapter, which is, the equilibrium in a Cournot rivalry between a private and a regulated generator in a deregulated wholesale electricity market characterized by loop flows as well as the optimal choice of the regulated generator's objective function by the regulator. The difference from the previous chapter is that we utilize the more general model we developed in Chapter 3 that accounts for congestion and transmission rights prices explicitly using a market-based congestion management mechanism. We also make slight modifications to model specifications of Chapter 4, mainly with respect to the generator cost structure (constant vs. increasing marginal costs) and the regulated firm's objective function space (welfare vs. consumers' surplus maximization).

Our qualitative findings are very similar to those of Chapter 4. That is, except in a few limiting cases, the optimal choice of objective function is never pure profit maximization or pure consumers' surplus maximization, but a strictly convex combination of the two. The introduction of transmission rights prices into the model created a problem that did not exist in the original model (in Chapter 4): multiple equilibria. In order to do any welfare comparison analysis and thus analysis of optimal choice of objective function for the regulated firm, one must deal with the issue of multiplicity of equilibria. We develop equilibrium selection criteria based on the profits (total net congestion cost collection) of the Independent System Operator, which yields a single equilibrium outcome in each relevant region of the parameter space.

Chapter II: **Restructuring, Privatization and Regulation Experiences around the Globe and Lessons for the Turkish Electricity Sector***

1. Introduction

After 1980 restructuring of the electricity sector became an issue in many countries. Due to its properties as an economic product and in parallel to the requirements of the generation technology, electricity was being supplied to the consumers by vertically integrated monopolies in most countries until the 1980s. The public sector was keeping the operations of these monopolies in check either by directly owning and operating them or by regulating these franchised private companies.

This monopolistic structure of the sector generated the financial resources required for the capital-intensive investments, and it achieved a significant increase in per capita consumption reliably and with falling real prices of electricity in the developed countries from the end of the Second World War up until 1980s. By the end of the 1970s increases in cost caused by the oil shock and lower demand growth rates triggered a period of increasing real prices of electricity.[1] Discontent with the performance of the sector and the general trend of increased role of the private sector in the economy led to the restructuring in the sector.

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*This chapter is a partial reproduction (and translation from Turkish) of a paper (Zenginobuz and Ogur (1999)) that was prepared for and presented in the conference "Regulatory Role of State: Privatization and Competition in the Electricity and Telecommunication Sectors in Turkey" on December 10, 1999 organized by TESEV (Turkish Economic and Social Studies Foundation) and published in the Conference Proceedings.

The British experience in restructuring the electricity sector is very striking in that the new structure was radically different from the previous monopolistic structure. After a process that began in 1988, Britain totally vertically unbundled its industry structure that was previously fully integrated. In this new structure the generators that used to belong to the public sector were privatized, and the electricity generation segment was fully opened to the private sector participation. A new regulatory regime was formed to let the wholesale electricity prices be determined without government regulation. A separate monopoly was established for the operation of the high-voltage transmission network, and its ownership was transferred to the private sector, which was regulated. The distribution network was divided into 12 zones and operation of each zone was franchised to a separate private monopoly. These 12 regional monopolies, which also jointly owned the transmission grid, were also subject to regulation. The supply segment, the last segment before electricity reaches the end-users and includes setting retail rates, metering, invoicing and collections, were also opened to competition.

This radical restructuring in Britain was noticed by other developed and developing countries and served as an example to all of them.

The electricity supply industry, as for all the economies in the world, has a very fundamental and growing significance for the Turkish economy. It is clear that the electricity industry is one of the sectors that directly determines the growth capacity of the Turkish economy since it uses many resources as its inputs and supplies usable energy to the residential, commercial and industrial establishments.

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[1] For a discussion of the reasons behind the electricity industry restructuring efforts in the industrialized countries, see Newberry (1995) and Gilbert, Kahn and Newberry (1996).

The electricity sector requires huge overhead costs. Like almost all developed and developing countries in the world, Turkey has decided to restructure its electricity industry to be able to meet the great demand for funds this sector has and to utilize the advances in technology and operations. In this study we try to examine the experiences and the results of these experiences of the countries that have passed through the paths Turkey is about to walk. We also try to scrutinize the theoretical advances in the field and regulatory and industrial restructuring alternatives for Turkey and possible consequences of each.

2. Electricity Sector and its Regulation

The provision of electric power to consumers has all the properties of a natural monopoly. Under natural monopoly conditions one firm produces a group of goods or services at less economic cost than multiple firms. Under these conditions where the production technology displays subadditive costs, it will lead to inefficient allocation of resources for more than one firm to be established and operate since it will duplicate the fixed investments and increase the total variable cost of production. Blocking the entry of more than one firm by the public sector in the interest of economic efficiency brings the necessity to control the firm so that it cannot abuse its market power.

Some other observed fundamental properties of the industries that are often determined to be natural monopolies are that they are capital-intensive; they require a minimum scale; the product is not storable while the demand is very volatile; there are economic rents stemming from supply being limited to specific regions; the product being offered is a necessity good or service and it is necessary to transport the good directly to the customers.[2] These properties necessitate that only one firm operates in a given region for efficient production purposes. It is clear that these conditions prevail in the supply of electricity.

The desire to control the monopoly power resulted in public ownership of this monopoly in many countries. The reason for this ownership choice is that controlling the market power of private monopolies is difficult and costly. However, there have always been countries where operating natural monopolies under private ownership has been preferred. For example electricity generation and supply were almost always undertaken by private regional monopolies in the United States.

The traditional way to regulate a private monopoly has been to determine the price of the good or service so as to allow a certain amount of return on investment. In this method, called *rate-of-return regulation,* the price to be charged to the consumers is calculated by adding some return on the capital used to the cost of production and operating expenses.

It is obvious that the private franchised monopoly will have superior knowledge about its production costs and other properties of its production process compared to the authority that regulates it. Under the rate-of-return regulation, the monopoly cannot be expected to truthfully reveal the information that will directly determine the profit it will earn. Many countries chose to let these monopolies be public in the hope of avoiding the costs of collecting such information from the regulated firms. The assumption under

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[2] See Berg and Tschirhart (1988)

this choice is that the natural monopoly will operate in the interest of the public under public ownership.

The performances of natural monopolies operating under public ownership in terms of economic efficiency vary from country to country. However, costs of producing under public ownership began to be understood in the 1980s.[3] It especially came to light that forming the incentive mechanisms to make the managers of the public monopolies make the correct investment and production decisions in terms of economic efficiency is significant but not trivial. It was also observed that the monopoly being under public ownership made political interventions easier, that would totally ignore economic efficiency issues.[4] On the other hand, advances in the production technologies altered the natural monopoly conditions in some industries; for example, in the electricity industry it was noticed that there could be more room for private sector participation by unbundling the traditionally vertically integrated structure.[5]

More private sector participation in the industries where traditionally public monopolies reigned caused the issue of economic regulation to come to the forefront. Although private sector participation is expected to enhance economic efficiency, it is unavoidable that the profit motive might have welfare-reducing effects under imperfect competition conditions which may arise due to technological or other reasons. Therefore, with the increasing private sector participation, the issue of choice of methods and tools to use where the market is not sufficiently competitive is gaining significance.

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[3] Gilbert, Kahn and Newberry (1996).
[4] Newberry (1995).
[5] Gilbert, Kahn and Newberry (1996).

2.1 Electricity generation and evolution of the electricity sector

The traditional way to supply electricity to the end-users has been via a vertically integrated industry structure. The first segment of this integrated structure is the *generation* segment. The second segment is the *transmission* segment where the generated electricity is transported to the load centers at high voltages. The *distribution* segment in which the electricity transmitted to the load centers reaches the end-users is the third segment. It is possible to see the invoicing, metering, payments and collection of the distributed electricity as the fourth segment under the name of *supply* segment.

There is no competition in this structure where the vertical integration is complete. Every decision about the generation segment is made by the public or private monopoly. The public authority tries to ensure that these decisions are made consistent with social welfare maximization, possibly subject to some constraints, directly in case of a public monopoly and via regulation in case of a private monopoly. Among the decisions to be made are the location, capacity, and primary fuel source of the generating plants to be built; expansion and maintenance investments in the transmission and distribution networks; and determination of the price tariffs; as well as demand forecasts that will guide these decisions.

Although there may be increasing returns to scale in the generation segment over some capacity range, this does not necessarily preclude multiple companies from operating in this segment. Increasing returns to scale in generation stem from difficulties in storing electricity and the fact that the demand always has to be met, although it shows great variability with time and location. The difference between peak power demand (which cannot be known in advance with any precision) and the reserve capacity required to meet this demand reliably and uninterruptedly makes the plants with capacities above some threshold economic. A significant portion of the installed capacity that is going to be used to meet the demand at peak times will be idle during vast majority of the hours. The required reserve margin of a utility serving a larger customer group is smaller than the required reserve margin of a utility serving a smaller customer group.

In order to be able to utilize the increasing returns to scale, excess generation available at one node needs to be transmitted to a node where excess power is needed. The rationale for building a common transmission network that connects the generation nodes to the consumption nodes is taking advantage of increasing returns to scale in generation. Some of the electricity to be transmitted from one point to another is unavoidably lost on the way. These losses decrease as the voltage increases. Therefore, long distance transmission of electricity is done via high-voltage transmission lines, which require heavy investments. Due to high investment costs, the cost-minimizing action is to build a single grid that connects the generation and consumption nodes only indirectly, instead of connecting them directly to each other. Transmission-capacity expanding investments will be undertaken only if nodes previously not connected to the grid are added or the transmission capacity on the existing lines is insufficient. Given these properties, it is observed that this second segment of electricity industry, high-voltage transmission sector, has the properties of a natural monopoly.

The existence of a transmission grid brings out the question of which generator's (or consumer's) electricity is to be transmitted first when congestion occurs. A single transmission grid necessitates the central dispatch of electricity if economic efficiency is to be achieved. If generators have different marginal costs of generation, it is easy to see how important the *dispatch* issue is to meet the demand in the least-costly way. In an optimal system, electricity that reaches a consumption node at a given time must be the electricity that can be generated at minimum total cost. The problem of achieving central dispatch in an economically efficient way in a market where private independent generators are present is the most important problem to be resolved about the regulation of a vertically unbundled electricity industry.

The electricity that reaches the load centers at high voltage is transformed via transformers at different places into low-voltage that end-users can use. It reaches the end-users via the distribution network after this point. Since it would not be economic to link to the same consumption point from the distribution point with multiple lines, this segment also displays natural monopoly properties.

Just like in the generation segment, there is no economic obstacle to multiple firms to be in competition in the retail sale of electricity to end-users. If third party access is allowed to the regional transmission network, retail sale firms can sell the electricity they purchased from various generators to their customers by transmitting it through the high-voltage transmission grid and then the local distribution network. Naturally, these retailers would pay some fees for using both the transmission and the distribution network.

Before 1980, a vertically integrated structure was the only observed structure throughout the world. In this structure the operations of the public or private monopoly contained all the segments from generation to retail sales.[6] So the regulation in case of a private monopoly was the regulation of a completely vertically integrated firm. This type of vertically integrated structure continues to prevail in parts of the United States; for example, in the service territories of Entergy, American Electric Power and Southern Companies.

The vertically integrated structure of the electricity industry became a major policy issue in many countries after Britain fully vertically unbundled its electricity sector. In the new industrial organization in Britain, publicly-owned generating plants are privatized and electricity generation is fully opened to private sector participation, where wholesale price of electricity is determined in the market without being subject to any regulatory control. A different monopoly is established for the operation of the high-voltage transmission grid, ownership of it is transferred to the private sector and its operation is subject to regulation. The distribution network is divided into twelve zones, and the ownership and operation of each is transferred to a different private franchised monopoly. These twelve private regional monopolies that also jointly own the transmission grid are also subject to state regulation. The supply segment, which is the last segment before electricity reaches the end-users and includes setting retail rates, metering, invoicing, payments and collections is also fully opened to competition.

Regulation of a vertically unbundled electricity industry like the one in Britain has different properties than regulation of a vertically integrated private monopoly. Although there is no competition in any segment of the vertically integrated structure, the generation and supply segments are subject to competition in this new organization of

[6] As in the U.S. multiple private companies were granted regional monopoly franchises.

the industry. How will the competition in these segments fit together with the regulation of transmission and distribution segments, which are natural monopolies? How will it be ensured that public control of the regulated segments will not discourage the required investments in the competitive segments? Will the private sector investments be sufficient and economically efficient under the new structure? It is easily seen that the problem of regulation of a vertically disintegrated industry with some segments open to private sector competition is quite different from the problem of regulating the vertically integrated structure.

The reasons behind electricity sector restructuring attempts in developed countries are quite different from the ones in the developing countries. Deteriorating industry performance, in terms of investment and operating efficiency, and increasing electricity prices beginning in the 1970s triggered the search for alternatives in the developed nations. For the industrializing nations, the restructuring attempts stemmed from serious difficulties in making installed capacity investments that were necessary for high growth rates. Pricing policies that prevented the sector from undertaking required investments with its own revenues and public sector deficits led to the search for domestic or foreign private sector participation. The changes taking place in the developed countries at the same time also began to be taken as models.

Industrialized countries usually are not in need of huge investments in their electricity sectors because of more mature markets and lower growth rates compared to the developing countries. They also have the institutional and legal structures that can develop regulatory regimes that would not be discouraging for the private sector. Thus it is easier for them to design institutions that will emphasize economic efficiency in the regulation of the new structure of the electricity industry that is open to competition. In the industrializing countries the stable institutional and legal structures that regulate the activities of the private sector are not yet fully in place. This makes it difficult for the private sector participants to foresee the returns on their investments with some confidence and in turn reduces the investments by the private sector. On the other hand, high return guarantees required to attract investments make it difficult to restore competition in the sector in the coming years. We discuss this issue further in the sections about the regulation of the electricity industry in its new structure.

2.2 Safeguarding institutions and private investments

Investments in the electricity sector are large-scale, capital-intensive, durable, sector-specific and immobile. Thus it is very important for the investors to have institutional guarantees that secure their returns to some extent. Some structural and institutional properties a country should possess in order to make the private investors intending to invest in the electricity sector feel safe are:

1. Existence of a well-functioning legal system with respect for property rights.
2. Independent regulatory institutions that are not subject to heavy influence of politics.

For example, if the regulatory institutions can obtain their funding from an independent source, they will be functioning more independently than their counterparts whose funding is legislatively or administratively determined.

3. High growth rates in the sector or in the economy as a whole.

High growth rates mean need for large amounts of investment funds. If the government would expropriate the assets of the incumbent firm, it would then have to undertake by itself further future expansions due to loss of reputation of the government. Thus the cost of this opportunistic behavior is larger under high growth rates.

4. Political stability or the ability to deter future governments from changing the regulatory system toward their own interests.

If the governments are stable over time in a country, that is if the same parties come to power often, the probability of altering the regulatory structure for short term gains would be small. The fact that they will internalize the benefits and the costs of their actions would force the parties in power to be careful about the changes they consider making.

5. Division of regulatory responsibilities among central and local organizations.

Such a division would restrict the ability of governments to administratively expropriate industry specific assets and this will make the investors feel safe.

It should come as no surprise that public ownership in the electricity sector is frequently observed in the countries characterized by unstable politics, weak legal and regulatory institutions and slow growth. The pricing and investment policies of the publicly owned electricity companies are mostly determined by redistribution and macroeconomic concerns of the governments. As a consequence, electricity prices may not cover long-run costs and residential prices may be heavily subsidized. As a result of all this, inefficient generation, transmission and distribution stock and chronic electricity shortages are observed.

Therefore, to attract private investors to the electricity sector, sufficiently strong and legally enforceable guarantees that they are assured of a fair rate of return on their investments are needed. On the other hand, a firm that has these guarantees would have little incentive to invest prudently. Thus the regulatory problem can be viewed as devising a system that rewards prudent investments while punishing inefficiency.

Electricity cannot be stored, so supply has to be adjusted continuously. Technical and economic efficiency requires central dispatch and coordination of the investments in generation and transmission. So a second test for various regulatory systems is the extent to which they facilitate efficient wide-area coordination of grid expansion and use.

The optimal size of the area over which central dispatch is exercised or optimal degree of coordination depends on the benefits of central dispatch versus the costs of required structuring. The factors influencing the cost savings of central dispatch are the degree of variation in short-run avoidable costs, the reserve margin required to reduce risks of shortages and the degree of variation in demand over space and time.

2.3 Regulatory Regimes

There are three main categories of sector structures that would require different regulatory methods. In the first one, there is a vertically integrated franchised monopoly operating in all of the segments. This approach dismisses the possibility of competition in any of the segments, e.g. generation. Along with allowing a monopoly, the pricing and investment decisions of the monopoly are regulated via rate-of-return, cost-plus or price cap regulation.

The structural difference that separates the second approach from the first is that along with the vertically integrated monopoly, private independent generators are also allowed to operate. However, the transmission grid is still operated as a monopoly by the vertically integrated firm.

The third approach is completely vertically unbundling the sector and designing the generation, transmission, distribution and supply segments. This approach was first put into practice in the U.K. In this organization, regulation is avoided in the potentially competitive generation and supply segments whereas the natural monopoly segments, transmission and distribution, are subject to regulation.[7]

2.3.1 Vertically Integrated Utility and its Regulation

In the sector structure that forms the basis of the first regulatory method there is only a monopoly present and this monopoly operates in all segments of the sector. However, this company cannot freely set prices. The regulator limits the prices the monopoly can charge by a method called "rate-of-return regulation". The aim of this regulatory method is restricting the profits of the monopoly to a certain fraction of its total cost or capital base. By allowing a certain rate of return, the investor is in some sense guaranteed to make some profits and encouraged to invest in a sector where investments are large scale, capital intensive, immobile and highly sector specific. By limiting the rate of return of the firm, electricity prices, which are very important for all of its users, are kept under control. The elements that the firm can include in its total cost and capital base are also announced beforehand since they determine the allowed return.[8]

[7] Newberry and Green (1996).
[8] Gilbert, Kahn and Newberry (1996).

This sector structure of a vertically integrated private monopoly regulated by rate-of-return regulation is mostly found in the United States. However, including some parts of the United States, most of the countries following this approach are restructuring their electricity sectors and altering or abandoning this structure. However, some interests claim that this sector structure should be continued with some improvements. The argument for this is that unbundling of generation from transmission is costly and the efficiency increase from introducing competition into generation segment would not be worth incurring this cost. Another argument is that after unbundling the three segments of the sector, extracting the private information about the costs, especially transmission costs, necessary to correctly assess sector performance can be very difficult. The possibly very high cost of eliciting the cost information can be larger than the benefits of competition.[9]

2.3.2 Regulation of a Vertically Integrated Utility with a Fringe of Private Power Producers

In the second type of organization there is also a franchised firm operating in all three segments. This firm is a monopoly in transmission and distribution segments and the prices it charges are subject to regulation. However it is not a monopoly in the generation segment. Other firms are also allowed to generate. These independent generators may be allowed to transact with large customers and sell electricity to them directly. In some countries like the United States the franchised utility that is a monopoly in other segments is obliged to buy power from some independent suppliers meeting certain criteria at its avoided cost. There are two problems the regulator is supposed to

[9] Gilbert, Kahn and Newberry (1996).

resolve: (i) handling of the market share of the franchised utility (ii) regulation of the distribution segment.

There are two different mechanisms to decide on the market share of the utility in generation and the amount of investments the utility is allowed.[10] The first one is bidding for long-term contracts. In this mechanism the utility bids with the independent generators for long-term contracts and the outcome of the auctions determine the market share and investments of the utility. The difficulty here is that the bidding system involves multiple dimensions like fuel type, level of development, location on the transmission network, environmental impacts and operational flexibility, in addition to price. Thus it is critical to pick the criteria or mechanism that determines the winning bids. Greater knowledge of value possessed by the firm makes it difficult for the regulator to know whether the bid evaluation criteria have been slanted to favor the utility's project.

The second mechanism to determine the market share and investments of the utility is explicit allocation by the regulator on a case by case basis. For example, the utility might have some unique assets or capability that is unavailable or more costly if acquired from independent generators, like re-powering of old plants. In some situations where the utility does not decide to use this idle capacity on its own the regulator should be able to decide to utilize this facility. If the cost of making an idle facility usable is much less than building a new plant and the utility is not doing this for one reason or another, the regulatory commission should have the flexibility of deciding to put that facility into use. On the other hand, due to the economic benefits these facilities bring to their regions and the possible pressures from the industry of the fuels of these facilities use, this mechanism would be open to political manipulation.

The most important problem in the wholesale segment is the conflict of interest the utility is put into. That is, the utility is supposed to compete with private suppliers, yet still must act as the agent for consumer interest. What tools will be used to make the private utility, whose aim naturally is profit maximization, act in the interest of consumers or the whole society? The utility should also be expected to conceal the information about its operation from the regulators and use its monopoly control over the transmission grid to put independent generators at a disadvantage. Again, how will the regulator manage this conflict in the face of little information?

The main regulatory problem in the distribution segment is the multiplicity of goals. Distribution of electricity is assumed to be a natural monopoly and thus should be subject to franchise regulation. This raises the issues of efficient pricing and marketing, demand side management and investment in the distribution grid. In the absence of competitive pressures, how will the regulators encourage efficiency and promote social objectives simultaneously?

2.3.3 Regulation of a Franchised Utility in the Distribution Segment

There are three alternatives to regulating the distribution segment of the electricity industry. The first one is the traditional rate of return regulation. It has been observed to work well in the absence of serious efficiency problems and social goal agenda. For example it is observed that the investor owned utilities in the United States began

[10] See Gilbert, Kahn and Newberry (1996).

investing heavily in distribution networks in response to their declining market share in generation. Although this rapid growth in investment in the distribution system may be the result of long-delayed needs in that segment, it may also be an attempt to increase the capital base that determines the allowed returns in a protected market without considering its efficiency implications.[11]

The second approach to regulating the distribution segment is regulation supplemented with targeted incentives. Targeted incentives refer to rewarding the utility for achieving certain goals. These goals are usually about conservation and demand side management. There should also be incentives for efficient purchasing if the utility must purchase electricity from independent suppliers. The main practical problem is the combination of appropriate incentive levels and finding reasonable measures of performance. It is often difficult to find the amount of money that is adequate to induce desirable but not excessive behavior although there is a consensus that incentives are useful. Similarly, measurement of desirable performance is a difficult issue. It is challenging to determine whether good outcomes are due to luck and clever manipulation of the incentive scheme or efficient behavior.

A third approach to regulating the distribution segment is comprehensive incentive regulation. This is basically a price-cap regulation based on an external price index that is determined by factors totally exogenous to the firm's behavior. For example, the companies in Britain are allowed to increase prices by the Consumer Price Index (CPI) minus X. The factor X is determined by exogenous estimates reflecting anticipated

[11] The behavior of increasing the capital base that determines the allowed returns in a protected market in a way that is not compatible with economic efficiency is called the "Averch-Johnson" effect in the literature (see Averch and Johnson (1962).

changes in productivity and it is fixed for a period of time. In this period the utility increases its profits to the extent it reduces its costs. Thus it gives the utility incentive to be cost-efficient since the reduction in costs are fully internalized by the utility.[12] On the other hand, this method would fail to account for conservation and demand side management activities as long as they conflict with profit maximization of the utility.

2.3.4 Regulation of the Vertically Unbundled Electricity Sector

A third possible regulation of the electricity industry is a radical restructuring like in the British model. The sector is fully vertically disintegrated. Wholesale generators sell their power to the grid at prices determined in a national spot market. The local distribution companies purchase electricity also from the grid again at the spot prices in the wholesale market, plus a premium to cover the transmission costs. It is also possible to enter into long-term and fixed-price contracts to avoid the risk of price volatility. Almost all electricity purchasers mitigate their price risk by entering into such contracts.

2.4 Regulation of the Transmission Segment

Transmission capacity and access are the most significant issues in a Britain-like electricity industry organization that is vertically unbundled. All of the wholesale trade occurs through the transmission network. If private producers have fair access to the transmission network then they can raise capital without entering into long-term contracts. There are four main approaches to the regulation of the transmission segment.

[12] Gilbert, Kahn and Newberry (1996).

The first approach neglects the unique properties of the electricity sector and the transmission network. The owners of transmission facilities are allowed to decide upon terms and conditions without regulatory interference. In the countries in which this approach is followed it is observed that it did not result in much access by third parties. However, joint ownership was observed due to economies of scale and shared ownership in generation facilities. Since utilities are in a position to appropriate all the benefits, private ownership gives strong incentives for efficient transactions. However, the issue of loop flow balances this positive property. Some hard to foresee electrical properties of transmission networks may result in unintended effects, affecting third parties who are not involved in the exchanges at all. This is difficult to price and it interferes with scheduling bilateral transactions. Loop flow also interferes with incentives for investment in new transmission facilities under a private ownership paradigm since investment can have production externalities (negative or positive) on other parties. Under such circumstances and private ownership, uncoordinated investment decisions aimed at profit maximization cannot be expected to be the “right” decisions.

A second approach to the regulation of the transmission segment is the formation of Regional Transmission Organizations and coordination of transmission via reciprocal arrangements between the firms in the pool. It is possible to see these organizations as power pools. In fully integrated power pools the dispatch is done centrally, however this is not necessary for a power pool. In the absence of central dispatch, the power pool operates like a brokerage service where parties post buy or sell offers and transactions occur through bilateral arrangements. A successful Regional Transmission Organization at the minimum requires a transmission resource plan, a cost model for this transmission resource plan and mechanisms to calculate the incremental cost of additional demand for transmission services and allocating the fixed costs to the members.

The third approach to transmission regulation is mandating the access charges centrally. The transmission facility owners have to offer access to the network for all parties at the centrally determined prices. Though it is obvious that transmission services provided to third parties have opportunity costs, it is very difficult to estimate them in practice. One view on these costs is that the access price is going to be very high, practically eliminating all transactions and enhancing the market share of the utility. According to a contrary view the access charge is going to be very low and thus it can just be ignored. A compromise solution to access pricing would be charging long run incremental cost. However this would usually be too high since generally a user's incremental cost to the system is much lower than the average unit cost of capacity addition to the system. Furthermore, this price does not provide users with the right signals for expansion of the network. A more sensible solution would be setting a price cap for access at long run incremental cost and then letting the users negotiate the final price. However, in this method the asymmetric information problem about the long run incremental costs between the utility and the regulator would continue to exist. Since it is possible for transmission demand to exceed capacity at times, the grid authority is obliged to come up with a capacity rationing method. It can be a price or non-price mechanism to allocate scarce capacity.

The fourth possible regulation regime is nodal pricing. Different access prices are set at different transmission points depending on the different incremental costs added to the system. The economic efficiency properties of this method are not yet completely studied and practical applications of it can also be complicated.

Evaluation of these four regulatory alternatives in terms of some desired criteria results in the following:

Efficient Dispatch:

The dispatch is going to be central thus efficient in the first alternative.

Regional Transmission Organizations can achieve efficient dispatch to the extent they can centralize dispatch.

Nodal pricing assumes central dispatch since otherwise nodal prices cannot be reliable indicators of transmission costs.

Mandated access policy is risky because it can easily displace efficient production with inefficient production.

Reliability:

Since the reliability of the system is determined by the efficiency of the dispatch, the methods will be ranked just like they are ranked in efficient dispatch.

Efficient Investments:

As long as the coordination among the transmission owners who are affected by expansion decisions is incomplete, the parties do not have the right incentives to invest in the grid. Since such a complete coordination would be rare, this alternative should not be expected to lead to the efficient amount of investment.

Nodal pricing is known to provide efficient signals for new investments only if the transmission cost function is well behaved (technically speaking, globally concave). However, empirical studies show they usually don’t possess this property.

A Regional Transmission Organization can be thought of as a forum for evaluation of alternatives to expand the network in a cost-efficient manner. However, it is difficult to reach the efficient level of investments since each member will try to minimize their costs and thus behave strategically and opportunistically. On the other hand, Regional Transmission Organizations are expected to improve on the first alternative by resolving the impacts on neighboring transmission systems.

The performance of the alternative where centrally mandated prices are used depends very much on the institutional details. If transmission service purchasers have the right to demand expansion when the service is unavailable then the result may be too much expansion or expansion at the wrong place or time and in the wrong amount. On the other hand, if the transmission owners are not obligated to expand then centrally determined prices that allow the owners to just break even could result in too little investment.

2.5 Value of Competition in Regulated Industries

2.5.1 Independent generators as auditors

Recent developments in the theory of economic regulation focus on the issue of incomplete information. The principal-agent theory views regulated firms as the agents of the regulatory commission where the regulatory commission is the principal that is acting in the interests of the society as a whole. The agent is under the control of the principal but the principal can observe the actions of the agent only incompletely. In such a setting, the competitive fringe can be a valuable tool for the regulator by helping to uncover the true costs of the regulated firm.

For example, in a framework where avoided costs are used, private producers have great incentive to uncover the avoided costs of the utility since that is the basis on which they will be paid. Since avoided costs are very important information for other regulatory goals as well, uncovering these costs is critical.

However, the fact that the independent generators serve as auditors does not obviate the need for regulation. Since independent generators also follow their own interests, they will not always reveal these avoided costs even if they uncover them. The information reflected and proposals made by the independent generators will be determined in accord with their strategic goals, whether or not the utility has inefficient planning or operations. They will always have an incentive to argue that the demand for electricity is very high, it is very costly to meet this demand and the avoided costs are very high no matter what the true costs are.

Another factor limiting the efficiency of controlling the regulated firm through independent generators is the ultimate market share of these independent producers in the sector. What will happen if these generators are capable of greatly increasing their generation and capture a big share of the market? In such a situation the audit function of these private producers would be unnecessary and useless.

2.5.2 Competition in the wholesale market

Can the wholesale electricity market be competitive? If the answer is yes then regulation of this segment will eventually come to an end. If the answer is no then the most important decision a regulatory commission has to make is whether protecting the independent private producers is worthwhile to preserve the benefits of auditing and increased potential for technological innovation in the sector.

A major factor that will determine the answer is the role of unregulated affiliates of the utility in the sector. The concern here is that the affiliates of the utility can become a dominant factor in the unregulated power market. The utility can keep the prices in this market high via its affiliates and ensure enormous profits by purchasing from its affiliates. The regulation method that would allow this is the rate of return regulation where costs can be reflected in the price and this can be prevented by a price-cap regulation. There is also a danger of reciprocal dealing where two different utilities can buy expensive power from each other's affiliates.

Other forms of collusion are also possible in the presence of independent generators. There were high hopes on competitive bidding for long-term electricity purchasing contracts at the beginning. However, these did not result in the expected impacts. Indeed, it is observed that they raised the entry barriers for small generators.

A possible development that would prevent regulated franchise utilities from having a large market share in the wholesale electricity market through their affiliates is the entry of the big industrial companies into the electricity generation market. If this entry does not materialize, then either we would abandon the competitive generation segment approach or try to support it via attempting to somehow regulate the utility affiliates. However, this seems to be doomed for failure since usually the legal authority and the information of the regulator will be insufficient to monitor these firms.

2.5.3 Regulatory policy in a regime with independent power generators

Should the growing market share of independent generators lead to more or less regulation? The view that the role of regulation should increase is gaining ground due to increased emphasis on demand side management. Moreover, an approach that argues that the central authority should be given more say on generation capacity planning in order to avoid increases in costs to be added to the capital base and disputes on this began to find some acceptance in some states in the U.S.A. like Wisconsin.

Another development that increases the role of regulatory commissions is the increase in the number and type of investments done through auctions in the electricity sector. The difficulties in evaluating bids and setting the criteria for determining winning bids has increased and this led to a situation where each auction is evaluated separately on its own. With the increase in the number of auctions, more situations started coming up for the regulatory commission to interfere with.

Also, the methods that minimize social costs and that minimize ratepayer costs are different. Examples of this are demand side management and environmental impacts. This also calls for an expanded role for the regulatory commissions.

2.6 Utility as the residual risk taker

The regulated utility will still have the obligation to serve even in a framework where private generators play a substantial role. Planning activities of the utility will now be more difficult since both end-use demand and supply of the fringe is uncertain. Projects of the private power generators may fail in the development or the operational stage. When the utility needs to meet an unexpected capacity need it cannot select the most efficient source of supply. For these cases either the utility should be able to purchase power from neighboring utilities at reasonable prices or contractual remedies must be established to make the failed companies compensate the utility.

3. Post-1990 Developments in Electricity Sector Regulation: Experiences of USA, Britain and Latin American Countries

3.1 United States of America[13]

There are many organizational forms in the U.S. electricity sector today consisting mainly of private, municipal, public and federal ownership. The sector is subject to regulation at the federal and state level. Although the dominant model in generation and distribution is private ownership, the role of the public sector is also significant. The private companies account for 76% of installed capacity, 77% of generation and 79% sales.

The regulatory structure that regulates the section of the industry belonging to the private sector has three main themes: (i) geographically distinct franchise monopolies operated by vertically integrated companies; (ii) price regulation aimed at limiting monopoly profits; (iii) an obligation to serve all customers.

The dispute on the origins of regulation is not yet resolved. Regulation by the state instead of the federal government was demanded by the utilities themselves. Therefore, whether regulation arose to limit monopoly profits or to make it easy to raise capital for

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[13] For more detailed information on the historical development of the electricity industry of the United States, see Gilbert and Kahn (1996).

private firms has been an issue of controversy. A study conducted on the utilities in the states that adopted regulation first shows that these firms had lower profits and rates when regulatory policies began, compared to the other utilities in the country.[14] The profits of and the prices these same firms could set increased faster than the other firms. It was also observed that during the 1920s, the prices of the companies subject to federal regulation were falling much faster than the prices of the firms subject to state regulation.

Therefore, regulation at the state level seems to be a policy that protects the producers rather than limiting excessive prices. However, one cannot infer from this observation that consumers were harmed by this policy. Local governments might have thought about foregoing short run benefits of competition and giving the franchise monopolies incentives to invest and utilize economies of scale by restricting entry to the market. It was observed that investments in the sector exploded after switching from federal to state regulation. Large productivity gains are also reported in parallel with the investments. Therefore, the local governments might have intended to supply cheaper and more reliable electricity to the consumers by helping the industry grow fast, despite the appearance that their policies were heavily pro-utility.

There were serious disputes about public interference in industry structure and regulation before and after the Second World War. These controversies were carried to the national level for the first time when the Republican Party nominated Wendell Wilkie as their presidential candidate for the 1940 elections. Wilkie, who had close ties with a holding company doing business in many states, was against public ownership. These

[14] See Jarrell (1978).

disputes did not end despite the fact that Wilkie lost the elections. Election of Eisenhower in 1952 signaled that the expansion of federal investments in the electricity sector would stop, and indeed they did after the completion of the projects that began before 1950. While this was taking place at the federal level, expansion of the cooperative and municipal sectors continued.

The share of municipalities, cooperatives and the federal government are 14%, 7.2% and 2% in retail sales; 8.8%, 4.4% and 8% in total generation; and finally 10.4%, 3.7% and 9.5% in installed capacity, respectively. 8.2% of all electricity firms are private, 61.8% are municipal, 29.6% are cooperatives and 0.3% are federal. It follows that average generation, sale and installed capacity of private firms are well above those of municipalities and cooperatives.

The dominant regulatory method after the Second World War in determining the electricity rates was traditional rate-of-return regulation. This form of regulation attempts to set prices so that total revenues cover total costs. Since 1980s this approach has often been replaced by price mechanisms that give incentives for more efficient generation and investments. This replacement process is ongoing, however as of today a significant portion of private utilities are still subject to rate-of-return regulation. Starting with the oil shock of the 1970s, fuel and non-fuel costs are calculated separately in determining the revenue requirement of the firms. The distribution of these costs to consumer groups and the rates to be applied to raise the required revenues from those consumer groups are determined after total costs are determined. In earlier years these rates were set on an accounting basis and no attention was paid to the marginal costs. After the 1980s, thanks to the increased influence of economists in the commissions, the prices started to be determined more in line with the marginal costs. Marginal costs are mostly used to determine the rates for large industrial and commercial customers whereas residential rates continue to be subject to rate-of-return regulation.

Although it should be expected that the prices set according to rates of return would depend only on the costs and not on user group, region or industry type, it was observed that exceptions to this principle were not rare. Some states subsidized only low-income residential customers whereas other states extended this subsidy to all residential customers. Agricultural customers usually pay low prices for electricity that are difficult to justify on the basis of costs. Some geographical regions and industries get low electricity prices as an incentive for economic development. Moreover, prices of the public sector are lower than the private sector prices.[15] The main reasons for this are that public sector companies don’t pay taxes and the federal government sells cheap power to them from its hydro plants. Furthermore, the commercial customers are being discriminated against by both private and public firms. In comparison with the costs of supplying power to these groups, the commercial customers are paying higher prices than the residential customers.

Significant amount of wholesale electricity trade takes place between electricity companies. There are two types of power markets: firm power market and economy exchange market. Firm power refers to the case where the seller has the obligation to transmit the power and has to keep reserve capacity that would ensure availability. This type of trade takes place between two neighboring firms directly connected to each other with high-voltage transmission lines since having to use a third party's transmission lines to deliver the promised power increases the chances of interruption that the seller can do nothing about. On the other hand, economy power exchange does transactions on hourly basis and the contracts do not bind the seller. The buyer may not always find all the power it needs in this market. The difference between these two markets is the payments made for the fixed capacity. If the buyer wants some electricity to be kept ready for her, she makes a fixed payment for that amount to be kept available to her and then pays some more if she indeed buys that power. There are no fixed capacity payments in the economy exchange since the amount of electricity that can be bought is not guaranteed.

Retail sales are subject to regulation at the local level. On the other hand, all wholesale transactions are subject to regulation of the U.S. Federal Energy Regulatory Commission (FERC). The justification for federal regulation is that wholesale transactions occur on an interconnected grid and fall under federal jurisdiction for interstate commerce.[16] FERC regulation focuses on reasonable pricing rules and it has in practice been weak compared to regulation at the retail level. FERC exempts power pools from regulation because terms and conditions of trade in these organizations are defined by the rules that are already reviewed by the FERC. Size of transactions realized within the power pools range from 1% (Western System Power Pool) to 10% (New York Power Pool) of total transactions. On the other hand, total amount of

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[15] Gilbert, and Kahn (1996).
[16] See, for example, FERC Order 888.

purchased power, which is also called sales for resale, is just above one third of total generation.[17]

In the 1970s and 1980s the disparity between supply and demand was huge. In the 1970s demand was dangerously close to available supply. First, capacity growth slowed down because of long construction times of large capacity plants and delays or cancellations of nuclear plants due to tighter environmental regulations. The oil shock of 1973-1974 made the coal and nuclear plants more attractive and the rise in interest rates in this period led to a decline in investment demand. At the end of the 1970s short term marginal costs were very high, reserve margins were very low and unfinished investments were excessive. In 1980s the process was reversed. Economic stagnation slowed down the growth of consumption demand. Oil prices began to decline. A major portion of new plant projects got cancelled or stopped. Out of the 107 nuclear plants ordered between 1972 and 1974, 38 were cancelled between 1975 and 78 and another 48 were cancelled between 1979 and 1982. Despite all these attempts to adjust supply there was excess capacity until the middle of the 1980s. Growth rate of generation capacity continued to decline until 1990. On the other hand, investments in the distribution segment increased by 40% in the same period. No significant investments were made in the transmission facilities. The rationale for this is very understandable since expanded transmission facilities would make it easier for independent generators to reach large customers and put competitive pressure on the utilities. The utilities could not be expected to heavily invest in the transmission network under these circumstances.

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[17] Gilbert, and Kahn (1996).

The U.S. electricity industry has been in the process of restructuring since 1997. This process is now limited to a few states. These states are the ones where the electricity prices are high like New York, New Jersey, Massachusetts and the leader of the effort, California.[18] We are only at the beginning of this process and it is difficult to tell how well it is working and what shape it will take in the future. However, the tendency is to form a spot wholesale market like in Britain along with forward energy and options markets to hedge price risk. It is understood that transmission will continue to be recognized as a natural monopoly.

3.2 Britain[19]

Prior to the First World War the British electricity industry had a dispersed structure. On the one hand, there were small generation facilities of the municipalities and a distribution network for each and on the other hand, there were private generators who were generating on slightly larger scales. Since economies of scale were not being utilized the costs and thus prices were high and there was not much demand for electricity at these prices. Due to little and stagnant demand the capacity and generation were not increasing. Therefore, the electricity industry of Britain was a very inefficient industry before the First World War. This situation became obvious via outages, which led to the discussions about the potential role of the government. With the law passed in 1926 in the face of stiff opposition, Central Electricity Board (CEB) was established. This legislation put CEB in charge of building and operating the grid,

[18] Joskow (2000).
[19] For more detailed information on the evolution of the British electricity sector, see Newberry and Green (1996).

doing central dispatch and coordination of new investments. The role of the existing electricity companies was limited to building and operating generators and locally distributing power. The national grid was completed and put in operation in 1933. By 1938, overall grid savings from interconnection rose to 11% of total payments of electricity. Reserve margin was cut back from 40% to 10% and this amounted to 11% of annual capital costs. Hannah (1979) calculates that real return on the grid investment was more than 6% per annum, which was well above the cost of borrowing, excluding any postwar benefits of the grid. Competitive innovation was fostered by leaving the design and construction of power plants to the private sector's undertaking. By 1935, some stations had thermal efficiencies of 27%, comparable to best practices in the U.S. Generation grew very fast between 1926-1935. Supply of the public sector rose 70%. 48% of this was financed by profits and the rest from low-interest bonds. Despite the depression going on in the world, credit availability for the fast-growing sector was not an issue. The private companies that were doing one third of the generation had to borrow with higher interest rates since they did not have the government guarantees on their loans and did not have any tax exemptions. This did not turn out to be a deterrent, either. The share prices of these companies stood in premium even during the 1929 crisis due to the facts that they were not subject to a tight regulation and they were seen as companies with very bright futures.

The municipality undertakings were subject to price-cap regulation but the caps were set ineffectively high. The residential rates of municipal companies were 25% lower than those of private companies, taking into account that the ratepayers were voters as well.

Private companies were also regulated by usually ineffectively high price caps. But at the same time they were subject to profit regulation. They were allowed to increase dividends only if they cut prices. This was also ineffective since prices were lowered to attract commercial customers anyway, or because firms could circumvent it by issuing preferred shares instead of paying dividends. When selling to the grid, they were rate-of-return regulated. But they inflated costs by borrowing money or purchasing inputs from unregulated subsidiaries at excessive rates. There was no problem of regulatory commitment during this period of rapid growth and cost reduction due to autonomous and commercial nature of the CEB. This period showed the value of public enterprise in achieving coordination in the natural monopoly element (grid and dispatch) while accommodating a competitive and diverse generation business.

The distribution segment was considered a natural monopoly. It is calculated that coordination between distribution networks would have saved as much as the transmission grid did, but it was not realized due to special interests and political opposition to nationalization.

By the Electricity Act of 1947, the whole electricity supply industry was nationalized and British Electricity Authority (BEA) and twelve Area Electricity Boards were established. These institutions replaced the CEB, Electricity commissioners and 537 authorized undertakings.[20] In 1958 Electricity Council and Central Electricity Generating Board (CEGB) were established. For the next 32 years CEGB took over generation and transmission and sold all of its output to 12 Area Boards, under the terms of a Bulk Supply Tariff. Each area board then distributed and sold the electricity to the consumers in its region using its own tariffs. The Electricity Council consisted of the chairmen of the thirteen boards, two CEGB representatives and up to six central members. The council had no formal control on the industry and its duties were limited to advising the minister and assisting the industry coordination. It is observed that there was excessive intervention into the sector by the ministers after nationalization. No meaningful financial sanctions could be designed and applied to the industry since it was state-owned.

The main concerns of the industry during this period were the obligation to meet all reasonable demand and the need to obtain the minister's approval for all of its programs. The level of investment was determined by the required capital stock implied by demand forecasts and reliability standards. Thus the effect of rate-of-return regulation was not on the investments but merely on prices. There were incentives to over-invest since political and social costs of outages to the public administrators were much higher than the cost of building excessive idle capacity. Public ownership was effective for coordinated expansion of the sector in the early period but inflexibilities of a centrally planned CEGB were not effective to respond to the uncertainties in demand after 1973. Until 1965 the demand was systematically underestimated and power outages occurred frequently. After 1965 demand was overestimated systematically. However, it should be noted that demand forecasting was a very difficult task and each and every country in the world experienced the failures Britain did.

The oil shock of 1973 and miners' strikes in the 1970s caused concern about the inputs of the electricity supply industry and led the government to search for alternative generation methods. A nuclear program was put into effect in this framework. This

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[20] Newberry and Green (1996).

program, whose details will not be discussed here, turned out to be a complete failure. Nuclear plants invariably took longer to build and cost more and were less reliable than planned. It was also realized that operating nuclear plants reliably required specific skill sets which Britain did not have at that time. Even the variable costs of nuclear plants were higher than other types of plants, which was unexpected as well. Despite all the efforts these plants could not be privatized during the privatization program in 1990. However, it should be mentioned that Britain is not alone in its failure of nuclear plant experience. The U.S. nuclear energy attempts usually were also disappointments, though not to the extent of the British experience.

The Energy Act of 1983 forced Area Boards to purchase electricity from other entrants at avoidable costs. This led the CEGB to alter the Bulk Supply Tariff to make the demand charges lump sum and lower the avoidable cost of CEGB power. Due to this alteration, no entry occurred in the absence of long-term contracts. Electricity prices declined until 1973, rose sharply in the next ten years, and then declined again. Fuel costs were the main determinants of prices in the postwar era. It is observed that commercial customers were paying more compared to their average costs, likely because they neither had votes nor bargaining power.

Low growth of total factor productivity in the sector was likely due to reluctance to reduce excess employment in the face of collapsing demand growth. This evidence is consistent with the widely held belief that nationalized industries put more weight on employment than profits. In fact, privatization done in 1990 showed there was excessive employment in the sector. The annual rate of return on investments in the electricity sector before 1990 was a mere 2.7%. This is quite low compared to the rest of the

British industry. This result was probably due to under-pricing, excessive costs (especially of nuclear plants), excessive employment in the sector and the very high prices paid for British coal.

The most distinguishing characteristic of the nationalization period is extremely high investment costs. This is so even after discounting the overinvestment due to poor demand forecasting. Under CEGB, power stations cost 50 to 100 per cent more than in other industrialized countries, took as much as twice as long to commission and rarely achieved the economies of replication that a large buyer might have expected. One reason for excessive generation costs was the high cost of domestic coal, which in turn was caused by lack of international competition in the coal market, monopoly power of National Coal Board (NCB) and the government's refusal to allow CEGB access to the international coal market. The reluctance to import fuel, reluctance to allow the cheap North Sea gas to be used for generation and failure to restructure NCB greatly increased the cost of power.

There were two main motives for the privatization of the industry in the 1990. First, in some European countries and the U.S., such industries operated under private ownership with apparent success. Second, there was a belief that nationalized industries were inflexible, bureaucratic and secretive and largely out of political control. By the Electricity Act of 1989, CEGB was separated into four companies: National Grid Corporation (NGC), PowerGen, National Power and Nuclear Electric. NGC was responsible for transmission organized as a regulated natural monopoly. It was transferred to joint ownership of the Regional Electricity Companies (RECs), which were formerly the twelve Area Boards. The new structure divided the sector into 4 segments:

generation, transmission, distribution and supply. Generation accounts for two thirds of total costs, transmission accounts for 10%, distribution 20% and supply 5%. Supply is further divided into sales to a franchise market of small customers, restricted to local RECs, and a non-franchise market of large customers, which can be served by any company acting as a private supplier.

The fact that no private firm entered the bulk supply market in the presence of CEGB led the government to break it up. Transmission and distribution were accepted as natural monopolies and were subjected to regulation by the Office of Electricity Regulation ("Offer"). However, generation segment was not recognized as a natural monopoly and was opened to competition. These firms were not subject to detailed regulation and were accepted to be competing against each other and potential entrants.

This spot market or the power pool comprises the most radical part of the 1990 reforms. Each morning the generators report the available facilities and at what price they would operate them. The price schedules consist of one capacity commitment price and up to three per unit prices increasing in the megawatt-hours to be generated. Furthermore, all users of the transmission grid submit their demand forecasts at each node for each half-hour of the next day. In light of this information the NGC determines by a computer program which generator will run and generate how much for each half-hour. Thus NGC initially solves the dispatch problem by ignoring transmission congestion. When some stations cannot be run due to transmission congestion, more expensive stations are called upon. According to this revised schedule, the nodal prices are set.[21]

This new system worked very well and it is also considered a technical success. Many firms entered the market and generation increased almost by 20% between 1990 and 1996. The most important factor in the entry of many suppliers is argued to be decreased risks in the sector due to long-term contracts.

Economic efficiency has several dimensions. The efficiency problem in the short run is whether power is generated at least cost, respecting the transmission constraints. In the medium term, it is whether the industry is using the right input mix. And in the long run, it is whether the right amounts of investment are undertaken at least cost, at the correct locations and with the best technology. In a field like the very capital-intensive electricity industry, the biggest impact of restructuring should be observed in investment efficiency. It is difficult to compare the performance of the vertically unbundled sector with the old CEGB regime. The combined-cycle gas turbine stations that are being used since 1990 reach the minimum efficient scale at a rather low output level and they take a very short time to build. Such technology was not available in the plants of CEGB and thus technological changes make the post-1990 era more advantageous. On the other hand, CEGB regime was trying to develop and implement new technologies if they were expected to reduce costs. Private companies usually don't take this risk and use proven technologies. In countries with a relatively small market (compared to the U.S., for example) like the U.K. the second alternative is more likely to be the optimal strategy.

[21] This system is much more sophisticated and detailed than explained here. However, because these are technical details that change often and this kind of structuring doesn't seem imminent for Turkey, we are not getting into the details of this system.

Therefore, one would expect investment efficiency to rise after privatization. Although it has not been long since privatization, the first observations are in line with this expectation.

The data at hand are insufficient to evaluate the operational efficiency. The size of two privatized generation companies allowed them to set prices above marginal costs and this caused a large welfare loss. A competitive long term contract market with a lot of entry can force these companies to decrease contract prices and keep them at the long-run marginal costs of potential entrants. Competitive pool prices can induce investments by being above long run marginal costs when there is a capacity shortage. When there is excessive idle capacity, the prices fall below long run marginal costs. The prices moved in line with expectations in the beginning of 1990s. Due to the prevailing contracts, electricity and coal contract prices were low until 1992. After most of these contracts expired in 1993, the prices rose sharply due to capacity shortage and large amounts of investment were undertaken in the following three years. This shows the sensitivity of prices to capacity and market participants to prices and suggests that the new system is working well.

If pricing is one component of efficiency, reducing generation costs is an even more important one. Under this new system each generator has an incentive to reduce their costs and that is precisely what happened. The generators cut their labor force by half and shut down their research labs in the three years following privatization. Nuclear Electric, a public company, greatly increased its efficiency to be able to compete with the private generation companies and took its place in the competitive market. A negative feature of the system is that the transmission pricing implemented now cannot relate the prices to transmission losses. Because thermal losses are directly proportional to the square of the flows on a line, the marginal cost of using a transmission line between two points is an increasing function of flow. In the system today all producers sell to the grid at the same pool price irrespective of their location. However, differences between generators due to losses can be as high as 10% of the pool price. According to the calculations in Green (1994) taking into account transmission losses can reduce total costs by 2 million pounds per annum. However, this policy change would create big winners and losers and thus it can be difficult to implement since the losers would object.

3.3 Argentina, Brazil and Uruguay[22]

In all three countries the electricity sector is comprised of publicly owned companies. In Uruguay there is only one company in the sector. Private sector participation is almost nonexistent despite the fact that it is not prohibited by law. In all three countries, especially in Brazil, the share of self-producers in generation is high. The self-generators in Argentina are not connected to the transmission grid whereas in Uruguay the law prohibits them from being connected. Thus, these generators can only serve the load on the site and cannot sell the excess power into the grid.

The regulatory structure is not transparent in either of the countries. For example the electricity prices are determined by the cabinet despite the fact that there is a governmental agency with the duty to do it.

[22] For a more detailed analysis of the restructuring processes of Argentina, Brazil and Uruguay electricity sectors, see Spiller and Martorell (1996).

In Argentina, Ministry of Public Works and Services, through the Office of the Deputy Secretary of Energy, is charged with controlling the electricity sector's planning, licensing, tariffs and development. However, the tariffs and investment programs were determined by the Ministry of Economics in practice. In a law passed in 1991, the Deputy Secretary of Public Enterprises of the Ministry of Economics took the power to control the operative aspects of the public electric firms. The sector is being operated according to the Electricity Energy Law passed in 1960. It does not stipulate a method to compute tariffs or a regulatory structure. It specifies that the regulatory regime should be determined for each license separately. It is also very confusing in its treatment of returns on capital and many other concepts.

There is not a separate agency responsible for regulation of the sector in Uruguay. The prices and investment plans of the electric company must be approved by Office of Planning and Budget of the Presidency. The tariffs are set by the executive power with extensive intervention by the Ministry of Economy and Finance.

There are several agencies involved in determining the tariffs and investment policies in Brazil. In principle, the National Department of Waters and Electric Power is responsible for setting prices and contractual conditions. However, in practice, the Secretariat of Planning controls investment programs and intervenes in the determination of electricity rates.

Because these three countries had high inflation rates during the 1970s and 1980s, the governments had the tendency to manipulate electricity prices as part of anti-inflation programs. Thus during hyperinflation periods the real electricity prices fell sharply, but they went back up sharply after. In all three countries the investment decisions were made by the central governments and long-term investments were curtailed during periods of macroeconomic adjustment and political instability.

Public ownership, nontransparent regulatory structures and direct intervention by the administration in the pricing and investment decisions of the electricity companies, along with unstable political regimes, produced relatively similar pricing policies in all three countries. Prices were below long-run average costs, tariffs discriminated by end-user and pricing is meant to be uniform across regions as much as possible.

3.4 Chile

Chile went through a radical restructuring concerning its regulatory process and ownership structure in 1978. Pre-1980 tariffs were based on a rate of return method. Now regulated tariffs are determined on long-run marginal cost principles with rates for large customers and wholesale rates being determined in the open market. Before the 1978 reforms the rates were directly determined by the government. Now the rates are set through a mechanism that does not allow government intervention in the short run.

The distinguishing characteristic of this restructuring is the unbundling of local distribution from generation and transmission. Specific parameters of regulation of distribution companies vary depending on their number of customers. The large generation companies were privatized by selling shares to the public whereas smaller ones (less than 50 MW) were sold directly by the government through auctions.

The restructuring was successful. Prices are closely related to long-run marginal costs, private investors invested in all areas of the sector and electricity companies are widely held by the public and are traded in the local stock exchange. The electricity market in Chile is very dynamic. There is a lot of trade between generation, transmission and distribution companies through contracts. The regulatory system sustained the financial crisis of the early 1980s and proved to be resilient to government and interest group pressures. The fact that shares of major electricity companies were widely held among small investors and pension plans may have contributed to the stability of the regulatory regime. The success of restructuring is mostly due to the nature of the regulatory regime developed after the creation of the National Energy Commission (CNE) in 1978.

In contrast with the other three South America countries, the regulatory system of Chile is very transparent. CNE is the main regulatory institution responsible for developing and coordinating investment plans, policies and regulation for the sector. It is organized as a decentralized entity directly under the Office of Presidency. It is made up of seven ministers and an Executive Secretary. The Ministry of Finance approves its budget annually.

CNE has two basic functions. First, it determines the prices the regulated firms will charge. These prices are subject to the approval of the Ministry of Economics. However, the administration can only interfere with major retail tariffs. Firms have recourse to the courts if the proposed prices deviate excessively from long run marginal costs. Second, it coordinates the independent generation, transmission and distribution companies in the interconnected systems.

There are two basic approaches used in rate determination. First, it is expected that, in the absence of strong economies of scale, competition at the generation level will bring wholesale prices in line with the system long run marginal cost. Therefore, large customers were allowed to bargain with the generation companies to get the type of service they want. Negotiations usually involve interruptible or firm service, peak or off-peak service and partial joint investments in transmission lines.

Second, it is recognized that the distribution and supply of electricity exhibits large economies of scale. CNE regulates this segment by a price-cap method. These caps are meant to be proxies of long run marginal costs. They are composed of three parts: long-run marginal energy and power costs, long-run marginal transmission costs, and value of distribution added.

The regulated energy and power prices determined by CNE are used for two purposes. On the one hand, it determines the price cap for power sold to distribution companies and on the other hand it forms a part of the maximum rate the distribution companies are allowed to charge to their customers. Because it makes the price the generation companies can charge the distribution companies predictable, it provides generation companies with investment incentives. However, it reduces the incentives for the distribution companies to search for the lowest cost electricity supplier. But whenever the regulated price determined by CNE deviates from wholesale prices by more than 10%, they are adjusted automatically. Therefore inefficiency of the system cannot be large.

When determining regulated transmission costs, CNE takes into account the location of the distribution company relative to the center of the system, capacity of the distribution system and whether the flow is from or to the reference bus (which is Santiago in Chile). Transmission costs plus energy costs determine the nodal prices. The transactions between transmission and distribution companies take place at these prices. Nodal prices are adjusted every six months to match the average of the expected marginal costs over three years. They are computed using indexing formulae that depend on fuel costs, equipment costs, dam levels, exchange rates, etc. As a rule, the pricing calculations are repeated whenever energy or power charges increase by more than 10%. Moreover, it is not allowed for any nodal price to be above more than 10% of the average wholesale electricity price.

Regulated distribution costs are derived from a typical system efficiently adjusted to the population size and density of the territory. There are three distribution sizes: high, medium and low density. For each customer, value added of distribution is allowed to depend on only three factors: administrative costs including invoicing and customer service, power demand costs at a peak time (which includes the cost of expanding the distribution system and buying an additional unit of peak electricity) and costs of losses from the distribution. Thus retail prices depend on four factors, none of which is based on actual operating costs of the distribution companies. Therefore the distribution companies have a great incentive to reduce their costs so as to increase their profits. The value added of distribution is recalculated every four years.

The principles behind Chile's electricity pricing methods can be summarized as follows. Prices should be close to long run marginal costs, they should not vary by end-use and they should depend on the nature of the location. The fact that prices are close to marginal costs do not prevent electricity companies from making reasonable profits. The regulatory regime of Chile has succeeded to attract very large sums of private investment into the sector. As of 1989, the installed capacity of the public sector was 586 MW whereas private sector had 2,902 MW of installed capacity.

The electricity sector of Chile displays dramatic differences from the electricity sectors of other three South American countries. In Argentina, Brazil and Uruguay, the ownership of the sector is heavily public and pricing rules are far from covering total costs and being related to marginal costs. On the other hand, Chile's system was based on competitive markets and a regulatory regime based on legislation that attempts to replicate marginal cost pricing. Electricity prices in Argentina, Brazil and Uruguay displayed huge fluctuations whereas this was not the case in Chile where prices moved in a slow downward trend. Argentina, Brazil and Uruguay displayed big investment bottlenecks, especially in distribution, whereas investment demand in Chile for each segment was consistently strong. The price dispersion in Argentina, Brazil and Uruguay among regions was almost nonexistent whereas in Chile, according to marginal cost principles, there were differences between regions in terms of prices. Tariffs in Argentina, Brazil and Uruguay discriminated among users depending on the nature of their use whereas customers were given different tariff structures that they could choose from.

The main source of electricity energy all four of these countries is hydro. So differences between outcomes of the electricity sectors stem from the regulatory regimes in these countries. Chile's regulatory system is based upon very specific legislation that guarantees substantial independence from the political process whereas prices and investment decisions in Argentina, Brazil and Uruguay have been determined at the cabinet level.

4. Electricity Sector in Turkey

4.1 Historical Development[23]

The first electricity generator in Turkey was built and operated in 1902 in Tarsus by a Swiss-Italian group. With this first private sector investment, electricity was produced from a generator of 2 kilowatt capacity and distributed to the town. After that Thessalonica, Damascus and Beirut, Ottoman cities at that time, were electrified again by the private sector. Electrification of Istanbul was done in 1914 by the Silahtaraga plant built by the Ottoman Electricity Corporation which was a joint venture of the Hungarian Ganz Corporation, Banque de Bruxelles and Banque Generale de Credit. The Silahtaraga plant was also the first coal plant in Turkey. In 1913 the "Law on Privileges Regarding Public Benefits" was passed to regulate the franchises granted to the foreign corporations, which is still in effect. The Ottoman Electricity Corporation continued its operations until July 1st, 1938 when it was bought by the state.

When the Republic of Turkey was established in 1923 the total installed capacity of 38 plants was 32.8 MW. Almost all of them were motor-powered. 14 of these belonged to individuals, 13 to partnerships and 11 to municipalities. The total annual generation of these plants was 44.5 GWh. Only 5% of the population had electric service at that time and per capita annual electricity consumption was around 3 KWh.

The period of joint venture franchises with foreign capital: 1923-1930

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[23] This section is gathered together from various annual activity reports of TEK, TEAS and TEDAS, Kulali (1997) and TUSIAD (1998).

In accord with the liberal economic policies being tried in the country in general, the trend of franchises in the electricity sector, which was also dominant before the republic was established, continued. For example, Ankara was electrified in 1925 with a diesel generator built by the partnership of the German corporations MAN and AEG. Most of the companies operating in the electricity industry were German, Belgian, Italian and Hungarian joint ventures. The first domestic private company in the sector was Kayseri and Vicinity Electricity Corporation, which was established in 1926. At the end of this period there were 48 plants in operation, 3 of which were coal-fired thermal, 11 were hydro, 27 were diesel, 4 were steam-engine and 3 were gas-engine. By 1930, the installed capacity of Turkey had reached 74.8 MW, annual electricity generation reached 106.3 GWh and per capita annual electricity consumption reached 6.2 kWh.

First Nationalist policies in the sector: 1930-1950

With the effects of the Great Depression of 1929 that started to shake all the world economies, more nationalist economic policies began to be followed in Turkey. The First Five-Year Development Plan was put into effect in 1933. In this plan it was prescribed that the state would develop and use thermal and hydro resources and have a more active role in electricity generation. In 1933 some of the privileges of the foreign franchises were taken away and with the “Municipalities Law” the municipalities were granted the permission to build and operate electricity facilities. Electricity Sector Studies Office was established in 1935. Almost all foreign franchises were nationalized between 1938 and 1944. In this period the task of electricity generation was taken on by municipalities and companies owned and operated by various state establishments. The financing of municipalities for this purpose was done via Bank of Municipalities, founded in 1933, and Bank of Provinces, which was founded as a result of reorganization of Bank of Municipalities. By 1950, the installed capacity reached 407.8 MW, annual electricity generation reached 789.5 GWh and per capita annual electricity consumption reached 32 kWh. 23% of the population was electrified at the end of this period and per capita annual electricity consumption of those who were electrified was 141 kWh.

Period of incentives for the domestic private sector: 1950-1960

From 1950 on Turkey began implementing economic policies that put more emphasis on the private sector. As a result of this, between 1952 and 1956, four private domestic companies were established that were given franchises. From these corporations, Cukurova Electricity Corporation, which was granted with the franchise in 1953 to generate electricity from Seyhan Dam and hydroelectric plant, transmit it to load centers and bulk sale of it and Kepez and Antalya Vicinity Electricity Generators Corporation, which was established and given the franchise in 1956 to build a hydroelectric plant in Kepez, Antalya, to transmit the generated electricity to load centers and bulk sale of this electricity, continue to operate today. Northeast Anatolia Electrification Corporation was established in 1952 and was given the franchise to generate electricity from the Sariyar Dam and sell this electricity in Northeast Anatolia. However, it did not turn out to be a successful venture and it was shut down in 1960 and its operations were transferred to the newly formed Etibank Electricity Undertakings Establishment. Likewise, Aegean Electricity Corporation, which was established and granted the franchise to generate electricity from Gediz Demirkopru Dam and Hydroelectric Plant and distribution of it to the surrounding cities in 1955, did not survive and it was shut down in 1971.

After 1950 Turkey decided to give more emphasis to hydroelectric plants and Office of National Waters (DSI) was established in 1953 for this purpose. The hydro installed capacity, which was 17.9 MW in 1950, reached 411.9 MW by 1960. In the same period thermal installed capacity increased from 338.9 MW to 860 MW. Thus total installed capacity in 1960 reached 1272.4 MW. Total electricity generation in 1960 was 2815.6 GWh and per capita annual consumption was 86 kWh. 32% of the population was electrified at the end of this period and annual per capita electricity consumption for the ones who had electric service reached 276 kWh.

Planned development period and return to nationalist policies in the sector: 1960-1980

The impact of the planned development efforts on the electricity sector was the implementation of more nationalist policies. In this framework, Ministry of Energy and Natural Resources was established in 1963 to coordinate the national energy policies. In 1970, Turkish Electricity Establishment ("TEK") was established as a state economic enterprise to operate as a monopoly in all segments of the electricity sector. All the plants that belonged to Etibank, DSI, Bank of Provinces and the municipalities were transferred to the ownership of TEK. However, the transmission and distribution facilities that belonged to the municipalities were left to the local administrations. Thus the policy of generating, transmitting and distributing electricity via private franchises was abandoned. However, the corporations that were in operation at that time, namely Cukurova Electricity Corp., Kepez and Antalya Vicinity Electricity Generators Corp. and Kayseri and Vicinity Corp. were allowed to continue their operations. From 1970 to 1980 the installed hydro capacity increased from 725 MW to 2,131 MW whereas thermal capacity increased from 2,235 MW to 5,119 MW. Total electricity generation in 1980 was 23,275 GWh and per capita annual consumption was 459 kWh. By the end of this period 80% of the population had electric service and per capita annual electricity consumption of the electrified population was 576 kWh.

Privatization and Efforts for Participation of Private Capital in the Sector: 1980-

With the economic liberalization policies that dominated the period after 1980, policies were implemented to encourage the private sector's involvement in the energy sector. As a first step, with the Law 2705, the plants in the ownership or operation of the local governments were transferred to TEK. The aim of this move was collecting the firms operating in different areas of the electricity sector together to form a structure that would make privatization easier. With this law the legal monopoly rights of TEK and DSI to build electric plants were abolished. The private sector was given the right to generate electricity and sell it to TEK. This model can be viewed as a Build-and-Operate model. An application was made to build a hydroelectric plant in Kayseri. Despite the fact that the project was given permission it got cancelled later on due to financing problems. With the passing of Law 3096 in 1984 that ended TEK's monopoly in the electricity sector, more participation of the private sector at all levels was targeted. This Law envisioned that the private sector would invest in the electricity industry via the Build-Operate-Transfer scheme. The construction of the first big-scale project could only start in 1996 due to legal problems that Law 3096 did not resolve.

Kayseri and Vicinity Corp. was given the franchise to generate, transmit and distribute the electricity to all of Kayseri and some towns and villages of Sivas in 1989 for a period of 70 years. In 1990, Cukurova Electricity Corp. was granted the franchise to generate, transmit and distribute electricity to the cities of Adana, Mersin and Hatay.

Kepez and Antalya Vicinity Electricity Generators Corp. was granted with the franchise to generate, transmit and distribute electricity to Antalya. Again starting from 1990, Aktas Electricity Corp. was given the franchise for generating, transmitting and distributing electricity to the Anatolian side of Istanbul for 30 years.[24]

In 1993 TEK was restructured as two different state economic enterprises called Turkish Electricity Generation-Transmission Inc. ("TEAS") and Turkish Electricity Distribution Inc. ("TEDAS"). These companies started their operations in 1994. Later on the distribution networks of TEDAS were restructured as 9 separate electric distribution companies.

Under Law 3974 passed in 1994 it was determined that privatization decisions of TEAS and TEDAS would be made by the Cabinet upon a recommendation from the Ministry of Energy and Natural Resources. According to the same law, the privatization revenues, net of the expenses, would be put into the Electric Energy Fund which would be channeled, by way of the ministry, into the state and private enterprises operating in the generation, transmission or distribution branches of the electricity sector. However, this law was annulled by the Supreme Court in December 1994.

In June 1994 Law 3996 was passed. This law regulates the conditions of entrusting the corporations with private and foreign capital in the Build-Operate-Transfer model framework on the issue of building, operating and transferring large infrastructure investment projects that require advanced technology and large funds. However, by Law 4047 passed in the November of 1994, the projects concerning generation,

[24] The legal problems about the franchise given to Aktas Electricity Corp. could not be resolved for a long time. Finally, the contract granting the franchise was nullified by the court in 1999. What is going to happen to Aktas Electricity Corp. and its franchise is still uncertain.

transmission and distribution of electricity were transferred to jurisdiction of Law 3096 from jurisdiction of Law 3996.

A governmental decree in 1996 and Law 4283 in 1997 were passed about the Build-Operate model, intending for these to include electricity sector investments as well. However, it was argued that foreign capital is behaving timidly about investments into the sector because the Supreme Court nullified some laws and decrees of this sort in the past.

The legal framework, that allows transferring of operation licenses of the electricity generation and distribution facilities to the private sector by the method of granting franchises to the assigned companies via cabinet decisions, is Law 3096. However, the Council of State ruled several times that electricity distribution services are public services; the contracts of transferring facilities to the private sector by the Operation-License-Transfer method, according to Law 3096, should be viewed as franchising contracts; and thus these contracts legally have to be passed through the scrutiny of the Council of State. The main reason for the nullifications is that the constitution does not allow international arbitration. Thus, in the contracts made with companies with foreign partners, these type of conditions pose legal problems. It is argued that in the absence of international arbitration conditions in the contracts, due to increased risks to these companies, financing costs go up significantly and this greatly reduces the investments of foreign capital in the electricity sector. This problem seems to be eliminated by the changes made in the constitution in 1999 that allows international arbitration.

The generation capacity of the hydro plants increased from 2,130 MW in 1980 to 10,306 MW in 1998 whereas the thermal installed capacity increased from 2,988 MW to

13,045 MW in the same period, therefore total installed capacity that was 5,119 MW in 1980 reached 23,352 MW in 1998. Electricity generation in 1998 totaled 111,022 GWh whereas annual per-capita net consumption was 1302.5 kWh in 1997. Thus generation capacity of Turkey has increased 712 fold since 1923.

4.2 Current State of the Sector

The current state of the Turkish electricity industry in the midst of its restructuring can be summarized as follows[25]:

1. There is a strong positive correlation between the growth in electricity consumption and GDP growth. Therefore, to meet the goal of significant growth of per capita GDP, required installed capacity expansion investments should be carried out to meet the corresponding increase in electricity consumption.

2. The funding requirement for the necessary investments in installed capacity is high. Public sector investments that were relatively high in terms of level and growth rate between 1970 and 1990 almost dried up after 1990. If high growth rates of electricity consumption and installed capacity are to be achieved, all sorts of public and private funds will be required for this purpose.

3. Private sector participation in the Turkish electricity industry, despite various legal and economic incentives from 1980 on, is very limited as of 1999. The share of the public sector in installed capacity and electricity generation is around 85%.

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[25] For a detailed historical, current and internationally comparative survey of the Turkish electricity sector, including capacity, production, consumption, investment, growth, production costs and prices, please see Zenginobuz and Ogur (1999).

4. In the generation segment of the industry, there are franchised generation companies, private self-producers and private generation companies operating under Build-Operate-Transfer, Build-Operate and Operating-Right-Transfer models, in conjunction with the public sector generation companies.

5. In the Build-Operate-Transfer model, private investors bid to acquire the right to build plants in the auctions held by the public sector and then transfer the plants to the public sector after operating it for a specified period. The public sector guarantees to purchase a predetermined amount of electricity at predetermined prices during this period, backed with Treasury guarantees for payments. This model appears to be an alternative way of financing public investments rather than private sector participation in the sector.

6. In the Build-Operate model, domestic and foreign private investors bid to acquire the right to build and operate thermal plants in auctions conducted by the public sector (hydro, geothermal and nuclear plants are kept outside of this model). As in the Build-Operate-Transfer model, the Treasury guarantees payments for purchases of a predetermined amount of electricity at predetermined prices by the public sector.

7. In the Operating-Right-Transfer model, some or all of the electricity generation, transmission, distribution and retail sale functions for a region are transferred for a specified period of time to a company determined via an auction conducted by the public sector. The public sector, as in the Build-Operate-Transfer and Build-Operate models, gives price and purchasing guarantees to the winning bidders, backed by the Treasury payment guarantees.

8. Every generation company operating under one of these three models can sell electricity to all other firms who are connected to the grid and, with the condition that they pay the transmission and distribution costs, to the other generation companies with an installed capacity of at least 4 MW as well as to TEAS.

9. The regulated prices in the Build-Operate-Transfer, Build-Operate and Operating-Right-Transfer models are determined by the cost-plus model, where all approved investment expenses are included in the cost base.

10. Cost-plus pricing and purchasing guarantees, backed by the Treasury's payment guarantees, reduces the investors' risk to a great extent. The motivation for this is to reduce the investment cost to the public sector by reducing the risk premium in the returns on investments the investor is going to demand. However, this pricing policy that reduces the investment cost to the public sector gives no incentive for the operating firm to be efficient.

11. The only available form of participation for private investors in the Turkish electricity sector is "competition for contracts" during the auctions. The contracts containing price and purchasing guarantees eliminate the necessity for the firm who won the auction to compete in the market.

12. Despite the fact that these guarantees reduce the investment costs to the public sector, they should be granted for only a limited amount of time, especially in the Build-Operate and Operating-Right-Transfer models. The elimination of the competitive disadvantage of the electricity firms that could enter the market in future should be aimed by gradually moving away from the price and purchasing guarantees.

13. The dispatch and transmission of electricity over the interconnected system is the responsibility of TEAS, which is a state economic enterprise. TEAS at the same time controls 85% of generation. It is going to take some time for this high share in generation to fall. In order not to cause a conflict of interest to TEAS in its relationship with other independent generators competing in the market, transmission and dispatch functions should be performed by an independent entity.

14. For technological reasons the transmission and dispatch functions together are considered to be a natural monopoly. The success of regulation of the electricity industry under the participation of the private sector is going to critically depend upon the well functioning and successful structuring of this natural monopoly segment.

15. Just like in transmission and dispatch of electricity, natural monopoly conditions are intact in the distribution segment. By a recent policy decision, Turkey is divided into 29 regions and the distribution and retail operations in each region are granted to a private sector company via the Operating-Right-Transfer method. Rates and tariffs of these regional monopolies are subject to government approval. However, monopolization of the local distribution segment should not be extended to the supply and retail operations segments, which are now widely accepted to be competitive lines of business.

16. The share of natural gas-fired plants in the installed capacity is increasing, including the self-producer segment, public and private. The natural gas plants, which have short construction times and low investment costs, have, on the other hand, large per unit generation costs. The biggest share of unit generation costs is the fuel cost and thus generation costs are subject to significant fluctuations with the price of natural gas

in the world commodity markets. This current state of affairs in the industry should be considered in the future privatization and restructuring efforts.

17. Turkey's installed reserve margin (defined as installed capacity over peak demand) is significantly above what is considered to be optimal. This probably stems from the relatively high share of hydro generation and it is expected to improve as the share of thermal plants increases.

18. Both industrial and residential electricity prices are significantly above unit generation costs. Furthermore, until recently, industrial prices have been higher than residential prices, which is counter to marginal cost-based pricing.

19. The high electricity prices (relative to unit costs) can in part be explained by the tax burden on electricity usage. Turkey taxes industrial electricity use at 13.9%, whereas this rate is zero in Austria, Belgium, Finland, France, Greece, Ireland, Holland, New Zealand, Portugal, Spain, Sweden, Switzerland and the U.K. It is 12.9% in Denmark, 7.8% in Germany, 17.8% in Italy, 2.9% in Japan and 12.3% in Mexico. The tax rate for electricity used in residences is 17.2% in Turkey, 2.8% in Japan, 4.8% in Portugal, 6.1% in Switzerland, 56.8 % in Denmark, 21.5% in France, 27.2% in Norway, 24% in Italy and 33.4% in Sweden.[26]

[26] Sources: IEA Statistics (1996) and Yildirim (1998).

5. Restructuring in the Turkish Electricity Sector: Privatization, Regulation and Competition

In light of the theoretical problems discussed in Section 2 and the paths followed by other countries discussed in Section 3, there are various lessons for restructuring and regulation of the Turkish electricity sector.

In restructuring the electricity sector and transitioning to a new regulatory regime, extensive ownership and control by the public sector in the industry might paradoxically turn out to be an advantage. In situations where ownership rights are dispersed amongst private parties, hurting the interests of some parties, which inevitably happens in any transition, leads to political pressures that delay the process. Restructuring under public ownership will also lead to harming some interests and it will create pressure against the new structure. However, looking at other countries' experiences of restructuring, advantages of starting the restructuring process under public ownership outweigh the disadvantages.

This observation suggests a cautious approach to privatization in the sector until the new structure matures. Once the private property rights are allocated, making changes to regulatory policies becomes increasingly difficult. For example, it is suspected in the U.K. that the wholesale electricity prices formed in the power pool have deviated from the prices that would be observed under perfect competition and are way above marginal costs. However, buyers and sellers making transactions in this market engage in "contracts for differences" to get rid of the risk of wild price fluctuations. Since changing the price formation in the power pool is going to hurt the property rights that are formed by such contracts, which can be signed for rather long periods time, it is very difficult to implement the proposals calling for a change. Especially under a stable institutional and judicial structure, the only way the governments can make changes that will affect the private property rights is by compensating whoever is harmed by the changes. It is observed that the privatizations that are made before the new regulatory structure becomes clear can cause significant problems. If the unforeseen problems that arise after the privatization are not successfully dealt with, then loss of economic efficiencies can come about. In most cases, it will be too costly to compensate the private property rights owners whose interests will be harmed by the changes that will resolve these problems. An unstable institutional and judicial structure may prefer solutions that are basically equivalent to confiscation of private property rights rather than compensation. For the countries whose institutional and judicial structure has not yet stabilized and the confiscation probability is perceived to be high, the only way to attract private investors to the infrastructure industries such as the electricity sector is to offer very high returns associated with the perceived very high investment risk. The adoptions such as state guarantees given to investments, price and purchasing guarantees for the good or service to be produced, etc. are the costs the countries should incur to decrease the risks perceived by the investors. For example, when the long-term price and purchasing guarantees are granted to the investors, this stands in contradiction with the competitive market targeted in the sector.

Chile's restructuring of the public electricity companies so as to change the prevalent structure of the sector before starting the privatization and developing a new regulatory system that is in accord with this new structure is an example for Turkey that should be emphasized. The public companies were privatized only to the extent that such privatization would lead to the new targeted structure in the sector. That the institutional and judicial structure of the regulatory system of the electricity sector triggered trust resulted in attracting huge amounts of private investments into the sector.

In light of the British and Chilean examples, Turkey should first firmly decide on what kind of structure she wants in her electricity sector and then should speedily settle the institutional and judicial structure of the implied regulatory system. The public electric plants should be privatized only to the extent that that such privatization would lead to the new targeted structure in the sector. Before surrendering the option of making changes in the industry structure under public ownership, it should be made sure, as much as possible, that the need for change will not arise again. From this perspective, intense ownership of the public sector in the industry might be interpreted as advantageous.

The three main issues that should be resolved in the process of restructuring the electricity industry of Turkey and forming a new regulatory system are:

1. To what extent is the new structure of the sector going to be vertically disintegrated?
2. Which segments of the industry will remain under public ownership and which segments are going to be transferred to private sector?
3. Which segments of the sector are going to be subject to regulation? What technical properties is this regulation going to have?

These three main issues are discussed separately below.

5.1 The New Structure of the Sector

One extreme about the structure of the electricity industry is the totally vertically integrated model that is still the dominant model in the United States and the other extreme is the vertically completely disintegrated structure in the United Kingdom.

To form the structure in the UK, public generating units were privatized and new firms were allowed to enter the generation segment. A wholesale market where electricity was traded with market-based unregulated prices was created to complement this new structure. A private monopoly was granted the franchise of operating the transmission grid and its operations were subject to public regulation. The distribution network was divided into twelve zones and a different private monopoly was given the franchise to operate each. These twelve private regional monopolies, which also jointly owned the transmission grid, were also subject to regulation. The supply segment that happens to be the last segment before the electricity reaches the end-users and that also includes such services as rate-setting, measuring, billing and invoicing was opened to competition. Furthermore, a regulatory body responsible for implementing all regulatory policies was formed.

An alternative solution to the two extreme structures in the US and UK is keeping the transmission segment under public ownership and integrating it, directly or indirectly, into the generation segment. However, if there is a scarcity of installed capacity then there are economic efficiency problems with opening up the generation segment into competition without regulating it. In this case, the operator of the publicly-owned transmission grid should either be merged with the generation segment or it should be organized as the sole purchaser of electric power, through an auction process, from the competitive generation segment that includes private independent generators. In such a regulatory regime it is kept as an option to privatize the operation and/or property of the transmission grid when the competition settles in the generation segment and the sector stabilizes at its new equilibrium.[27]

It is understood that it is decided in Turkey to unbundle the transmission segment from the generation segment. It is being announced that the generation, transmission and retail functions of TEAS will be continued under different firms.

Disintegrating the high-voltage transmission grid from the rest of the sector and giving it to the operation of an independent firm is going to be the most critical step to be taken in the process of restructuring the industry.

The process of transferring the electric generation plants to the private sector via the Operation-Right-Transfer contracts has begun and is still continuing. Until this transferring process is completed, the plants that are not yet transferred to the private sector will have to be operated within a separate public company. The plants that are thought of as “strategic” and the nuclear plants to be built in the near future will seemingly be operated within this public generation company.

Private sector participation in generation is at very low levels despite the fact that it has been increasing in recent years. The long-term price and purchasing contracts signed with the generators built within the Build-Operate-Transfer and Build-Operate models make it impossible for prices in generation to be determined in a power pool

[27] There are various announcements of officials of Ministry of Energy and Natural Resources on this issue.

market as in Britain for a long time. Thus the direct role of public sector in wholesale buying and selling of electricity will continue for a long time.

It is obvious that there are obstacles on the way to the point where the wholesale prices of electricity are determined in a market. To close the perceived deficit in the installed capacity very quickly, private sector investments were invited and still are, before the institutional and legal details about the regulation of the electricity sector was made clear. In a framework of unsettled institutional and legal structure the private investments are realized only at very high costs that would correspond to perceived high risks in the sector. One of the forms these costs take is the guarantees given to the newly built plants to buy electricity from them at given prices and amounts for a long time. The regulatory structure should be settled and these guarantees should be avoided as much as possible since they are obstacles in front of introducing economic efficiency enhancing competition in different segments. This issue should also be considered in contracts made with plants whose operation rights are transferred to private companies.

In the generation segment the private and public companies will seemingly coexist for a long time. Especially the strategic plants and the nuclear plants, whose auctions will be held soon, may never be transferred to the private sector. The British experience suggests that due to the high-risk situation arising from environmental and security problems, the nuclear plants might not be transferred to the private sector even if it is intended. Within such a mixed structure, how will the competitive environment be created in the generation segment that will enhance economic efficiency once the contracts with price and purchasing guarantees expire? In this structure where public and private companies coexist, the efficiency of the public generation companies can be controlled by the yardstick competition method. However, the private sector generators will have little incentive to be cost-efficient once they have the price and purchasing guarantees and thus will be insufficient for the role of auditing the costs of the public generators.

Seemingly, technical operations of the transmission grid and wholesale transactions of electricity are intended to function under structures independent of each other. This approach can be interpreted as positive from a few points of view. Technical operations of the transmission grid and wholesale electricity transactions are two separate activities with totally different properties. It is evident that there is enough expertise in Turkey for operating the high-voltage transmission grid. The central dispatch that will minimize total system cost can be done under this structure also responsible for the transmission grid. Buying and selling of electricity from and to private and public generators requires some other specialization. Since the public sector will be taking a major part in the generation segment for a long time, it looks appropriate to let the companies that will operate the transmission grid and handle the wholesale electricity transactions be state-owned companies. Also, it is argued that for safer operation of the transmission grid the operator should have direct control over some generators. It will be natural for the public generators and the public sector controlled grid to be in such a relationship.

After disintegrating the high-voltage transmission from the other segments under an independent company the kind of regulation for this company should be decided upon. Good organization and operation of this segment, where natural monopoly conditions exist and network externalities are dense, will directly determine the performance of the new vertically disintegrated structure of the electricity industry.

That the grid is under public sector ownership and operation does not make it easier to decide on the regulation issue. One of the important decisions to be made about the regulation of the grid is whether “third party access” will be allowed. For there to exist any competition in the retail segment of electricity sector there should be access to the grid by parties that are not generators. When access to the grid is not allowed for third parties, only generators and consumers of wholesale electricity (distribution companies) can directly access to the grid. There are opponents of third party access claiming that it makes safe and uninterrupted transmission very difficult.[28] Allowing the generators to sell electricity to large customers is an issue that is partially linked to this point and partially different.

Due to network externalities it is very difficult to price transmission access in accord with economic efficiency. On the other hand, the price of high-voltage transmission access is critical to give the right signals about how the grid will expand and where the generators and consumers will place themselves. This is where the vertically disintegrated structure is in disadvantage to the traditional vertically integrated structure. It is observed that the model used in Britain could not prevent the generators from being built in wrong places and had problems coordinating generation and transmission to minimize system costs.

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[28] See Verbruggen (1997).

Another effect of disintegrating the transmission from other segments on electricity prices is that it makes the pricing process transparent and cross-subsidization of some consumer groups difficult.

Whether a central wholesale electricity market will be created at some point is yet another issue to be determined about the regulation of the transmission segment. Another related issue is whether the generators will be allowed to sell electricity to large customers directly using the transmission grid. Wholesale electricity markets are complicated and the properties of their performance are not yet well understood. The fact that the dominance of the public sector in the generation segment, directly or indirectly through contracts with price and purchasing guarantees, will last for a long time puts the formation of such markets in doubt.

The public company that will be responsible for wholesale electricity transactions may bring some competition to this segment through an auction process. However, it is evident that the contracts with guarantees that will be binding on buying and selling decisions for a long time is going to severely limit competition in the bulk electricity market even through the bidding process for contracts. Where this limiting factor is absent, what the competition between public and private companies for contracts will result in is yet another issue to be considered.

For the case where a public company takes on wholesale electricity transactions the following regulation can be considered: Electricity is bought from the generators via two-part tariffs that will cover both fixed and variable costs; load dispatch is regulated; electricity is sold to the distribution companies and large customers at a price that will cover the transmission costs; and the rates set by the distribution companies are regulated. Although it is difficult to know the true variable costs of generation, they can be estimated with some certainty through some control mechanisms including inter-company comparisons in cases of multiple generators. The variable cost of each generator is used to determine the merit order and per unit payments. The first generator to be run will be the one with lowest variable cost. This will solve the problem of economically efficient dispatch. In this system that will be used where spot electricity markets are absent, there is the problem of how the sales from generators to large customers will be allowed. This regulatory regime, which does not put any economic efficiency pressure on the grid operator and the distribution companies, can be changed once a competitive environment in generation and distribution arises and then the grid operator can be disposed of in determining the wholesale electricity prices. However, in this case if there are distribution companies subject to regulation whose owners or partners also own generation companies, they should be watched so that they don't use inflated prices in their purchases from these generators.

5.2 Determination of the Segments to be Privatized

The result arising from various studies comparing the relative performance of public and private sectors is that for efficient use of resources it is the regulation method that matters rather than the ownership type.[29]

In some studies it is found that ownership type also matters slightly in efficiency, as well as the regulation method. It is calculated that the costs of private generators can be as much as 5% lower than the costs of public generators.[30]

Although the supporting evidence is not very strong, it is thought that the private sector is more efficient than the public sector in electricity generation. This claim is strengthened by the fact that the costs of generators that were transferred to the private sector in Britain fell considerably. On the other hand, it is not clear whether the cost reductions were caused by ownership transfer only or also by changes in the regulatory structure. The general opinion now is that a competitive environment with private participation in generation is possible. To increase this competition, it is argued that self-producers, just like regular generation companies, should have access to the grid and should be able to buy and sell electricity from and to the grid.

No apparent difference in performance of public and private sectors in the distribution segment is found. The ownership of distribution companies in Britain did not change during the restructuring.[31] In a study conducted after the privatization of regional distribution monopolies in Turkey, a small difference was found in favor of private ownership.[32] The ownership type that is going to be preferred in distribution may depend upon the organization of transmission and who has the responsibility to meet demand.

Britain organized the transmission segment as a private monopoly subject to regulation. Until the prescribed new structure of the sector settles down it might be a better idea to keep the transmission segment under public ownership to make it easier to do the changes whose necessity might arise in the future. This is exactly what is intended in Turkey. Another issue about the ownership of the transmission grid is

[29] See Vickers and Yarrow (1988).
[30] See Pollitt (1993).
[31] See Newberry (1995).

whether the generators will be allowed to sell electricity directly to large customers using their own wires. This kind of connection has begun to be allowed in Turkey. The advantages and disadvantages of this depend on the properties of regulation that the transmission grid is subject to.

5.3 Criteria that will determine the Regulatory Structure

The pricing policy that will be allowed by the regulatory mechanism should (i) allow the required return on the investments that will be undertaken by the relevant company for it to meet the financing needs and (ii) encourage economic efficiency in both investment and operation decisions. Efficiency in investment decisions requires correct decisions on type, location, capacity and investment costs of the generator. It is usually impossible in practice to achieve both goals at the same time since they are in contradiction with each other.

The rate of return regulation that guarantees the required return to the regulated firm does not encourage cost efficiency. The price cap regulation whose latest applications are in the form of RPI –X have some problems of their own as well. It is very difficult to determine the level of X that is subtracted from the increase in the price index due to the predicted efficiency improvements. If this level is determined too low, pressures from consumers come for it to be changed. On the other hand, this level should also take into account the return required to find the financing necessary to undertake the investments. Yardstick competition is an element that is helpful in determining this level.

[32] See Bagdadioglu, Waddams Price and Weyman-Jones (1996).

Price cap policies result in reduced cross-subsidization due to the transparency of pricing process it brings.

Another issue to be resolved in distribution regulation is the determination of the customers whose rates will be subject to regulation. Small customer rates have to be regulated but it is possible to allow large customers to negotiate the prices with the generators. The issues of who should do the investments in the distribution networks and how they should be financed are still unresolved.

In cases where there are independent private generators in the generation segment, another issue to be considered is whether the primary energy sources used by the plants is obtained under competitive circumstances. The large plants in Turkey are mostly natural gas fired. Natural gas prices are still the determinants of investment and generation decisions for these types of plants where the share of fuels in unit cost exceeds 80%. BOTAS is the monopoly in natural gas sales and distribution in Turkey.

6. Political Economy of Regulation: Some Thoughts on the Structure of the Regulatory Commission

The subject of electricity sector regulation, beyond its technical complications, is also a political issue with its property rights transfer and income distribution related dimensions. It is a commodity produced under natural monopoly conditions and it is a basic necessity for both residential and industrial customers. In the production process under monopoly, economic rents are unavoidable even under regulation. However, the regulatory system directly determines the magnitude and distribution of these rents.

Some technically sophisticated methods used to regulate various industries in the industrialized countries take as given a certain institutional and judicial infrastructure. In these countries there is a social consensus on what the private property rights are and how they can be transferred and the judicial system that determines the outcome when controversies arise is also settled. The parties trust that the judicial system is going to resolve the controversies without ever taking sides.

In the industrializing nations the institutional and judiciary systems are not yet settled. Therefore, trying to implement the complicated regulation methods observed in developed market economies without the institutional and judicial framework they rely on working in the background can result in unanticipated and unwanted outcomes.

In a framework with not yet settled institutional and judicial structures, mechanisms that will politically effectively resolve the conflicts that are unavoidable in the process are needed for the regulatory structure to have favorable outcomes.

In light of this observation, what are the issues to be considered when setting up the regulatory commission to regulate the newly restructured electricity sector that will mostly have private participation?

Besides setting up the rules about the ownership type, investments and operations in the electricity sector; the regulatory system and the regulatory commission must be created in a way that can resolve conflicts of interest, determine the duties and responsibilities of all officials and parties who are participating and will guarantee transparency in all operations. The issues to be decided upon about the properties and operation of the regulatory commission can be summarized as follows:

1. Should the commission be mostly composed of technicians or from politicians and the people appointed by them?
2. Who should appoint the members of the regulatory commission?
3. From what and whom should the regulatory commission be independent of and to what extent?
4. What will be the control mechanisms that will prevent the regulatory commission from abusing its power?
5. Who should participate in the decision-making process of the regulatory commission and whom should these people be representing?
6. Should the regulatory commission be just a consultative body or a body with the authority of making final decisions?
7. Is there a need for more than one regulatory commission? If so, should one of them be at the local government level?
8. Should a body responsible for all the industries, like the Competition Commission, be delegated the power to, to regulate the industry instead of forming a regulatory commission for the electricity sector alone?

If the regulatory commission that will be formed until the institutional and judicial structure settles down is only a commission with technical properties, then the commission will lack the political power that is necessary for its decisions to be effective. The big weight of political decisions in the formation of the regulatory commission is not just due to the fact that this commission only has political properties but it is also due to the fact that the participation in this political process is limited. Regulations that will encourage bigger political participation in the appointment of the members and in the decision-making process of the commission should be considered. For example, there has to be a mechanism that will process the complaints of small customers whose bargaining power is so limited.

In such a framework the regulatory commission will not be independent of a certain political authority. However, making it mandatory to present the information to the relevant parties that is necessary in the decision-making process upon demand and making the decision-making process transparent will lessen the significance of political dependence. For example, increased participation via selling or even giving away shares of the electricity companies directly to the public will force the control and transparency of the commission. Giving all parties the right to appeal to the courts about whatever they see wrong in the sector is also important in this context.

The regulatory commission should be formed in such a way that it will not be serving the interests, directly or indirectly, of the sector it is regulating.[33] Especially bureaucratic structures with emphasis on the technical side are observed to enter into relationships after a while with the firms they are supposed to regulate that are not suitable for their functions. Career bureaucrats can be rewarded for deciding in favor of a company by being employed there after they leave their jobs. For the purpose of not wasting the experiences of the bureaucrats, them being employed in the same sector is not a pointless thing to do. This will also be a means of positive influencing between the private and public sectors. However, this potential channel of corruptness that will destroy the meaning of regulation should be closely watched. Despite the fact that there are legal regulations on this subject, they are not strictly followed. A regulatory commission with a heavier political influence might be better to cope with tacit tie formations. If there is transparency in the operation of the commission, this will create a platform to defend the interests directly.

In light of these opinions, it will be more appropriate for the electricity sector regulatory commission to be appointed by the political authority for a limited time, just like most other sectors' regulatory commissions. This commission will have the final say on the issues and it also will have to be in direct technical cooperation with the public company that will operate the transmission grid. Therefore, qualified technical personnel should be employed on a permanent basis by the commission who will be in contact with the other private and public companies and the customers in the sector. In this context, despite the fact that the final decision authority will be in the hands of the political commission, there have to be measures that will discourage the technical personnel from abusing their knowledge edge in cooperation with the other firms in the sector.

It should be accepted that the subject of regulation of the electricity industry is in the end a political one. The policies followed so far were more of an allocation war and resulted in almost ignoring the economic efficiency issue. This is the rationale lying behind the restructuring wind in the sector. It is believed that introducing private sector competition into some segments will result in the desired efficiency gains. However, natural monopoly conditions in some segments necessitate regulation and the final allocation of the economic rents that will inevitably be brought about by monopoly conditions is mostly determined by the structure of the sector and its regulation method.

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[33] This is the issue that is called "regulatory capture" in the literature.

With the new regulatory structure a situation where rent-seeking wars contradict less with economic efficiency is attempted. The changes that will increase economic efficiency will inevitably create winners and losers compared to the old regulation. Until a solid and working institutional and judicial structure about public order that also includes economic processes settles down, it is a more applicable solution to resolve the allocation wars in a political structure with representative authority. It is evident that trying to resolve the allocation conflicts directly by a political regulation will reduce the demand for an institutional and judicial structure that will reduce the need for such a direct solution. The guarantee of resolving the conflicts between parties fairly and anonymously by a settled institutional and judicial structure should be approached via setting up a structure where the regulatory commission functions transparently and the warrants and responsibilities are clearly specified.

Chapter III: **Impacts of Transmission Ownership of Generators in the Presence of Loop Flows**

1. Introduction

In many countries, infrastructure sectors that have historically been vertically integrated natural monopolies subject to public regulation, such as electric power, natural gas production and distribution and railroads, are being restructured. Most restructuring programs distinguish between potentially competitive sectors (e.g. electricity generation and natural gas production), where prices and entry will be deregulated, and natural monopoly segments (e.g. electric transmission and natural gas pipeline and distribution networks) which will continue to be subject to some form of public control of prices, service quality and entry. A key fact here is that suppliers in the competitive segments require access to the network infrastructure segments in order to supply their services to consumers.

The demand for usage of these networks varies widely from hour to hour, day to day and season to season. During some time periods, one or more interfaces on the network can become congested as the demand by the suppliers to use the interface exceeds the capacity, if the price of using the interface is not set high enough. At those periods the value of output of the suppliers depends on whether they have to transport their products and if so whether they are located on the cheap or expensive side of the network constraint. Prices and profits in these competitive segments can fluctuate widely over time and across locations as demand and supply conditions vary. These variations in prices create a demand by risk-averse producers and consumers for instruments to hedge price fluctuations. To some extent, these prices and variation of prices over locations provide the signals that should guide investment in additional infrastructure capacity.

For electricity markets the transmission grid has always been an important part of the infrastructure network, even when the industry was a vertically integrated natural monopoly subject to public regulation. However, the significance of the transmission grid stemmed from different reasons than today. The transmission grid was important in order to exploit economies of scale in power generation and regional cost differences. It was possible to produce all the electricity for a region at one location, thus minimizing the average cost of generation, and then transmitting the power demanded by customers at each location over the grid. Alternatively, it was possible to generate high amounts electricity at a very low variable cost (hydroelectricity, for example) at a location where there is almost no demand and transmit it to the urban areas where opportunity costs of production are high and so is the demand for power.

In an era of deregulated electricity generation, the transmission grid maintains its old role, but it also takes on additional and more significant roles. Since generation services are deregulated, the producers are free to make any investment, enter any market and charge any price they wish. When different markets are not connected, making it impossible to transport electricity generated at one location to another location, producers may have enormous market power at the location of their generators. However, if there is a transmission grid able to transport large amounts of electricity, those locations that were previously characterized by market power, high prices and low output will merely be part of one big market. Producers who had market power at their locations will compete with any other producer connected to the transmission grid, regardless of where they are located.

Significant questions arise in this context as to how the market and grid operations will be organized, and what institutions are going to support the competitive environment. At the very least, institution(s) are needed to accommodate competition in services, generation and contracting while preserving the reliability of the transmission system. Alternative models are many and can be grouped under the categories of "Transco," "Gridco," "ISO/PX," 'ISO" and organizations for transmission loading relief (TLR).

A Transco is an independent (of generation and load) company that combines ownership of the grid and responsibility for system operations in managing the use of the grid. This company may be a for-profit or a not-for-profit one. An example of this type is the National Grid Company in England and Wales. The motivation for creating a Transco is to exploit the incentive effects of profit. Presumably profit opportunities would provide inducement for improved operations and market-responsive investment. At a minimum, with ownership of significant assets, there is an argument that regulators would have greater leverage in controlling the performance of Transcos. In fact, the strongest claims for this institution are that the profit motive is all that would be needed and with incentive regulation the Transco could be left to make its own rules for transmission access, operations and pricing. Therefore, just establishing a for-profit Transco would save the regulators from all the difficulties associated with evaluating the pricing and access rules for transmission and system operations. Unfortunately, there is no known system of incentive regulation that could achieve this result. The arguments against Transcos are that when it faces a tradeoff between generation and transmission solutions to the system when it becomes constrained, ownership of the wires and control of system operations (i.e. dispatch) would create a conflict of interest for a Transco with incentives to tilt operations to induce investment in transmission. A second argument against it is that if it were that easy to set the proper incentives for the Transcos, then there would be no need for restructuring and unbundling in the first place.

A Gridco is a regional entity that owns the wires and is independent of generation and load, but is not responsible for controlling the use of the system. So it must be paired with a system operator. An example of this model is GPU Powernet in Victoria, Australia. The maintenance and expansion of the grid would be the responsibility of the Gridco. Many of the advantages of the Transco model apply to the Gridco model, without all of the problems. More specifically, the incentives for the Gridco, which would own significant assets, would be similar to those of the Transco, but without the conflicts of interest in system operations and dispatch decisions. Providing the proper incentives again would not be easy, but would be easier compared to a Transco by the virtue of a Gridco not making the dispatch decisions.

ISO/PX refers to an organization where operation of the spot market is run through a power exchange (PX) and control of system operations through an ISO. These two institutions have separate access and pricing rules. The only example of this model in the U.S. is the now abandoned California model. This kind of an arrangement, especially in the short run, creates significant operational difficulties. The experience from California is that this design precludes the ISO from pursuing an economic dispatch and segments interdependent functions, reducing options and increasing costs.[34] Moreover, if the system operator performs its functions through a voluntary, bid-based, security-constrained, economic dispatch, the separate power exchange would have little to do other than arrange the accounting settlements.

An Independent System Operator (ISO) provides a dispatch function that coordinates the spot market. The ISO does not own transmission lines. If there is a separate entity called the PX, then it does not have responsibility for coordinating the spot market and transmission usage. The challenge for an ISO is to find the best mix of unbundled activities and associated pricing rules.

Some controversial issues in the organization of the transmission segment are the role of the system operator, the role of the power exchange, whether it should be bid-based economic dispatch with nodal pricing or bilateral contracts-based, whether zonal pricing or nodal pricing should be adopted, congestion management and ownership and expansion of the transmission grid. The reason for these current controversies is that the existing institutions are abandoned to pave the way for the new structure of the sector. The existing transmission institutions were not compatible with a deregulated wholesale electricity market and retail markets. However, nothing has yet replaced these institutions in most regions of the U.S. In others, the ISO model prevailed. For example, PJM Interconnection, Midwest Independent System Operator, ISO New England, New York ISO, California ISO are all organized in a framework where the incumbent utilities keep ownership of the transmission system, but the ISO unilaterally

[34] See Hogan (1999)

makes the pricing and security constrained economic dispatch decisions based on the bids it receives in the spot market. Current ownership structure of the generation, transmission and distribution assets seem to be a hurdle on the way to creating the market and transmission institutions that would enhance the efficiency of and reduce the market power in the wholesale and retail electricity markets in the regions that did not form an ISO.

In this chapter we model a wholesale electricity market with spatially differentiated demand and supply to analyze these questions. There is market power on the supply side whereas consumers are price takers on the demand side. We assume that the imperfect competition between the generators takes the form of a simultaneous quantity-setting game, i.e., they compete a la Cournot. Cournot competition is a standard way of modeling the wholesale electricity market in the restructuring literature. Borenstein, Bushnell and Stoft (1998) use and justify the Cournot assumption. Furthermore, Wolak and Patrick (1996) provide evidence that exercise of market power in the UK has taken place through capacity withholding. At high demand times the two large firms in the UK appear to have made some of their generation capacity unavailable in order to raise the market clearing price. Oren (1997), Cardell, Hitt and Hogan (1996), Smeers and Wei (1997), Joskow and Tirole (2000) also use Cournot competition in their analysis.[35]

[35] There are alternative models of competition in electricity markets. Klemperer and Meyer (1989) present a model of supply function competition. Green and Newberry (1992) apply it to the UK market. Baldick, Grant and Kahn (2000) use the framework of linear supply functions. Wolfram (1999) finds that UK prices are below those that the Cournot model would predict, but argues that the reason might be elsewhere, like in the threat of regulation. von der Fehr and Harbord (1993) suggest a multi-unit auction approach to evaluating competition in wholesale electricity markets.

We use a simplified three-bus (node) network. Although we cannot address all the issues that arise in real networks, the model is general enough to address many interesting issues, including congestion, loop flow, externalities and interaction between the energy market and the transmission rights market. Along with it comes the advantage of analytical tractability which is absent for any network that has more than three nodes. It is conceptually straightforward to extend the analysis to arbitrarily many nodes. Given the nodal injections and withdrawals, the flows on the lines are determined by the physical characteristics of the grid and the laws of nature governing the electrical networks. However, it is not tractable and it is almost impossible to analyze such large networks without the use of computer simulations. That is why three-node networks are so common in the literature (See, for example, Joskow and Tirole (2000) and Smeers and Wei (1997)).

We model the wholesale electricity and transmission rights markets as two distinct but interrelated markets. We consider two separate and completely unbundled products: electricity and transmission capacity reservations ("TCR"). The electricity market is characterized by Cournot competition whereas the TCR market is assumed to be perfectly competitive. The prices in the transmission rights market are set equal to opportunity cost for each generator so in equilibrium no generator wants more or less TCRs. The equilibrium in this interconnected system requires both markets to be in equilibrium simultaneously. The concept of transmission rights we use is the one presented in Smeers and Wei (1997). These are very general multi-point to multi-point transmission rights and they differ from the traditional link-based rights in Chao and Peck (1996). They can be interpreted in terms of link-based rights for the three-node case and are more general and tractable than link-based rights for more general networks.

We discuss the various types of equilibrium and derive the conditions under which each is obtained. The possible types of equilibria are where there is no congestion on the network and where there is congestion on one of the lines. Given the parameters of the model, the line capacities determine which type of equilibrium is obtained. After the characterization of equilibrium, we turn to evaluating the impacts of generator ownership in the grid company, which can be interpreted as transmission rights ownership of a generator. We find that allowing generators to own (non-voting) shares of the transmission company is not necessarily detrimental for the consumers or the overall societal welfare. Entitling a generator to a portion of the transmission grid revenues may induce it to expand its output. However, this is not necessarily sufficient for it to be welfare-enhancing. Increased output by one generator can be accompanied by a larger output reduction by other generators, thus leading to higher energy price and lower consumer surplus. We demonstrate all of these possibilities in the context of our model. As a result, we conclude that efficiency and welfare impacts of partial ownership of the grid (or transmission rights) by generators should be evaluated on a case-by-case basis and a general rule banning or allowing such practice under all circumstances will be harmful to the consumers in some cases.

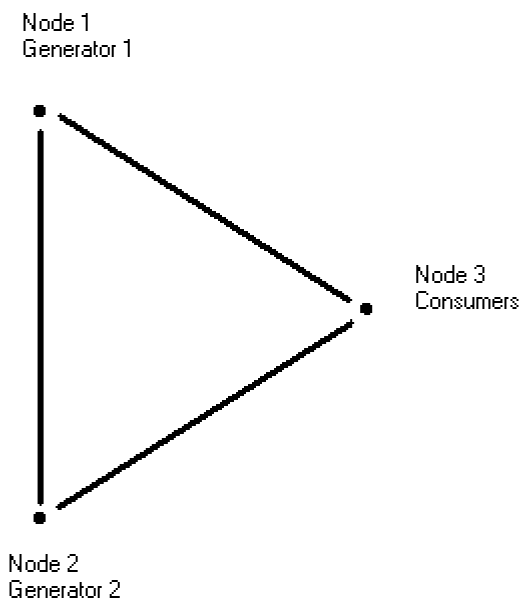
This chapter is organized as follows: Section 2 describes the model and defines the equilibrium concept utilized. Section 3 presents the results for equilibrium in electricity and transmission rights markets. Section 4 evaluates the impacts of generator ownership of shares of the grid company. Section 5 concludes.

2. The Model

We consider an electrical power network consisting of three nodes, which is the simplest configuration for the analysis of the impacts of loop flow. Each pair of these nodes is connected by a transmission line with some fixed capacity, that is, there is a maximum amount of power that can safely flow on the line.

There is a generator on node 1 (Generator 1 or G1) and a generator on node 2 (Generator 2 or G2). Generator 1 is assumed to be more cost efficient than Generator 2 for a given level of output; that is, given an output level, it costs less for G1 to generate that output compared to G2. Both generators' technologies are characterized by positive and increasing marginal cost functions. There is no demand for power on node 1 or node 2, all consumers are located on node 3. Demand for power on node 3 is characterized by a concave revenue function *P(Q)Q*. There is no generation capacity available on node 3, thus all the power that is consumed is transmitted from the other two nodes via the transmission network. The representation of the transmission network is depicted in the figure below.

Figure III-1: Transmission Network Representation



Determination of power flows on the lines given the injections is unique to the electric power networks. As opposed to almost any other industry where the direction of flow of goods is the direction of trade, flows on the transmission lines are determined by the physical laws governing the electric circuits, namely the Kirchoff's Laws. Technically, these two laws state that (1) the algebraic sum of all line flows into each node is zero; and (2) the algebraic sum of all voltage drops around any loop of the network equals zero.[36] We ignore transmission losses on the lines in this chapter. However, it is worth noting that in a DC flow model, the electrons move in a way that minimizes total line losses. Our simplifying assumption about the network of equal impedance of each line,

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[36] These are the versions of Kirchoff's Laws for DC (direct current) networks. Throughout this paper DC load flow approximations are used.

combined with the Kirchoff's Laws yields the result that, for each unit of power injected into node *i* and withdrawn at node *j*, two thirds of it flows through the direct link (i.e., on line *(i,j)*) and one third of it through the indirect link (i.e., on lines *(i,k)* and *(k,j)*).

The generators compete a la Cournot, i.e., by simultaneously setting their output levels. These quantities are pre-dispatch generation schedules submitted to the Independent System Operator ("ISO"), whose task is to dispatch generators and operate the transmission system reliably. If the chosen quantities by the generators induce power flows that exceed the thermal limit of at least one of the lines, the ISO lets them know that the bid dispatch is infeasible and asks the generators to adjust their output. However, since we model the transmission rights market explicitly, feasibility of output choices will be ensured by appropriate choice of transmission rights prices by the ISO, as discussed below.

The transmission network is assumed to be fixed and all of its costs are sunk costs. We do not consider the investment in the transmission grid, but rather take it as given. In that sense, total welfare and profits of the transmission company are short-run welfare and profits. This is a standard modeling approach in the literature, except for the models that specifically investigate optimal or equilibrium level of investment in the grid.

Along with the electricity market, there is also a market for Transmission Capacity Reservations (TCR). The amount of tradable TCRs at each node is determined by the ISO based on system capability and reliable operations. TCRs are auctioned off to the generators by the ISO. A generator needs a unit of TCR to transport electricity from or to a node. The concept of TCR was first introduced by the United States Federal Energy Regulatory Commission ("FERC") in Order 888. In this chapter we consider a general version of multi-point to multi-point TCRs analyzed in Harvey, Hogan and Pope (1996). There is no restriction being imposed on a TCR contract to make the injection and withdrawal reservations equal. The only restriction is that the sum of these reservations over all generators should be feasible for the network.

The generators are price takers in the market for TCRs. The TCRs are assumed to be priced at opportunity cost, which is a condition inspired by FERC's Order 888. The equilibrium in the market for transmission services requires that no generator wants more or fewer TCRs than it owns. Therefore, the price of the TCR at one node should be the same as the opportunity cost of an additional TCR at that node. So the opportunity-cost price is unique for each generator. Opportunity costs are kept as an option by FERC in its definition of TCR and they are also used extensively by Hogan (1997) in his analysis of market power.

The price of a TCR at node *i* is denoted by λ_i. Without loss of generality we set λ_1 to zero. The problem facing G1, taking q_2 and the prices of the TCRs as given, is the following:

$$\underset{q_1}{Max}\ q_1 P(q_1+q_2) - C_1(q_1) - (\lambda_3 - \lambda_1) q_1 \qquad (3.1)$$

Along with the usual revenue and cost items, profit maximization of G1 takes into account the transmission rights market as well. The net payment for the transmission rights of each unit of output of G1 is the difference between the prices of TCRs of node 3 and node 1, λ_3-λ_1. It costs λ_3 to withdraw a unit of energy from the consumption node and -λ_1 to inject a unit of energy into node 1. However, since the price of a TCR at node 1 is set to zero, first order necessary condition for the problem in (3.1) is

$$P(q_1+q_2)+q_1P'(q_1+q_2)-C_1'(q_1)-\lambda_3=0 \tag{3.2}$$

The Cournot profit maximization problem faced by G2, after taking into account (net) payments for transmission rights, is

$$\underset{q_2}{Max}\ q_2P(q_1+q_2)-C_2(q_2)-(\lambda_3-\lambda_2)q_2 \tag{3.3}$$

The first order necessary condition for problem (3.3) is

$$P(q_1+q_2)+q_2P'(q_1+q_2)-C_2'(q_2)-(\lambda_3-\lambda_2)=0 \tag{3.4}$$

The feasibility in the TCR market constrains the set of possible dispatches. The system operator rules out all the combinations of TCR contracts that induce a higher power flow than the safe flow limit of at least one line. Given the injections and withdrawals into and out of the nodes, the power flows on the lines are completely determined by the physical characteristics of the transmission grid and the laws of nature governing the electrical networks (i.e., Kirchoff's Laws). This is purely an engineering phenomenon and there is no discretion involved on any agent's part, including the ISO.

Given power injections of q_1 and q_2 into nodes 1 and 2, respectively, power flows on the lines are as follows:

$$f_{(1,2)}=\frac{q_1-q_2}{3}$$
$$f_{(1,3)}=\frac{2q_1+q_2}{3}$$
$$f_{(2,3)}=\frac{q_1+2q_2}{3}$$

We denote the capacity of the line connecting nodes *i* and *j* by K_{ij}. So the capacity of the line between the generator nodes is K_{12}, the line between G1 and consumers has capacity of K_{13} and the line between G2 and consumers has capacity of K_{23}. The flow on a line cannot exceed its thermal limit; the ISO does not authorize a dispatch that would lead to a flow on a line beyond its limit. Thus the flows on the lines, directly derived from the power injections given the physical characteristics of the network, should obey the following restrictions:

$$f_{(i,j)} \leq K_{ij} \;\; i, j \in \{1,2,3\} \;\; i \neq j \tag{3.5}$$

Condition (3.5) should be satisfied in any dispatch to prevent a reliability violation, not just in equilibrium. So feasibility of dispatch and thus the feasibility of the TCRs is a necessary condition of any equilibrium in this system.

Equilibrium in this setup consists of two quantities (output of each generator (q_1 and q_2)) and three prices (price of electricity (p) and TCR prices λ_2 and λ_3) such that:

(i) Each generator is at a profit maximizing output level given the TCR prices and the output level of the other generator.

(ii) Electricity market is in equilibrium.

(iii) Generators' output choices are feasible for the system.

(iv) TCR market is in equilibrium.

Condition (i) is simply a restatement of first order conditions in (3.2) and (3.4). Condition (ii) states that demand for electricity at node 3, given p, is equal to the total output of G1 and G2. Condition (iii) is a restatement of the condition in (3.5). Finally, condition (iv) states that given the prices and quantities, no generator wants to acquire more or less TCRs at any node. For this to be true, TCR prices should be such that the transmission cost each generator faces must be equal to opportunity cost, i.e. profit foregone by that generator in the energy market by producing one less (or more) unit of output.

To summarize, equilibrium satisfies the following conditions:

$$
\begin{aligned}
&P(q_1^* + q_2^*) + q_1^* P'(q_1^* + q_2^*) - C_1'(q_1^*) - \lambda_3^* = 0 \\
&P(q_1^* + q_2^*) + q_2^* P'(q_1^* + q_2^*) - C_2'(q_2^*) - (\lambda_3^* - \lambda_2^*) = 0 \\
&p^* = P(q_1^* + q_2^*) \\
&f_{(i,j)}(q_1^*, q_2^*) \le K_{ij} \\
&\text{"equilibrium in TCR market"}
\end{aligned}
\qquad (3.6)
$$

When there is no congestion on the network, the TCR prices are zero because no generator causes an externality on the other. Equilibrium values of q_1 and q_2 follow from the simultaneous solution of (3.2) and (3.4). These quantities must satisfy (3.5) (with strict inequality), otherwise a no-congestion equilibrium doesn't exist.

A no-congestion equilibrium is characterized by the solution to the following system:

$$
\begin{aligned}
&P(q_1^* + q_2^*) + q_1^* P'(q_1^* + q_2^*) - C_1'(q_1^*) - \lambda_3^* = 0 \\
&P(q_1^* + q_2^*) + q_2^* P'(q_1^* + q_2^*) - C_2'(q_2^*) - (\lambda_3^* - \lambda_2^*) = 0 \\
&\lambda_2^* = \lambda_3^* = 0 \\
&\frac{q_1^* - q_2^*}{3} < K_{12} \\
&\frac{2q_1^* + q_2^*}{3} < K_{13} \\
&\frac{q_1^* + 2q_2^*}{3} < K_{23}
\end{aligned}
$$

The first two equations are the Cournot profit maximization conditions for G1 and G2, respectively. The third equation is the TCR market equilibrium condition. The three inequalities are the conditions that ensure that the flow on each of the three lines is strictly below its limit.

Another possible type of equilibrium is a constrained equilibrium where one of the lines is congested, i.e., the line capacity limit is binding and the flow on the line is equal to the safe flow limit. There are three distinct kinds of constrained equilibria: congested line *(1,2)*, congested line *(1,3)* and congested line *(2,3)*. For example, consider a situation where the line between the two generators, i.e. line *(1,2)*, is congested in equilibrium. When the output levels induce congestion on any of the lines, TCR prices will not be zero anymore in equilibrium. Such an equilibrium is characterized by the solution to the following system:

$$
\begin{aligned}
&P(q_1^* + q_2^*) + q_1^* P'(q_1^* + q_2^*) - C_1'(q_1^*) - \lambda_3^* = 0 \\
&P(q_1^* + q_2^*) + q_2^* P'(q_1^* + q_2^*) - C_2'(q_2^*) - (\lambda_3^* - \lambda_2^*) = 0 \\
&\lambda_2^* - \lambda_3^* = \lambda_3^* \\
&\frac{q_1^* - q_2^*}{3} = K_{12} \\
&\frac{2q_1^* + q_2^*}{3} < K_{13} \\
&\frac{q_1^* + 2q_2^*}{3} < K_{23}
\end{aligned}
$$

Again, first two equations are the Cournot profit maximization conditions for G1 and G2, respectively. The third equation is the equilibrium condition in the TCR market, which we discuss below in detail. The fourth equation is the condition of congestion on line *(1,2)*, i.e. the flow is equal to the line capacity. The two inequalities state that the flows on the other two lines are below their respective safe flow limits.

For the remainder of this chapter we assume that the demand and cost functions take specific functional forms. At the cost of losing generality, this approach simplifies the analysis by allowing us to obtain closed-form solutions. Furthermore, this approach is common in the restructuring literature.

3. Equilibrium in the Power and TCR Markets

In the previous section we introduced the general model and described equilibrium conditions of the model. In this section we parameterize the demand and cost functions. We assume demand for electricity is represented by the affine inverse demand function

$$p \equiv P(Q) = A - Q$$

where p is the price of energy consumers pay *and* the generators receive on each node, A is a positive constant and Q is the sum of the outputs of G1 and G2.[37] Cost of production for G1 is represented by

$$C_1(q_1) = \frac{1}{2}q_1^{\;2}$$

whereas the production cost function for G2 is assumed to be

$$C_2(q_2) = \frac{1}{2}cq_2^{\;2};\; c > 1\,.$$

Thus G1 is more efficient than G2 for a given output level. As before, K_{ij} are the maximum safe flow limits on the lines *(i,j)* and λ_i are the prices of transmission capacity reservations. λ_1 is again normalized to zero without loss of generality. With this specification, the first order necessary conditions for Cournot profit maximization of G1 and G2, given the TCR prices, are

[37] Consumption at node 3 is equal to generation at nodes 1 and 2 only because of our assumption that transmission losses are negligible. Otherwise, some of the energy injected at the nodes would be lost to

$$A - 3q_1 - q_2 - \lambda_3 = 0 \tag{3.7}$$

$$A - q_1 - (c+2)q_2 - (\lambda_3 - \lambda_2) = 0 \tag{3.8}$$

As discussed in the previous section, equilibrium may involve no congestion on the grid, or it may involve congestion on one of the lines. Thus equilibrium of this model can be analyzed in four distinct cases: (i) no congestion; (ii) congestion on the line connecting the generator nodes; (iii) congestion on the line between G1 and consumers; and (iv) congestion on the line connecting G2 and consumers.

3.1 Equilibrium with no congestion

When equilibrium involves no congestion on any of the lines, all TCR prices are zero:

$$\lambda_2^N = \lambda_3^N = 0 \qquad (3.9)$$ [38]

Then the first order conditions for Cournot profit maximization of G1 and G2, respectively, are

$$A - 3q_1^N - q_2^N = 0 \tag{3.10}$$

$$A - q_1^N - (c+2)q_2^N = 0 \tag{3.11}$$

In the no-congestion equilibrium capacities of all three transmission lines must exceed the corresponding flows on them:

$$f_{(1,2)}^N = \frac{q_1^N - q_2^N}{3} < K_{12} \tag{3.12}$$

$$f_{(1,3)}^N = \frac{2q_1^N + q_2^N}{3} < K_{13} \tag{3.13}$$

---

heat on the lines during transmission and consumption at node 3 would be less than the total generation at nodes 1 and 2.

$$f_{(2,3)}{}^{N} = \frac{q_1{}^{N} + 2q_2{}^{N}}{3} < K_{23} \tag{3.14}$$

Thus no-congestion equilibrium is determined by the solution to the equations (3.9), (3.10) and (3.11), and the solution must satisfy he inequalities (3.12), (3.13) and (3.14). If these inequalities are not satisfied by the solution, then there does not exist no-congestion equilibrium. All three line capacities should be sufficiently large to support equilibrium without any congestion.

Resulting equilibrium generation and consumption levels are

$$q_1{}^{N} = \frac{(c+1)A}{3c+5}$$

$$q_2{}^{N} = \frac{2A}{3c+5}$$

$$Q^{N} = \frac{(c+3)A}{3c+5}$$

and price of electricity directly results the inverse demand function:

$$p^{N} = \frac{2(c+1)A}{3c+5}$$

Consumers' surplus and generator profits are

$$CS^{N} = \frac{(c+3)^2 A^2}{2(3c+5)^2}$$

$$\pi_1{}^{N} = \frac{3(c+1)^2 A^2}{2(3c+5)^2}$$

$$\pi_2{}^{N} = \frac{2(c+2)A^2}{(3c+5)^2}$$

[38] The superscript "N" denotes the value of a variable in the no-congestion equilibrium.

Total surplus is given by the area under the demand curve between zero and the total production level less the total generation costs:

$$TS = \int_0^Q P(x)dx - C_1(q_1) - C_2(q_2)$$

Thus total gross surplus in no-congestion equilibrium is

$$TS^N = \frac{2(c^2 + 4c + 5)A^2}{3(3c+5)^2}$$

This leads to the following necessary (and sufficient) conditions on the parameters of the model for the existence of no-congestion equilibrium:

$$\frac{(c-1)A}{3(3c+5)} < K_{12} \quad (3.15)$$

$$\frac{2(c+2)A}{3(3c+5)} < K_{13} \quad (3.16)$$

$$\frac{(c+5)A}{3(3c+5)} < K_{23} \quad (3.17)$$

If A, c, K_{12}, K_{13} and K_{23} do not satisfy (3.15), (3.16) and (3.17), then there cannot exist an equilibrium with no congestion on the lines.

Left-hand side of all three inequalities above are increasing functions of A, which means an uncongested equilibrium is less likely with a higher vertical intercept of the inverse demand curve. (3.15) is less likely to be satisfied when c is higher, whereas (3.16) and (3.17) are more likely to be satisfied with higher c. The reason for this is that equilibrium output of G2 will be lower when its production cost is higher. Higher output by G2 induces higher flows on K_{13} and K_{23} whereas it induces a lower flow on K_{12}.

The (net) payments for transmission rights by the generators accrue to the owner of the transmission grid. Each generator has to pay the price of the TCR of the node it is withdrawing power from for each unit of electricity it withdraws. For example, G1 withdraws q_1 from node 3 and $-q_1$ from node 1[39] and thus pays $(\lambda_3 - \lambda_1)q_1$ for transmission rights. Similarly, G1's payment for the TCRs is $(\lambda_3 - \lambda_2)q_2$. The revenue of the grid owner is the sum of the payments of the generators:

$$R_t = \lambda_3 q_1 + (\lambda_3 - \lambda_2)q_2$$

Net total TCR payments of a generator can be positive, zero or negative depending on the pattern of congestion and whether the generator is at the aggravating or relieving side of congestion. When there is no congestion all TCR prices are zero, and so are the TCR payments of each generator and the transmission owner's revenues.

When the transmission lines have sufficient capacity and thus there is no congestion in equilibrium, there are no externalities and the model boils down to a standard Cournot model.[40] As is standard in the Cournot models, price, individual generation levels and profits, consumers' surplus and total surplus all increase with *A*. Price, generation and profits of G1 increase with *c* whereas generation and profits of G2, consumers' surplus and total surplus decrease as *c* increases.

[39] An injection is treated the same way as a negative withdrawal.
[40] This is a direct result of ignoring transmission losses. In a model that incorporates losses, there would be externalities even in the absence of congestion because marginal losses on a line are an increasing function of the flow on that line.

3.2 Equilibrium with the line between two generators congested

When there is congestion on any of the lines, TCR prices are no longer zero. In the case of congestion on line *(1,2)*, the line connecting the two generators, TCR prices are related as follows in equilibrium:

$$\lambda_2^{(1,2)} = 2\lambda_3^{(1,2)} \qquad (3.18)^{41}$$

For the TCR market, along with the energy market, to be in equilibrium, there should not be an opportunity for the generators to jointly make a marginal change to their production levels, and their corresponding TCR demands, which does not violate the line flow limits, but benefits both generators. More specifically, suppose G1 would like to produce an additional unit, which would yield a marginal energy market profit (excluding payments for TCRs) of λ_3 as per its first order condition of profit maximization. However, not to exceed the flow limit on line *(1,2)*, G2 needs to increase its production also by a unit, which would result in marginal energy market profit of (λ_3-λ_2) as per its first order condition. For there to be no mutually profitable trading opportunities, the sum of the marginal energy market profits for the two generators as a result of this hypothetical transaction should be zero. Solving for λ_3+(λ_3-λ_2)=0 results in (3.18).[42]

The first order necessary conditions for Cournot profit maximization of the generators are depicted in (3.7) and (3.8). Since line *(1,2)* is congested the flow on it should equal its capacity in equilibrium:

$$f_{(1,2)}^{(1,2)} = \frac{q_1^{(1,2)} - q_2^{(1,2)}}{3} = K_{12} \qquad (3.19)$$

On the other hand, flow on the other two lines should be below their corresponding limits:

$$f_{(1,3)}^{(1,2)} = \frac{2q_1^{(1,2)} + q_2^{(1,2)}}{3} < K_{13} \tag{3.20}$$

$$f_{(2,3)}^{(1,2)} = \frac{q_1^{(1,2)} + 2q_2^{(1,2)}}{3} < K_{23} \tag{3.21}$$

Simultaneous solution of (3.7), (3.8), (3.18) and (3.19) results in the following levels of outputs, consumption, electricity and TCR prices, consumers' surplus, profits, transmission revenue and gross total surplus:

$$q_1^{(1,2)} = \frac{2A + 3(c+3)K_{12}}{c+7}$$

$$q_2^{(1,2)} = \frac{2(A - 6K_{12})}{c+7}$$

$$Q^{(1,2)} = \frac{4A + 3(c-1)K_{12}}{c+7}$$

$$p^{(1,2)} = \frac{(c+3)A - 3(c-1)K_{12}}{c+7}$$

$$\lambda_2^{(1,2)} = \frac{2(c-1)A - 6(3c+5)K_{12}}{c+7}$$

$$\lambda_3^{(1,2)} = \frac{(c-1)A - 3(3c+5)K_{12}}{c+7}$$

$$CS^{(1,2)} = \frac{[4A + 3(c-1)K_{12}]^2}{2(c+7)^2}$$

$$\pi_1^{(1,2)} = \frac{3[2A + 3(c+3)K_{12}]^2}{2(c+7)^2}$$

---

[41] The superscript "(1,2)" denotes the value of a variable in the equilibrium where line *(1,2)* is congested.

$$\pi_2^{(1,2)} = \frac{2(c+2)(A-6K_{12})^2}{(c+7)^2}$$

$$R_t^{(1,2)} = \frac{3(c-1)AK_{12} - 9(3c+5)K_{12}^{\ 2}}{c+7}$$

$$TS^{(1,2)} = \frac{-9(c^2+10c+5)K_{12}^{\ 2} + 3(c-1)(c+9)AK_{12} + 2(c+9)A^2}{(c+7)^2}$$

The necessary condition for existence of equilibrium with a congested *(1,2)* line is

$$\frac{(c-1)A}{3(3c+5)} \geq K_{12} \qquad (3.22)$$

(3.22) is simply the negation of (3.15), which is a necessary condition for existence of no-congestion equilibrium. When the model parameters do not satisfy (3.22) there does not exist an equilibrium with a congested line *(1,2)*. Thus for there to exist an equilibrium with a congested line between the two generators, the capacity of the line between the generators should not be sufficiently small. At the same time, the other two lines should have sufficiently large capacity (so that the flows induced on them do not exceed their limits and cause a reliability violation):

$$\frac{2(A+(c+1)K_{12})}{c+7} < K_{13} \qquad (3.23)$$

$$\frac{2A+(c-5)K_{12}}{c+7} < K_{23} \qquad (3.24)$$

It is interesting to see what happens to the endogenous variables as the capacity of the line between the generators, K_{12}, increases. Of course, we are considering the changes in K_{12} from very small capacity up to threshold that supports the equilibrium

[42] For a formal derivation of this result, see Smeers and Wei (1997).

with congestion on line *(1,2)*. Once K_{12} is increased beyond this threshold congestion on line *(1,2)* is not sustainable in equilibrium.

As expected, the energy price in this equilibrium is higher than its value in the no-congestion equilibrium, it is decreasing in K_{12} and it approaches p^N as K_{12} increases to its threshold value in (3.22). The same relationship exists for the generation level of G2, q_2. G2 generates more in this equilibrium than it does in the no-congestion equilibrium, due to the fact that G2's production provides counter-flow on the congested line. In fact, this is reflected in the equilibrium TCR prices: G2's revenues from the TCR transactions are positive. For q_1, the opposite is true. G1 generates less in this equilibrium compared to its output in the no-congestion equilibrium and has negative revenues from TCR transactions. Both TCR prices are higher with smaller K_{12} and as K_{12} increases to its threshold value TCR prices decrease to zero. All the variables reach their no-congestion equilibrium values at $K_{12} = \frac{(c-1)A}{3(3c+5)}$, beyond which line *(1,2)* cannot be congested in equilibrium.

The marginal generation profit of G1 in this equilibrium is strictly positive due to the positive marginal cost it is facing for the TCRs it needs to acquire to increase its production. Similarly, G2's marginal generation profit is strictly negative but G2 is compensated for it by its TCR revenues. Profits of G1 increase with K_{12} whereas profits of G2 decrease with it. Consumers' surplus, along with consumption, increases with the line capacity; so does the gross total surplus. Revenue of the transmission owner is strictly positive as long as the line is congested and it approaches zero as the line capacity increases to its threshold value.

3.3 Equilibrium with the line connecting G1 to consumers congested

Two thirds of G1's power injection and one third of G2's power injection, both in the direction of node 1 to node 3, flow on *(1,3)*, the line connecting G1 to consumers. Therefore, in this case they are both congesting the line and thus both will be facing a positive cost of transporting power from their own generation node to the consumption node. For this type of equilibrium, necessary condition in the TCR market becomes

$$\lambda_3^{(1,3)} = 2\lambda_2^{(1,3)} \qquad (3.25)^{43}$$

To show this result, we employ a similar argument to the one we used in the previous section. Suppose G1 would like to produce an additional unit, which would yield a marginal energy market profit (excluding payments for TCRs) of λ_3 as per its first order condition of profit maximization. However, in order not to exceed the flow limit on line *(1,3)*, G2 needs to decrease its production by two units, since only one third of G2's production flows on line *(1,3)* whereas two-thirds of G1's output flows on *(1,3)*. The reduction of output by two units would result in marginal energy market profit of $-2(\lambda_3-\lambda_2)$ as per its first order condition. For there to be no mutually profitable trading opportunities, the sum of the marginal energy market profits for the two generators as a result of this hypothetical transaction should be zero. Solving for $\lambda_3-2(\lambda_3-\lambda_2)=0$ yields (3.25).

As usual, the Cournot profit maximization conditions of the generators are (3.7) and (3.8). Now the capacity constraint for line *(1,3)* should bind whereas the capacity constraints on the other two lines should not be binding:

$$f_{(1,3)}{}^{(1,3)} = \frac{2q_1{}^{(1,3)} + q_2{}^{(1,3)}}{3} = K_{13} \qquad (3.26)$$

$$f_{(1,2)}{}^{(1,3)} = \frac{q_1{}^{(1,3)} - q_2{}^{(1,3)}}{3} < K_{12} \qquad (3.27)$$

$$f_{(2,3)}{}^{(1,3)} = \frac{q_1{}^{(1,3)} + 2q_2{}^{(1,3)}}{3} < K_{23} \qquad (3.28)$$

Solving (3.7), (3.8), (3.25) and (3.26) yields the following equilibrium values:

$$q_1{}^{(1,3)} = \frac{3(2c+3)K_{13} - A}{4c+7}$$

$$q_2{}^{(1,3)} = \frac{2A + 3K_{13}}{4c+7}$$

$$Q^{(1,3)} = \frac{A + 6(c+2)K_{13}}{4c+7}$$

$$p^{(1,3)} = \frac{2(2c+3)A - 6(c+2)K_{13}}{4c+7}$$

$$\lambda_2{}^{(1,3)} = \frac{2(c+2)A - 3(3c+5)K_{13}}{4c+7}$$

$$\lambda_3{}^{(1,3)} = \frac{4(c+2)A - 6(3c+5)K_{13}}{4c+7}$$

This type of equilibrium exists only if K_{13} has "sufficiently small" capacity and K_{12} and K_{23} have sufficiently large capacities, as in (3.27) and (3.28). These conditions correspond to the following in terms of the parameters of the model:

$$\frac{2A(c+2)}{3(3c+5)} \geq K_{13} \qquad (3.29)$$

$$\frac{(c-1)K_{13}}{2(c+2)} < K_{12} \qquad (3.30)$$

[43] The superscript "(1,3)" denotes the value of a variable in the equilibrium where line *(1,3)* is congested.

$$\frac{(c+5)K_{13}}{2(c+2)} < K_{23} \qquad (3.31)$$

In this case, output of both generators, as well as the consumers' surplus, increase with K_{13} whereas the energy price and both TCR prices decrease with the capacity of line *(1,3)*.

3.4 Equilibrium with the line connecting G2 to consumers congested

This case is very similar to the previous case. Again both generators are on the congesting side of the transmission constraint. However, as opposed to the previous case, now two-thirds of G2's output flows on the congested line, *(2,3)*, whereas only one-third of G1's output flow on it. In this case, the necessary equilibrium condition on TCR prices becomes:

$$\lambda_2^{(2,3)} = -\lambda_3^{(2,3)} \qquad (3.32)$$

In order to see this result, an argument similar to the one in the previous section is sufficient. Suppose G1 would like to produce an additional unit, which would yield a marginal energy market profit (excluding payments for TCRs) of λ_3 as per its first order condition of profit maximization. However, not to exceed the flow limit on line *(2,3)*, G2 needs to decrease its production by one half of a unit, since two-thirds of G2's production flows on line *(2,3)* whereas only one-third of G1's output flows on *(2,3)*. The reduction of output by half of a unit would result in marginal energy market profit of –(0.5)(λ_3-λ_2) as per its first order condition. For there to be no mutually profitable trading opportunities, the sum of the marginal energy market profits for the two generators as a result of this hypothetical transaction should be zero. Solving for λ_3-(0.5)(λ_3-λ_2)=0 yields (3.32).

The first order conditions for generator optimizations are again given by (3.7) and (3.8). Now the binding line flow constraint is the one on line *(2,3)*:

$$f_{(2,3)}^{(2,3)} = \frac{q_1^{(2,3)} + 2q_2^{(2,3)}}{3} = K_{23} \tag{3.33}$$

The respective flows on the other two lines should be strictly below their corresponding capacities:

$$f_{(1,3)}^{(2,3)} = \frac{2q_1^{(2,3)} + q_2^{(2,3)}}{3} < K_{13} \tag{3.34}$$

$$f_{(1,2)}^{(2,3)} = \frac{q_1^{(2,3)} - q_2^{(2,3)}}{3} < K_{12} \tag{3.35}$$

Solving the system results in the following equilibrium values:

$$q_1^{(2,3)} = \frac{2A + 3cK_{23}}{c+10}$$

$$q_2^{(2,3)} = \frac{15K_{23} - A}{c+10}$$

$$Q^{(2,3)} = \frac{A + 3(c+5)K_{23}}{c+10}$$

$$p^{(2,3)} = \frac{(c+9)A - 3(c+5)K_{23}}{c+10}$$

$$\lambda_2^{(2,3)} = \frac{3(3c+5)K_{23} - (c-5)A}{c+10}$$

$$\lambda_3^{(2,3)} = \frac{(c-5)A - 3(3c+5)K_{23}}{c+10}$$

The restrictions on line capacities required to support this equilibrium, in terms of the model parameters, are:

$$\frac{(c+5)A}{3(3c+5)} \geq K_{23} \tag{3.36}$$

$$\frac{(c-1)K_{23}}{c+5} < K_{12} \tag{3.37}$$

$$\frac{2(c+2)K_{23}}{c+5} < K_{13} \tag{3.38}$$

As in the previous case, output of both generators, as well as the consumers' surplus, increase with the capacity of the congested line, K_{23}, whereas the energy price decreases with the capacity of line *(2,3)*. TCR price of node 3 decreases with K_{23} whereas that of node 2 increases with K_{23}.

This completes the analysis of equilibria in the energy and TCR markets when the grid ownership is independent of generation interests. We now turn to the problem of how ownership interest in the transmission grid (or entitlement to congestion revenues that accrue to the grid operator or the TCR market administrator) by a generator impact that generator's behavior and the overall marketplace.

4. Generator Ownership in the Transmission Company

Another controversial issue in the design of restructured markets following the deregulation of the electricity markets in the United States has been whether generators should be allowed to have ownership in the transmission grid or buy and sell transmission rights, which are instruments that pay the nodal price difference between two locations on the grid. More specifically, the issue of controversy is whether the generators should be allowed to have (voting or non-voting) stock of the grid company.

In this section we allow the generators to be able to have an ownership stake in the company that owns the transmission grid and thus be entitled to a proportion of the congestion or transmission revenues. More specifically, we look at the case where G1 owns α of the grid company and thus receives α proportion of the congestion revenues, where $\alpha \in [0,1]$. This changes the objective function of G1, as now it will maximize $\pi_1 + \alpha R_t$, the sum of its profits plus its dividends from the transmission company.

We do not address the issue of voting vs. non-voting stock here. We only look at the short term operation of the transmission grid, and not the long-term investment decisions regarding upgrading transmission line capacities. We also model the system operator as a rather passive entity, which does not have any pricing discretion, but just an oversight role of mechanical tasks. Thus, even if a generator owns voting stock and thus can interfere with the decisions and operation of the system operator, it would not amount to anything in our model due to the way we modeled the system operator's role. However, even passive ownership of the transmission company, i.e. entitlement to a portion of the revenues of the transmission owner (congestion rents) is sufficient to create a difference in the generator's behavior.

We further simplify the parametric model in this section by assuming *c=2*. All of the qualitative results we find in this section are independent of *c*, as long as *c>1*, as specified in the original model.

Formally, the only change in the model is the maximization problem of G1 and its corresponding first order necessary condition. Now the payoff maximization problem faced by G1 and its first order necessary condition are

$$\underset{q_1}{Max}\ q_1P(q_1+q_2)-C_1(q_1)-\lambda_3 q_1+\alpha(\lambda_3 q_1+(\lambda_3-\lambda_2)q_2) \tag{3.39}$$

$$A-3q_1-q_2-(1-\alpha)\lambda_3=0 \tag{3.40}$$

The Cournot profit maximization problem for G2 is as in (3.3) and its first order necessary condition is

$$A-q_1-4q_2-(\lambda_3-\lambda_2)=0 \tag{3.41}$$

As before, there are four different types of equilibria corresponding to no congestion, congestion on line *(1,2)*, congestion on line *(1,3)* and congestion on line *(2,3)*. We calculate and analyze these cases in turn.

4.1 Equilibrium with no congestion

As previously discussed in the chapter, transmission rights have no value in this case, so their prices are zero. Solving (3.40) and (3.41) together yields the equilibrium generation levels. For such unconstrained equilibrium to exist, the lines should have sufficiently large capacity. Thus (3.12), (3.13) and (3.14) are necessary conditions for this equilibrium, same as in the previous section. The values of endogenous variables in this equilibrium are:

$$q_1^N(\alpha)=\frac{3A}{11}$$

$$q_2^N(\alpha)=\frac{2A}{11}$$

$$p^N(\alpha) = \frac{2A}{11}$$

$$CS^N(\alpha) = \frac{25A^2}{242}$$

$$\pi_1^{\ N}(\alpha) = \frac{27A^2}{242}$$

$$\pi_2^{\ N}(\alpha) = \frac{8A^2}{121}$$

$$TS^N(\alpha) = \frac{34A^2}{121}$$

$$\lambda_2^{\ N}(\alpha) = \lambda_3^{\ N}(\alpha) = R_t^{\ N}(\alpha) = 0$$

The line capacities should satisfy the following parameter restrictions:

$$K_{12} > \frac{A}{33}$$

$$K_{13} > \frac{8A}{33}$$

$$K_{23} > \frac{7A}{33}$$

Note that these values are identical to their counterparts in Section 3.1 once the substitution is made for *c=2*. In the no-congestion equilibrium, the fact that G1 has an ownership interest in the grid company has no impact on anything because this share has no value in equilibrium.

4.2 Equilibrium with the line between two generators congested

The profit maximization conditions of G1 and G2, respectively, are (3.40) and (3.41). The equilibrium in the transmission capacity reservations market is given by (3.18), as in Section 3.2. The capacity constraint of line *(1,2)* is binding in this equilibrium and is given by (3.19). The requirement that the other two lines should have sufficiently large capacities is given by (3.20) and (3.21). Solving (3.18) ,(3.19), (3.40) and (3.41) together results in the following equilibrium values:

$$q_1^{(1,2)}(\alpha) = \frac{(2-\alpha)A + 3(5+4\alpha)K_{12}}{9-5\alpha} \tag{3.42}$$

$$q_2^{(1,2)}(\alpha) = \frac{(2-\alpha)A - 3(4-\alpha)K_{12}}{9-5\alpha} \tag{3.43}$$

$$Q^{(1,2)} = \frac{2(2-\alpha)A + 3(1+5\alpha)K_{12}}{9-5\alpha} \tag{3.44}$$

The parameter restrictions on the line capacities for an equilibrium with line *(1,2)* congested are

$$K_{12} \leq \frac{A}{33}$$

$$K_{13} > \frac{(2-\alpha)A + (6-7\alpha)K_{12}}{9-5\alpha}$$

$$K_{23} > \frac{(2-\alpha)A - (3+2\alpha)K_{12}}{9-5\alpha}$$

Differentiating (3.42) with respect to α reveals that $\frac{\partial q_1^{(1,2)}}{\partial \alpha} > 0$ for all $\alpha \in [0,1]$. In other words, G1 increases its output in response to an increase in its share of the transmission company. From (3.44) it is also easily checked that G2's output also increases in equilibrium with respect to a marginal increase in α, thus total output increases since both generators raise their output levels. This implies that price is lower and consumers benefit as consumers' surplus is also higher.

Since increasing q_1 also necessarily increases q_2, due to the transmission constraint having to be respected, and congestion revenue is an increasing function of both q_1 and q_2, G1 has extra incentive to expand its output with increased share of the transmission revenues. In fact, profits of G1 increase with α. Prices of TCRs and the transmission revenue also increase with α. Since the energy price decreases with α, the consumer surplus increases, so does the total surplus. The only losing party with an increase in α is G2 as its profit decreases. In fact, generation profits of G1 also go down with increased α, but the increase in transmission revenue more than compensates for that loss.

This suggests that generator ownership in the grid company is not necessarily detrimental for the consumers and thus should not be banned outright by the regulators. Rather, it should be considered on a case by case basis. If an ownership of a generator is going to give it an incentive to increase output and that in turn leads to an expansion in total output, thus reducing market price, than it is beneficial for the consumers and the society as a whole and should be allowed. However, that a generator's ownership interest in the grid company induces it to expand its own output is not sufficient for this ownership to be beneficial for the consumers and the society as a whole. It is possible for that this marginal incentive to increase the output of that generator but in turn reduce the output of the other generator even more, thus reducing total output and increasing energy price. This can happen because of the externalities due to loop flow and congestion on the network. Next section is an example of this rather counterintuitive possibility.

4.3 Equilibrium with the line connecting G1 to consumers congested

The generator profit maximization conditions for this case again are (3.40) and (3.41). TCR market equilibrium condition is given by (3.25), as discussed in Section 3.3. The condition for the binding capacity constraint of line *(1,3)* is given by (3.26). The other two lines should not be congested thus (3.27) and (3.28) should hold for this type of equilibrium to exist. Solving (3.25), (3.26), (3.40) and (3.41) together yields the following equilibrium values:

$$q_1^{(1,3)}(\alpha) = \frac{-(1-2\alpha)A + 3(7-8\alpha)K_{13}}{15-14\alpha} \qquad (3.45)$$

$$q_2^{(1,3)}(\alpha) = \frac{2(1-2\alpha)A + 3(1-2\alpha)K_{13}}{15-14\alpha} \qquad (3.46)$$

$$Q^{(1,3)}(\alpha) = \frac{(1-2\alpha)A + 6(4-5\alpha)K_{13}}{15-14\alpha} \qquad (3.47)$$

The parameter constraints on the line capacities are

$$K_{12} > \frac{\alpha A + (1-5\alpha)K_{13}}{8-7\alpha}$$

$$K_{13} \le \frac{8A}{33}$$

$$K_{23} > \frac{(7-2\alpha)K_{13} - \alpha A}{8-7\alpha}$$

This case is an example of a situation where an increased generator share in the transmission company is detrimental to the consumers even though the generator increases its own output. Differentiating (3.45) with respect to alpha shows that $\frac{\partial q_1^{(1,3)}}{\partial \alpha} > 0$ for $\alpha = 0$ and any other α below a threshold, that is, when G1 owns no or a small share of the transmission company. The output of G1 increases again with α whereas the output of G2 decreases this time, as can be easily calculated from (3.46). They cannot simultaneously increase since they are both congesting the constrained line and thus an increase in the output of one must come at the expense of a decrease in the output of the other. In fact, since $2q_1+q_2=K_{13}$ in this equilibrium, a unit of increase in G1's output must be matched by a decline in output of G2 by at least two units in order to respect the transmission constrained. Therefore, an increase in output by G1 must decrease the total output (as can be calculated from (3.47)), increase the energy price and thus make the consumers worse off in this equilibrium.

As can be seen from this case, a regulatory rule designed to allow a generator to own shares in the transmission company (or more generally, transmission rights) only if it induces the generator to expand own output would fail to protect the consumers. In an effort to increase its share of congestion revenues with this added incentive, the generator would expand output, which in equilibrium would require the other generator to decrease output. If, as is the case in this example, the distribution factor of the output of the generator with the transmission company share is higher than that of the other generator, total output is necessarily lower to obey the maximum flow limit on the already congested line, resulting in lower consumers' surplus.

4.4 Equilibrium with the line connecting G2 to consumers congested

In an identical manner to the cases in this section and the previous section, solving the relevant equilibrium conditions yield the following, with similar parameter restrictions to satisfy corresponding line flow limits (that line *(2,3)* is indeed congested and the other two lines are not, based on the flow, line capacities and model parameters).

$$q_1^{(2,3)}(\alpha) = \frac{(1+\alpha)A + 3(1-2\alpha)K_{23}}{6-\alpha} \quad (3.48)$$

$$q_2^{(2,3)}(\alpha) = \frac{-(1+\alpha)A + 3(5+\alpha)K_{23}}{2(6-\alpha)} \quad (3.49)$$

$$Q^{(2,3)}(\alpha) = \frac{(1-\alpha)A + 3(7-3\alpha)K_{23}}{2(6-\alpha)} \quad (3.50)$$

This case is another example where allowing a generator to own a (small) share of the transmission company results in higher total production and thus increased consumers' surplus. In this equilibrium, $\frac{\partial q_1^{(2,3)}}{\partial \alpha} > 0$, $\frac{\partial q_2^{(2,3)}}{\partial \alpha} > 0$ and $\frac{\partial Q^{(2,3)}}{\partial \alpha} > 0$, at least for small α, including $\alpha = 0$. In other words, G1's output as well as the total output rises, whereas G2's output falls, in response to a marginal increase in G1's ownership of the transmission company.

The binding constraint on the output levels in this case is $q_1+2q_2=K_{23}$. As in the previous case and for the same reasons, q_1 increases with α. Now this requires G2 to reduce output by only half a unit, as this is sufficient to maintain the line flow limit. As a result, reduction in G2's output is less than the increase in G1's output as a result of the marginal increase in G1's share of the transmission company, thus total output and consumers' surplus are higher in the market.

5. Conclusion

In this chapter we studied a model of the wholesale electricity sector consisting of two commodities: electricity and nodal transmission reservations (TCR). Two generators compete a la Cournot and consumers are price takers. In the TCR market the ISO sells the nodal transmission capacity reservations to the generators at opportunity cost. For the sector to be in equilibrium, both markets should be simultaneously in their own equilibrium states. The equilibrium in the electricity market is the usual Cournot equilibrium. The equilibrium concept in the rights market is the market-clearing. Given the equilibrium of the electricity market and the prices of TCRs, no generator should want more or less rights at any node. Depending on the capacities of the three lines, it is possible to have an equilibrium where any one of the lines is congested or there is no congestion on any of the lines.

Next we look at what happens to equilibrium in the rights and power market when a generator has an ownership interest in the transmission company. We find that the results are mixed in terms of the resulting consumers' surplus. Whether allowing such ownership is beneficial for the consumers depends on the particular case. We find that in certain equilibria allowing such transactions results in increased consumers' surplus whereas in other equilibria it is detrimental for the consumers. Therefore, we conclude that banning generators from owning shares in transmission company, or transmission rights in general, is not necessarily consistent with consumer protection or enhancing competition.

Chapter IV: **Imperfect Competition between Private and Public Generators on Electric Power Networks**

1. Introduction

In many countries public ownership of vertically integrated franchise utilities had been the dominant structure of the electricity supply industry prior to the end of 1980s. Since then many countries have witnessed a thorough restructuring in their electricity sectors: the U.K being the prime example. A number of countries - Australia, New Zealand, Chile and some states of the U.S, to name a few – unbundled their formerly vertically integrated franchise utilities, and deregulated and opened to competition the wholesale generation and retail segments while keeping the natural monopoly network segments, i.e., the high-voltage transmission and distribution segments, either under public ownership or strict regulation. Despite these developments, public ownership of generation assets and capacity is still the dominant type of ownership in many countries. Furthermore, in many cases where it is not, public production still constitutes a significant share of the wholesale generation segment. The policy challenge for public authorities in many countries is to determine the extent of the public generation assets that should be privatized and the objective function of any remaining public generation companies.

Wholesale electricity markets in many European countries are characterized by "mixed" oligopolies where public generators compete with their private counterparts. These past few years in the European wholesale electricity sector witnessed a trend toward fewer and larger players, (partial or full) privatization and listing of some publicly held generation companies, deregulation and opening to competition of national markets and establishment of cross-border trading institutions and regional power exchanges. All of these developments intensified competition between generators and made competition possible on larger scales and footprints.

Table 1 demonstrates the mixed oligopolistic nature of the overall European wholesale electricity market. The largest generation owner, three of the largest five and at least six of the largest fourteen generation capacity owners are state-owned (either in full or by a controlling majority) entities. Over sixty percent of total capacity of these largest generation owners is publicly controlled. EdF in France, ENEL in Italy, Statkraft in Norway, Vattenfall in Sweden, Fortum in Finland, CEZ in the Czech Republic and ESB in Ireland are all state-owned companies. EnBW in Germany is 45% owned by EdF, the French state-owned company. Table 2 presents the breakdown of generation capacity in two specific markets: the Nordic countries (comprised of Sweden, Norway and Finland) and Germany. Both markets can be described as mixed oligopolies: they are characterized by a few large generators, some of which are public, and a competitive fringe of smaller competitive players. Publicly owned electricity companies, all of which are involved in electricity generation, seem to be flourishing in the new cross-national electricity markets of Europe. The Nordic electricity market, linking Norway, Sweden and Finland, as shown in Table 2, is dominated by Vattenfall, Fortum and Statkraft. The most rapidly expanding multinational in Europe is EdF. EdF, a 100 percent state owned company, has activities not only in West European countries, but also in Central and Eastern Europe, North America, Latin America, Asia and Africa. In most of these markets publicly owned companies compete with privately owned companies.[44]

Table 1: Generation Capacity and State Ownership of Major European Electricity Generators[45]

COMPANY	COUNTRY	CAPACITY (GW)	STATE OWNERSHIP (%)
EdF	France	123	100
E.ON	Germany	54	0
Enel	Italy	47	42
RWE	Germany	45	0
Vattenfall	Sweden	33	100
Electrabel	Belgium	29	0
Endesa	Spain	29	0
Iberdola	Spain	20	0
EnBW	Germany	15	45 (by EdF)
British Energy	U.K.	12	0
CEZ	Czech Republic	12	67.6
EDP	Portugal	11	20.5
Fortum	Finland	11	59.3
Statkraft	Norway	11	100

[44] To cite an example, in Norway the breakdown of installed capacity by type of ownership is as follows: about 30 percent state owned, 15 percent privately owned, and the rest owned and operated by municipalities. For shares in actual production a very similar pattern is observed. (We thank Tor Arnt Johnsen and Trond Espen Haug for these data on Norway). See Hall (1999) for a more general account of publicly owned electricity companies in Europe.

Table 2: Generation Capacity Concentration in Nordic Countries and Germany[46]

COMPANY	NORDIC COUNTRIES	GERMANY
Vattenfall	21%	16%
E.ON/Sydkraft	8%	29%
RWE	-	37%
Fortum	14%	-
Statkraft	11%	-
EnBW	-	11%
Others	46%	7%

Profit maximization has typically not been a significant part of the objective of public generation companies. In Sweden, for example, Vattenfall's formal objective has been to break even, with depreciation on replacement values and a rate of interest on loans from the government at the bond rate level being included. Pricing in the wholesale market for bulk power has been indirectly regulated through state ownership of Vattenfall. This has established Vattenfall as a price leader, and yardstick competition between public and private generators has created a downward pressure on prices. As in Sweden, the formal, government-enforced regulations have historically been fairly weak in Norway and Finland as well. Instead, the industries are to a large extent characterized by publicly owned dominant firm leadership, self-enforced club-regulation,

[45] Source: Vattenfall 2005 Annual Report
[46] Source: Vattenfall 2005 Annual Report

and yardstick competition. In the U.S. non-private generators (publicly owned utilities, cooperatives and federal power agencies) are by law required not to maximize profit.

The European Union's ("EU") Electricity Directive - Directive 96/92/EC of the European Parliament and of the Council of December 19, 1996 concerning common rules for the internal market in electricity - does not explicitly require member countries to privatize electricity utilities. However, the EU introduced a new electricity law in 1998, which requires member states to open their electricity markets for international trading. Furthermore, as discussed in the Communication of 13 March 2001 given by the Commission[47], more radical changes in the EU electricity markets are under way which are intended to eventually result in a EU-wide single market. The changes that have been proposed for implementation, to name a few, are: clear and effective unbundling of vertically-integrated electricity companies, standard and published third party access tariffs to transmission and distribution networks, existence of independent national regulatory authorities, and a regulatory body at the European level.[48] On June 26, 2003, Directive 2003/54/EC and Regulation (EC) No. 1228/2003 of the European Parliament and of the Council were issued. The Directive implements the common rules for the internal market in electricity and repeals Directive 96/92/EC, whereas the Regulation lays down the conditions for access to the network for cross-border exchanges in electricity.

Directive 2003/54/EC attempts to ensure a level playing field in generation markets and reduce risks of market dominance through non-discriminatory, transparent and

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[47] COM(2001) 125, "Completing the Internal Energy Market".

[48] Most of these changes have now been adopted at the Barcelona European Council, March 15-16, 2002.

fairly priced access to transmission networks. It falls short of mandating structural unbundling of the transmission component from vertically integrated utilities but it requires legal separation and independent operation of transmission systems from generation and supply interests. This directive also orders non-discriminatory and cost-reflective balancing market tariffs until there is a liquid and competitive spot market for power. Finally, Directive 2003/54/EC requires harmonization of regulatory authorities of member states and lays down a minimum set of criteria and responsibilities they should satisfy. These criteria and responsibilities can be summarized as independence from electricity industry interests and ensuring non-discrimination, effective competition and efficient functioning of the market within their respective countries.

Regulation 1228/2003, on the other hand, attempts to establish fair, cost-reflective, transparent and directly applicable rules for cross-border tarification and calculation and allocation of available interconnection capacities. The Regulation's most significant and relevant provisions are that (1) it does not allow for distance related transmission rates or additional import or export charges on top of access fees, (2) it mandates transparent available transmission capacity ("ATC") figures and a uniform set of operational and planning standards for the calculation of ATCs, (3) it requires the congestion management procedures to be non-discriminatory among market participants, based on market mechanisms and sending correct economic signals to the market participants and system operators, and (4) it orders transmission prices to be established on the basis of forward-looking long-run average incremental costs.

In its current configuration, and to a greater extent in the European single market scenario, a public company is going to be acting like a public firm in its own country but like a private firm in the markets of other countries. Therefore, even markets that are currently totally dominated by a public firm, like France, will become mixed oligopolies.

Even in the United States, known as the stronghold of the investor-owned utility model, there is a non-negligible ownership of capacity by the public authorities. Table 3 below is constructed from the data reported by the American Public Power Association ("APPA").[49] As of year-end 2004 publicly owned utilities, federal power agencies and cooperatives collectively had 20.7% of the total U.S. nameplate capacity and 22.2% of the total U.S. electricity generation. It is also worth noting that capacity owned by investor-owned utilities for the most part is under state regulation, has fixed-price obligations to native load, and is not necessarily operated for pure profit maximization purposes.

Table 3: Capacity Ownership and Generation in U.S. Electric Industry (2004)

	Nameplate Capacity (MW)	% of Total	Generation (1,000 MWhs)	% of Total
Publicly Owned Utilities	98,686	9.6%	397,110	10.3%
Investor-Owned Utilities	408,699	39.6%	1,734,733	44.8%
Cooperatives	43,225	4.2%	181,899	4.7%
Federal Power Agencies	71,394	6.9%	278,130	7.2%
Power Marketers			42,599	1.1%
Non-Utilities	409,689	39.7%	1,235,298	31.9%

[49] American Public Power Association, 2006-07 Annual Directory & Statistical Report, page 22 <http://www.appanet.org/files/PDFs/nameplate2004.pdf>.

The U.S. electricity sector has historically been, and in most respects still is, characterized by state-level regulation of vertically-integrated electric utilities based on the grant of an exclusive local monopoly franchise. The utilities have owned generation, transmission, and distribution assets, and were responsible for providing reliable bundled service to their service territory defined in their franchise agreement with their state public utilities commissions. Attempts to introduce competition into the wholesale generation segment began by the Public Utility Regulatory Policies Act ("PURPA") of 1978. It was followed by significant milestones such as Energy Policy Act ("EPAct") of 1992, Federal Energy Regulatory Commission's ("FERC") Order No. 888 and Order No. 889 of 1996, Order No. 2000 of 1999 and Order No. 2003 of 2003.

PURPA defines a class of generating facilities, called Qualifying Facilities ("QF"), which are co-generators or small scale producers that meet certain FERC criteria based on fuel use, size, fuel efficiency and reliability. QFs are not considered to be utilities and thus are exempt from regulation under the Public Utility Holding Company Act ("PUHCA") and the Federal Power Act ("FPA"). Under PURPA, a utility is required to purchase power from QFs at its avoided cost. This act, as an unintended consequence, marked the effective end of the era in which public and private utilities monopolized electricity generation and created a fringe of independent power producers. The EPAct increased competition in the electricity generation sector by creating new entities that can generate and sell electricity at wholesale without being subject to regulation as utilities are under PUHCA. EPAct established "exempt wholesale generators" ("EWG") that are not considered electric utilities and are therefore exempt from PUHCA and FPA regulations. Under EPAct, state regulators could allow utilities to purchase electricity from EWGs at contracted market-based rates. Both registered and exempt holding companies under PUHCA may own and operate EWGs. As a result of EPAct, electric utilities and others could sell power to one another across state lines and utility territories on a competitive basis and thus a competitive interstate wholesale power market was created.

Concerned that obstacles to access to transmission would stifle generation markets, FERC issued Orders 888, 889 and 2000 in the second half of 1990s, pursuant to the EPAct. Order No. 888 requires that public utility and federal power marketing agency transmission owners provide open access to their grid to non-owners at cost-based maximum prices and non-discriminatory terms and conditions, make their best efforts to increase transmission capacity for third parties who are willing to pay associated costs, and behave as if they are not vertically integrated when they use their transmission systems to support wholesale power transactions. Order No. 888 also requires the transmission owners to participate in information-sharing systems to communicate their available transmission capacity, the terms on which it is offered and the rationing mechanisms to be employed in case of excess demand. Order No. 889 bolsters and operationalizes Order No. 888 by requiring public and private utilities to create or participate in an Open Access Same-Time Information Systems ("OASIS"), designed to provide transmission customers with up-to-the-minute electronic information about available transmission capacity, prices and other information that will make it possible to obtain open access, nondiscriminatory transmission service. All transmission owners in the U.S. filed open access tariffs with FERC and complied with Orders 888 and 889.

Order No. 2000 is a companion order to Order No. 888 and attempts to organize the many transmission owners in the U.S. into Regional Transmission Organizations ("RTO"). Order 2000 lays out four minimum characteristics and eight functions that an RTO must possess, but leaves the details up to the industry, subject to FERC approval. The four minimum characteristics are (1) independence from market participants, (2) appropriate scope and regional configuration, (3) possession of operational authority for all transmission facilities under the RTO's control, and (4) exclusive authority to maintain short-term reliability. As to the eight minimum functions, an RTO must (1) administer its own tariff and employ a transmission pricing system that will promote efficient use and expansion of transmission and generation facilities, (2) create market mechanisms to manage transmission congestion, (3) develop and implement procedures to address parallel path flow issues, (4) serve as a supplier of last resort for all ancillary services required in Order No. 888 and subsequent orders, (5) operate a single OASIS site for all transmission facilities under its control with responsibility for independently calculating TTC and ATC, (6) monitor markets to identify design flaws and market power, (7) plan and coordinate necessary transmission additions and upgrades, and (8) provide interregional coordination. Although joining an RTO is voluntary for a transmission owner, it has been made advantageous to do so by actions taken by the FERC. Among the incentives for joining an RTO are higher rate of return on transmission assets, automatic approval of market-based rate authority applications and automatically passing transmission market power tests in merger proceedings. In fact, overwhelming majority of jurisdictional utilities either joined or made an official commitment to the FERC or to their states to join an RTO.

The net impact of all these legislations and FERC policies has been elimination of discrimination against independent generators in dispatch, interconnection, transmission planning and access, transparent price signals for plant operation and investment, more targeted and local market power tests and mitigation measures, and thus increased competition on larger scales and footprints.

Analysis of a mixed electricity market can also be considered to apply to a wholesale power industry where regulated and unregulated private firms are competing, rather than public and private firms. Thus, it would at least apply to the RTO markets that use locational marginal pricing as the congestion management tool, such as PJM Interconnection, Midwest ISO and ISO New England. In these markets independent generators compete with generators that are owned by vertically integrated utilities. In this framework, to the extent profits from “off-system sales” of the utilities are shared between the shareholders and the ratepayers of the utilities, the utilities still have incentive to make profits from the generation assets, but not as strong as the incentives of independent generation companies that are entitled to all of the profits (and losses).

In addition to the countries discussed above, many other countries, developed as well as developing, have already partially privatized and/or totally restructured their electricity industries or are in the process of doing so. It is evident that it will take a long time, if it will ever happen, for all countries to sell all of their public generation assets. Therefore, the wholesale generation segment of electricity industry may remain a mixed oligopoly for many years, with public and private firms operating together.

It is well known from the Industrial Organization literature that in a standard industry structure without externalities, if a public firm competes with private firms in an imperfectly competitive market (i.e. in a 'mixed market') social welfare might in certain cases be higher when the public firm is instructed to maximize profits instead of maximizing social welfare.[50] The basic intuition behind this result is that when a public firm is instructed to maximize total social surplus, in some cases it tends to produce so much that gains to consumers from high consumption levels are dominated by the allocative inefficiency caused by inefficient public production displacing more efficient private production. Only in a sequential quantity-setting game where the public firm is the Stackelberg leader is it the case that instructing the public firm to maximize social welfare may indeed lead to higher social welfare.[51]

We do not discuss the results from those papers in detail here because they examine the very simplistic case that the only choices available to the public authority are tasking the public firm with pure profit maximization and pure total surplus maximization. However, it is also possible to instruct the public firm to take into account both. In that case, policy choice is a continuum between 0 and 1 where 0 corresponds to pure profit maximization, 1 corresponds to pure welfare maximization and a number between them corresponds to a weighted average of the two. As our results indicate, optimal regulatory policy is almost always an interior one, i.e. it is almost never optimal to instruct the public firm to maximize profits or total surplus. To our knowledge, optimal choice of a public firm's objective function in a mixed oligopolistic market has not been examined where potential choices include a weighted average of profits and total surplus (or consumers' surplus.)

[50] See De Fraja and Delbano (1989 and 1990). See also Cremer, Marchand and Thisse (1989) for a model in which the public firm is used as an instrument for regulating an oligopolistic market.
[51] See Sertel (1988).

Furthermore, the results on mixed markets do not cover some of the interesting features of electricity markets. For example, when two nodes are connected to each other through a transmission line, there might arise congestion on the interface if suppliers demand to use the line over its capacity. In other words, the interaction between the public and the private firm might be one in which a transmission capacity constraint is involved. To our knowledge this case has not been covered in the existing literature on imperfectly competitive mixed markets. Secondly, when the network involves more than two nodes, e.g. when two different suppliers at two different nodes are connected to the same third node where consumption takes place, certain network externalities arise. This is due to the existence of loop flows in electricity transmission. When different nodes are connected over a transmission network, a trade between two parties can impact a non-participating third party (positively or negatively) by congesting or de-congesting the connecting lines that the third party uses and thus alters the cost the third party faces or the quantity it will be able to sell at a particular node.[52]

In this chapter we consider an electricity sector that consists of an unregulated private firm and a regulated ("public") firm. A particular objective is to examine whether and under what circumstances the results mentioned above for mixed oligopolies in standard industry structures extend to the wholesale power markets that involve a looped transmission network.

We study both a two-node (no loop-flow) and a three-node (loop-flow) electricity network. In the two-node network, consumers are located on one of the nodes only.

[52] This is because electrons follow a unique path on an electrical transmission network determined by Kirchoff's Law rather than the direction of the trade.

One of the generators is located where demand is, whereas the other generator is located on the other node where there is no demand. We assume that one of the generators has a cost advantage over the other. Thus we are considering a situation where a local monopoly, be it private or regulated, faces competition from a more efficient producer that is located away from the market. The competition from the far away producer is limited by the fixed capacity of the transmission line linking the two nodes. We consider separately the case where the local monopoly is a private firm as well as the case where it is a regulated firm.

We then study a three-node network, which is the minimum configuration that allows us to analyze the effects of loop flows. Each pair of these nodes is connected by a transmission line with some fixed thermal capacity. The private and the regulated generators are located on two separate nodes and the consumers are located on the third node. There is no demand for power on nodes where the producers are located and there is no generation capacity available on the node where the consumers are located. The two generators are assumed to choose non-cooperatively and simultaneously the quantities they generate, i.e. there is Cournot type competition between them.[53] The quantities they choose are to be considered as pre-dispatch quantities submitted to an Independent System Operator (ISO) that is in charge of reliably operating the transmission network. If the chosen quantities by the generators induce power flows that exceed the thermal limit on any part of the network, the ISO warns about the infeasibility of the bid dispatch it received and asks the generators to

[53] See Borenstein, Bushnell and Stoft (1998) for use and justification of Cournot competition in power generation markets. See also Wolak and Patrick (1996) for evidence that exercise of market power in the

adjust their output. We study the choice of optimal regulatory policy for the regulated firm for a number of different cases.

The plan of this chapter is as follows. In Section 2 we introduce the general features of the model we study. In Section 3 we analyze the two-node network case. In Section 4 we study the three-node network case, which allows for explicit consideration of loop flows. In Section 5 we provide a summary of our results and offer some concluding remarks.

2. The Model

We adopt the two simple models of the electricity sector that were studied in Joskow and Tirole (2000). The general features of the model that are common in both the two- and the three-node analyses are as follows.

Let P denote the private firm and R denote the regulated firm. The production technologies of the generators are characterized by positive and strictly increasing marginal cost functions. Thus, letting $C_i(q_i)$ denote the cost function of firm i, $C_i^{'} > 0$ and $C_i^{''} > 0$, $i = P, R$. The consumers' demand for power is characterized by an inverse demand function $P(Q)$. To obtain closed form solutions, we adopt the cost function specification

$$C_i(q_i) = \frac{1}{2} c_i q_i^2 + F_i \qquad (4.1)$$

U.K. has taken place through capacity withholding. Oren (1997), Cardell, Hitt and Hogan (1996), Smeers and Wei (1997), Joskow and Tirole (2000) also use Cournot competition in their analysis.

where $F_i \geq 0, i = P, R$ is the fixed cost[54], and the affine inverse demand function specification

$$P(q_P + q_R) = a - (q_P + q_R) \tag{4.2}$$

The private firm's objective is the standard one, i.e. to maximize profits. The regulated firm is assumed to maximize a weighted average of total surplus and its own profits. Total surplus is defined as the sum of consumers' surplus and total short-run industry profits:

$$W(q_R, q_P) = \int_0^{q_R+q_P} P(Q)dQ - P(Q)Q + PS_P(q_R, q_P) + (1+\eta)PS_R(q_R, q_P) \tag{4.3}$$

where $PS_i(q_R, q_P)$ is the variable profit (total profit *plus* sunk cost, also known as producer surplus) function of firm $i, i = P, R, Q \equiv q_R + q_P,$ and $\eta \geq 0$ is a parameter reflecting the shadow cost of public funds. The presence of shadow cost of funds indicates that the taxes collected by the government to subsidize the regulated firm's losses are distortionary, and that each dollar raised and spent by the government costs $\$(1+\eta)$ to the society when the (marginal) excess burden of the taxes collected is taken into account.[55]

The regulated firm's objective function is assumed to be

$$\alpha W(q_R, q_P) + (1-\alpha)\Pi_R(q_R, q_P), \tag{4.4}$$

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[54] Throughout this paper we assume that the fixed costs are sunk for both firms. That is, we will be concentrating on output decisions in the short run after the firms' generating capacity decisions are already made.

[55] Note that the above specification assumes full extraction of the regulated firm's profits by the government.

where $\alpha \in [0,1]$ is the weight attached to total surplus. Thus, $\alpha = 1$ refers to a 'pure' public firm whose objective is to maximize total surplus, while $\alpha = 0$ case refers to a pure private firm. The cases where $\alpha \in (0,1)$ trace all possible regulatory regimes between total surplus maximization and profit maximization. An alternative interpretation would be to consider the regulated firm as partially privatized and partially owned by the government, where the parameter α indicates the government's share in the firm. In this case the firm's objective function would be assumed to reflect the ownership structure.

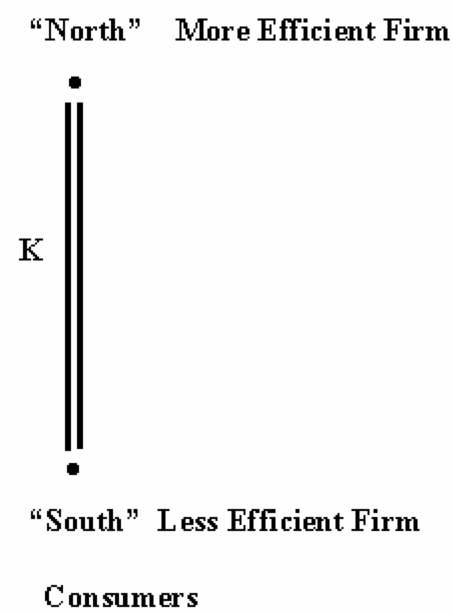
3. A Two-Node (No Loop Flow) Network

In this section we analyze the simpler two-node network case where consumers are located on one of the nodes only. Following Joskow and Tirole (2000) we denote the node where the consumers are located as "South'.' One of the producers is located where demand is, on the South node. There is no demand on the other node, namely "North," where the other producer is located. The producer located away from the consumers, i.e. the producer in the North, is assumed to have a cost advantage over the producer in the South (the local monopoly).

We first analyze the case where the firm in the South is the (profit-maximizing) private firm, and then analyze the case where the regulated firm is located in the South. Since the firm located in the South has direct access to consumers, it is assumed to face no capacity constraint in production, while the firm in the North is constrained by the capacity of the transmission line that connects the South node to the North node.

Let K denote the capacity of the line between the North and the South (see Figure IV-1 for the depiction of the two-node network configuration described above).

Figure IV-1: Two-Node Network



Firms are assumed to engage in Cournot competition, i.e. they compete by simultaneously choosing output levels, the choice of the output of the firm located in the North being constrained by the transmission line capacity.[56]

[56] See Borenstein, Bushnell and Stoft (1998) for use and justification of Cournot competition in power generation markets. See also Wolak and Patrick (1996) for evidence that exercise of market power in the UK has taken place through capacity withholding. Oren (1997), Cardell, Hitt and Hogan (1996), Smeers and Wei (1997), Joskow and Tirole (2000), among many others, also use Cournot competition in their analysis.

3.1 Regulated Firm in the North

In this section we analyze the case where the private firm is located in the South and the regulated firm in the North, thus it is the regulated firm that faces the capacity constraint K in its output decisions. The marginal cost advantage of the firm in the North is represented by assuming $c_R = 1$ and $c_P = c > 1$. The private firm's optimization problem then is

$$\max_{q_P} \Pi_P(q_R, q_P) = P(q_P + q_R)q_P - \frac{1}{2}cq_P^2 - F_P \qquad (4.5)$$

implying the response function

$$q_P(q_R) = \frac{a - q_R}{c + 2}. \qquad (4.6)$$

The regulated firm's problem can be written as

$$\max_{q_R} \ \alpha \frac{(q_P + q_R)^2}{2} + \alpha\left[P(q_P + q_R)q_P - \frac{1}{2}cq_P^2\right] + (1+\alpha\eta)\left[P(q_P + q_R)q_R - \frac{1}{2}q_R^2\right] \qquad (4.7)$$
$$\text{s.t. } q_R \le K$$

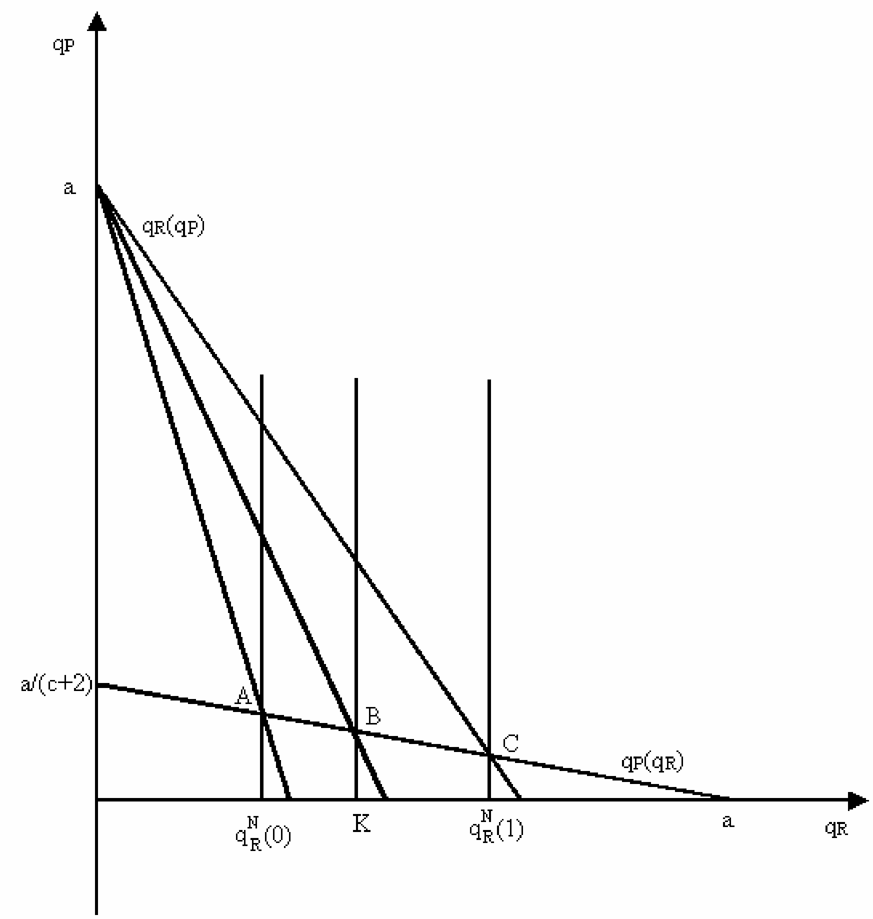
The capacity constraint appears in the regulated firm's maximization problem, because, as already mentioned, the ISO in charge of feasible dispatch on the transmission network enforces this constraint. The Kuhn-Tucker necessary conditions for the regulated firm's problem are

$$\frac{\partial L}{\partial q_R} = (1+\alpha\eta)a - [3(1+\alpha\eta) - \alpha]q_R - (1+\alpha\eta)q_P - \lambda = 0$$
$$\frac{\partial L}{\partial \lambda} \ge 0 \text{ and } \lambda[K - q_R] = 0$$

Depending on K, the response function of the regulated firm takes different forms. The unconstrained response function of the regulated firm is

$$q_R(q_P) = \frac{(1+\alpha\eta)[a - q_P]}{3(1+\alpha\eta) - \alpha}. \tag{4.8}$$

Figure IV-2: Response Functions with Regulated Firm in the North Node



Note that $q_R(q_P)$ above depends on α. Figure IV-2 depicts the response functions of the two firms for a given K. The response function of the regulated firm that passes through point A corresponds to the case where $\alpha = 0$. Let $q_R^N(0)$ be the equilibrium output of the regulated firm when $\alpha = 0$ and K is large enough so that the constraint is not binding for the regulated firm in equilibrium. Note from (4.8) that as α increases the regulated firm's response function becomes flatter (in a continuous manner). The response function that passes through point C corresponds to $\alpha = 1$. Let $q_R^N(1)$ be the equilibrium output of the regulated firm when $\alpha = 1$. Note that if $K < q_R^N(0)$, then regardless of the value of α, the capacity constraint is always binding; Similarly, if $K > q_R^N(1)$, then the capacity constraint does not bind for any value of α. Thus, for a given level of $K \in \left[q_R^N(0), q_R^N(1) \right]$, there exists an $\alpha = \alpha(K)$ such that the capacity constraint becomes just binding in equilibrium. The response function in Figure IV-2 that passes through point B shows such a case. For a given K, if $\alpha \le \alpha(K)$ then the capacity constraint is not binding in equilibrium, whereas for $\alpha > \alpha(K)$ it is binding.

For a given K, suppose that $\alpha \le \alpha(K)$. The (unconstrained) equilibrium levels of output of the regulated and the private firm are:

$$q_R^N(\alpha) = \frac{(c+1)(1+\alpha\eta)a}{(3c+5)(1+\alpha\eta)-(c+2)\alpha} \tag{4.9}$$

$$q_P^N(\alpha) = \frac{\left[2(1+\alpha\eta)-\alpha\right]a}{(3c+5)(1+\alpha\eta)-(c+2)\alpha} \tag{4.10}$$

Note that $q_R^N(\alpha)$ is strictly increasing and $q_P^N(\alpha)$ is strictly decreasing in α. The total amount of electricity produced when capacity constraint is not binding is

$$Q^N(\alpha) = \frac{\left[(c+3)(1+\alpha\eta)-\alpha\right]a}{(3c+5)(1+\alpha\eta)-(c+2)\alpha} \tag{4.11}$$

and price of electricity is

$$P^N(\alpha) = \frac{(c+1)\left[2(1+\alpha\eta)-\alpha\right]a}{(3c+5)(1+\alpha\eta)-(c+2)\alpha}. \tag{4.12}$$

Note that $\frac{\partial P^N(\alpha)}{\partial \alpha} < 0$, i.e. the (unconstrained) equilibrium price is strictly decreasing in α.

From (4.9) $\alpha(K)$, implicitly defined by $q_R^N(\alpha(K)) = K$, can be computed as

$$\alpha(K) = \frac{(3c+5)K-(c+1)a}{(c+1)\eta a - \left[(3c+5)\eta-(c+2)\right]K} \tag{4.13}$$

For a given K, suppose now that $\alpha > \alpha(K)$. In this case the capacity constraint is binding in equilibrium and the respective equilibrium output levels of the regulated and private generators are:

$$q_R^B = K \tag{4.14}$$

$$q_P^B = \frac{a-K}{c+2} \tag{4.15}$$

Total electricity production and the market price are:

$$Q^B = \frac{a+(c+1)K}{c+2} \tag{4.16}$$

$$P^B = \frac{(c+1)(a-K)}{c+2} \tag{4.17}$$

3.1.1 Optimal Regulatory Policy

Note that the equilibrium levels of production stated above are for a given α, which can be viewed as a regulatory policy tool. As mentioned above, $\alpha = 1$ refers to a 'pure' public firm whose objective is to maximize total surplus. A question that arises is whether in this setting it will indeed be optimal to set $\alpha = 1$.

The total surplus in the present case is given by

$$W(q_R, q_P; K, \alpha) = PQ + q_R q_P - \frac{1}{2}(c-1)q_P^2 + \eta(Pq_R - \frac{1}{2}q_R^2) \qquad (4.18)$$

We first calculate the optimal value of α when the corresponding equilibrium output for the regulated firm is unconstrained (which will be the case when K is large enough). Let $W^N(\alpha) = W(q_R^N, q_P^N; K, \alpha)$, which can be computed by substituting (4.9), (4.10), (4.11) and (4.12) in (4.18). Differentiating $W^N(\alpha)$ with respect to α, and checking that the second order conditions are satisfied, result in the following optimal value of α:

$$\alpha^* = \frac{c^2 + 3c + (c+1)\eta}{c^2 + 3c + 1 - (c+1)\eta^2 + 2\eta} \qquad (4.19)$$

When $c = 1$ and $\eta = 0$, i.e. when the private firm is as efficient as the regulated firm and the shadow cost of public funds is zero, α^* is equal to $\frac{4}{5}$. For a given η, α^* is increasing in c, and for a given c it is increasing in η. That is, the optimal weight of total surplus in the regulated firm's objective function increases with the cost differential and with the shadow cost of public funds. Note that for α^* to fall in the interval [0,1], as per its definition, it has to be the case that $\eta \le \bar{\eta}$, where $\bar{\eta} = \frac{(1 - c + \sqrt{c^2 + 2c + 5})}{2(c+1)}$.

Define $K(\alpha) \equiv \alpha^{-1}(K) \equiv q_R^N(\alpha(K))$. For a given α, $K(\alpha)$ is the capacity level which is just equal to the unconstrained equilibrium output of the regulated firm. It is easily checked that $\alpha(K)$ is strictly increasing in K.

If $K \ge K(\alpha^*)$, i.e. if K is high enough so that the equilibrium output of the regulated firm induced by α^* is not constrained, then the optimal regulatory policy is to set $\alpha = \alpha^*$.

If, on the other hand, $K < K(\alpha^*)$, i.e. if K is not sufficiently large so that the equilibrium output of the regulated firm is constrained at $\alpha = \alpha^*$, then the optimal regulatory policy is to choose $\alpha \in [\alpha(K),1]$. This is because total surplus is increasing in α for $\alpha < \alpha^*$, and thus it will be optimal to set α at least equal to $\alpha(K)$.

The following proposition summarizes the optimal regulatory policy when the (more efficient) regulated firm is located in the North.

Proposition 1: If $K \geq K(\alpha^*)$, then the optimal regulatory policy is to set $\alpha = \alpha^*$. If $K < K(\alpha^*)$, then the optimal regulatory policy is to set $\alpha \in [\alpha(K),1]$.

Observe in (4.19) that when $c = 1$ and $\eta = 0$, i.e. when the regulated firm and the private firm have the same cost functions and the shadow cost of public funds is zero, we have $\alpha^* = \frac{4}{5}$. As c or η increases, the larger will be the optimal α. As the public firm's efficiency advantage increases the total surplus increases if the public firm produces more, a behavior which a higher α induces. As for η, a higher η indicates a higher marginal social value of collecting public funds through the profits of the regulated firm. In that case a higher η implies a higher optimal α. Note that only in the limiting case where either c or η is very high is the optimal α equal to 1. In other words, in almost no instance it is optimal to instruct the regulated firm to maximize total surplus. When $K < K(\alpha^*)$, total surplus maximization is not part of an optimal regulatory policy under any circumstance.

3.1.2 Optimal Choice of Transmission Capacity

The analysis so far considered the capacity level K as fixed. This amounts to treating the capacity cost as sunk cost in an ex-post analysis. Alternatively, one might consider the optimal ex-ante choice of the capacity of the transmission line.

Let $C_T(K) > 0$ be the total cost of installing a transmission line of capacity K between the North and the South, where $C_T'(\cdot) \geq 0$ and $C_T''(\cdot) > 0$.

As it is costly to install transmission capacity, a total surplus maximizing ex-ante choice of capacity is the one that leaves no unused capacity in equilibrium. Letting $W^B(K) \equiv W(q_R^B, q_P^B; K, \alpha)$ be the total surplus at the constrained equilibrium, the optimal ex-ante choice of K is the solution to the following maximization problem:

$$\max_K W^B(K) - C_T(K). \tag{4.20}$$

Note that if $C_T(K) = 0$, i.e. if capacity can be installed at no cost, then total surplus maximizing level of transmission capacity is $K = K(\alpha^*)$. So when $C_T(K) > 0$ the optimal transmission capacity is less than $K(\alpha^*)$.

3.2 Regulated Firm in the South

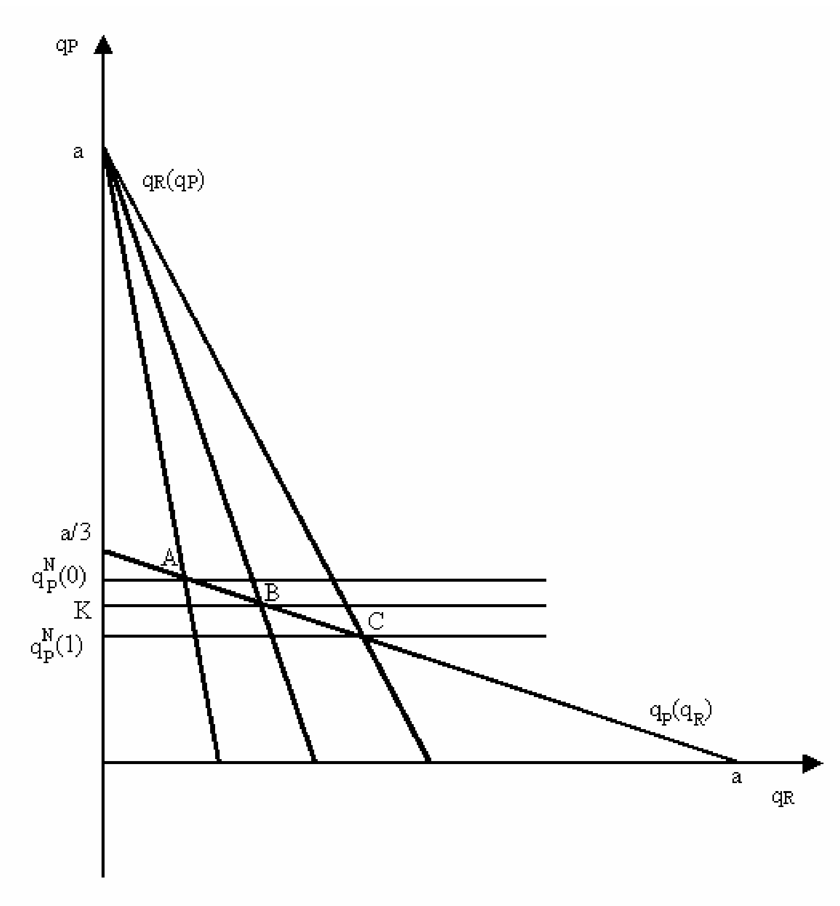
In this section we analyze the case where the private firm is located in the North and the regulated firm is located in the South. It is now the private firm that has the cost advantage. Specifically, we assume that $c_P = 1$ and $c_R = c > 1$. Now it is the private firm that faces the capacity constraint K in its output decisions. The private firm's problem therefore is

$$\max_{q_P} \ \Pi_P(q_R, q_P) = P(q_P + q_R)q_P - \frac{1}{2}q_P^2 - F_P \qquad (4.21)$$
$$\text{s.t.} \quad q_P \le K$$

The Lagrangian for this constrained optimization problem is

$$L = P(q_P + q_R)q_P - \frac{1}{2}q_P^2 - F_P + \lambda\left[K - q_P\right].$$

Figure IV-3: Response Functions with Regulated Firm in the South Node



The Kuhn-Tucker necessary conditions are

$$\frac{\partial L}{\partial q_P} = a - 3q_P - q_R - \lambda = 0$$
$$\frac{\partial L}{\partial \lambda} \ge 0 \text{ and } \lambda\left[K - q_P\right] = 0$$

Depending on K, the response function of the private firm takes different forms. The unconstrained response function of the private firm is

$$q_P(q_R) = \frac{a - q_R}{3}. \qquad (4.22)$$

The regulated firm's problem in this case is

$$\max_{q_R} \ \alpha \frac{(q_P + q_R)^2}{2} + \alpha \left[P(q_P + q_R)q_P - \frac{1}{2} q_P^2 \right] + (1 + \alpha\eta) \left[P(q_P + q_R)q_R - \frac{1}{2} c q_R^2 \right] \qquad (4.23)$$

implying the response function

$$q_R(q_P) = \frac{(1 + \alpha\eta)(a - q_P)}{(2 + c)(1 + \alpha\eta) - \alpha}. \qquad (4.24)$$

Note that, as in the previous case, the response function of the regulated firm depends on α. Figure IV-3 shows the response functions of the two firms for a given K. The response function for the regulated firm that passes through A corresponds to $\alpha = 0$. Let $\tilde{q}_P^N(0)$ be the equilibrium output of the private firm when $\alpha = 0$ and K is large enough so that the constraint is not binding for the private firm in equilibrium. Observe from (4.24) that as α increases, the regulated firm's response function becomes flatter (in a continuous manner). The response function that passes through point C corresponds to $\alpha = 1$. Let $\tilde{q}_P^N(1)$ be the equilibrium output of the private firm when $\alpha = 1$ and K is large enough so that the constraint is not binding for the private firm in equilibrium. Note that we have $\tilde{q}_P^N(0) > \tilde{q}_P^N(1)$. If $K < \tilde{q}_P^N(1)$, then regardless of the value of α, the capacity constraint is always binding for the private firm. Similarly, if $K \geq \tilde{q}_P^N(0)$, then the capacity constraint is not binding for any value of α. Thus, for a given level of

$K \in \left[\tilde{q}_P^N(1), \tilde{q}_P^N(0)\right]$, there exist an $\alpha = \tilde{\alpha}(K)$ such that the capacity constraint becomes just binding for the private firm in equilibrium. The response function in Figure IV-3 that passes through point B depicts such a case. For a given K, if $\alpha \geq \tilde{\alpha}(K)$ then the capacity constraint is never binding in equilibrium, whereas for $\alpha < \tilde{\alpha}(K)$ it is always binding.

For a given K, suppose now that $\alpha \geq \tilde{\alpha}(K)$. The respective (unconstrained) equilibrium levels of output of the regulated and the private firm in this case are:

$$\tilde{q}_R^N(\alpha) = \frac{2(1+\alpha\eta)a}{(3c+5)(1+\alpha\eta)-3\alpha} \tag{4.25}$$

$$\tilde{q}_P^N(\alpha) = \frac{\left[(c+1)(1+\alpha\eta)-\alpha\right]a}{(3c+5)(1+\alpha\eta)-3\alpha}, \tag{4.26}$$

Note that, as in the previous case, $\tilde{q}_R^N(\alpha)$ is strictly increasing and $\tilde{q}_P^N(\alpha)$ is strictly decreasing in α. It can be checked from (4.25) and (4.26) that $\tilde{q}_R^N(\alpha) > \tilde{q}_P^N(\alpha)$ if and only if $c-1 < \dfrac{\alpha}{1+\alpha\eta}$. This condition always holds if $\alpha = 0$. In other words, if both firms maximize only profits, the more efficient one will produce more, regardless of the value of η. However, when $\alpha > 0$, the regulated firm may produce more even though it is less efficient. For a given α, the regulated firm's equilibrium output is higher the smaller its relative cost inefficiency or the smaller is the shadow cost of public funds. The total amount of electricity produced and the price of electricity, respectively, when the capacity constraint is not binding are:

$$\tilde{Q}^N(\alpha) = \frac{\left[(c+3)(1+\alpha\eta)-\alpha\right]a}{(3c+5)(1+\alpha\eta)-3\alpha} \tag{4.27}$$

$$\tilde{P}^N(\alpha) = \frac{2(c+1)\left[(1+\alpha\eta)-\alpha\right]a}{(3c+5)(1+\alpha\eta)-3\alpha}. \qquad (4.28)$$

From (4.25) $\tilde{\alpha}(K)$, which is implicitly given by $\tilde{q}_P^N(\tilde{\alpha}(K)) = K$, can be computed as

$$\tilde{\alpha}(K) = \frac{(3c+5)K-(c+1)a}{\left[(c+1)\eta-1\right]a-\left[(3c+5)\eta-3\right]K}. \qquad (4.29)$$

For a given K, suppose now that $\alpha < \tilde{\alpha}(K)$. In this case the capacity constraint is binding for the private firm in equilibrium and the equilibrium output levels are

$$\tilde{q}_P^B = K \qquad (4.30)$$

$$\tilde{q}_R^B = \frac{(1+\alpha\eta)(a-K)}{(c+2)(1+\alpha\eta)-\alpha}, \qquad (4.31)$$

for the private and the regulated firm, respectively. The total amount of electricity produced in this case and the market price, respectively, are

$$\tilde{Q}^B = \frac{(1+\alpha\eta)a+\left[(1+\alpha\eta)(c+1)-\alpha\right]K}{(c+2)(1+\alpha\eta)-\alpha} \qquad (4.32)$$

$$\tilde{P}^B = \frac{\left[(1+\alpha\eta)(c+1)-\alpha\right](a-K)}{(c+2)(1+\alpha\eta)-\alpha} \qquad (4.33)$$

3.2.1 Optimal Regulatory Policy

As in the case where the regulated firm is located in the North, the problem of optimal choice of α, which is viewed as the regulatory policy tool, is examined in the present case. Note that in the previous case the regulated firm is located away from the consumers, and thus is subject to a capacity constraint. Furthermore the regulated firm was assumed to be the more efficient firm in the previous case. In the current case the regulated firm is located where the consumers are and the issue now is to see how competition from a more efficient private firm impacts outcomes and the optimal regulatory policy.

The expression for the total surplus in this case is given by

$$\tilde{W}(q_R, q_P; K, \alpha) = PQ + q_R q_P + \eta\left[Pq_R - \frac{(1+\eta)c-1}{2\eta}q_R^2\right] \qquad (4.34)$$

As was done in the previous section, calculating the optimal value of α when the corresponding equilibrium output for the private firm is unconstrained is a useful benchmark. Let $\tilde{W}^N(\alpha) \equiv \tilde{W}(\tilde{q}_R^N, \tilde{q}_P^N; K, \alpha)$, which is computed by substituting (4.25), (4.26), (4.27) and (4.28) in (4.34). Differentiating $\tilde{W}^N(\alpha)$ with respect to α, and checking that the second order conditions are satisfied, result in the following optimal value of α:

$$\tilde{\alpha}^{*N} = \frac{5+2\eta-c}{5+(c+1)\eta-2\eta^2}\,. \qquad (4.35)$$

Note that for $\tilde{\alpha}^{*N} \in [0,1]$, as per its definition, it has to be the case that the shadow cost of public funds $\eta \leq \tilde{\eta}$, where $\tilde{\eta} = \frac{\left(c-1+\sqrt{c^2+6c+1}\right)}{4}$. Also note that $\tilde{\alpha}^{*N}$ is increasing in η and $\tilde{\alpha}^{*N} \in \left[0, \frac{4}{5}\right]$.

Define $\tilde{K}(\alpha) \equiv \tilde{\alpha}^{-1}(K) \equiv \tilde{q}_P^N(\tilde{\alpha}(K))$. If $K \geq \tilde{K}\left(\tilde{\alpha}^{*N}\right)$, i.e. if K is large enough so that the equilibrium output of the private firm induced by $\tilde{\alpha}^{*N}$ is not constrained, then the optimal regulatory policy is to set $\alpha = \tilde{\alpha}^{*N}$. If, on the other hand, $K < \tilde{K}\left(\tilde{\alpha}^{*N}\right)$, then the equilibrium output of the private firm is constrained when $\alpha = \tilde{\alpha}^{*N}$. In the previous section where the regulated firm was more efficient but subject to a capacity constraint, the policy tool α no longer impacted the equilibrium outcome once the capacity constraint became binding. In the current case, where the regulated firm is less efficient but is not subject to a capacity constraint, α continues to impact the equilibrium outcome even when the private firm's output is constrained.

Let $\tilde{W}^B(\alpha) \equiv \tilde{W}(\tilde{q}_R^B, \tilde{q}_P^B; K, \alpha)$ which is computed by substituting (4.30), (4.31), (4.32) and (4.33) in (4.34). Differentiating $\tilde{W}^B(\alpha)$ with respect to α gives

$$\frac{\partial \tilde{W}^B(\alpha)}{\partial \alpha} = \frac{(a-K)^2(1-\alpha)}{\left[(c+2)(1+\alpha\eta)-\alpha\right]^3} \tag{4.36}$$

which implies that the optimal choice of α is 1.[57] Note, however, that $\tilde{q}_P^N(\alpha)$ is decreasing in α and when α is equal to 1 the constraint may no longer be binding. Therefore, if $K > \tilde{q}_P^N(1) = K(1)$, then it is optimal to set $\alpha = \tilde{\alpha}(K)$. If, on the other hand, $K \leq \tilde{q}_P^N(1) = K(1)$, then the optimal policy choice in this case is to set α equal to 1.

The following proposition summarizes the optimal regulatory policy when the less efficient regulated firm is located on the same node as the consumers and faces competition from a more efficient private firm connected to the demand center with a transmission line of capacity K.

[57] It can be checked that $\frac{\partial^2 \tilde{W}^B(\alpha)}{\partial \alpha^2}$ evaluated at $\hat{\tilde{\alpha}}^B = 1$ is strictly negative for all parameter values.

Proposition 2: If $K \geq \tilde{K}\left(\tilde{\alpha}^{*N}\right)$, then the optimal regulatory policy is to set $\alpha = \tilde{\alpha}^{*N}$. If $K < \tilde{K}\left(\tilde{\alpha}^{*N}\right)$, then the optimal policy is to set $\alpha = \tilde{\alpha}^{*B}$, where

$$\tilde{\alpha}^{*B} = \begin{cases} \tilde{\alpha}(K) & \textit{if } K > \tilde{q}_P^N(1) \\ 1 & \textit{otherwise} \end{cases} \quad (4.37)$$

Proposition 2 states that if the line capacity is not large enough, it is optimal to set α equal to 1, i.e. to instruct the regulated firm to maximize total surplus. For certain values of the cost and demand parameters it turns out to be optimal to induce the regulated firm to produce as much as possible despite its relative cost inefficiency.

3.2.2 Optimal Choice of Transmission Capacity

The analysis of ex-ante optimal choice of capacity level K of the transmission line in this case is exactly the same as in the previous case. As it is costly to install transmission capacity, a total surplus maximizing ex-ante choice of capacity is the one that leaves no unused capacity in equilibrium. Letting $\tilde{W}^B(K) \equiv \tilde{W}(\tilde{q}_R^B, \tilde{q}_P^B; K, \alpha)$ be the total surplus at the constrained equilibrium, the optimal ex-ante choice of K will be the solution to the following maximization problem:

$$\max_K \tilde{W}^B(K) - C_T(K), \quad (4.38)$$

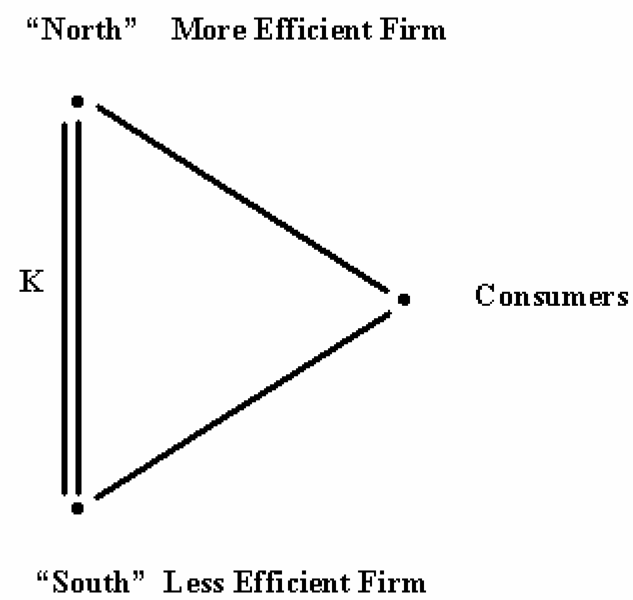
where $C_T(K) > 0$ is the total cost of installing a transmission line with capacity K, with $C_T'(\cdot) \geq 0$ and $C_T''(\cdot) > 0$. Similar to the analysis in the previous section, if $C_T(K) = 0$, i.e. if capacity can be installed at no cost, then total surplus maximizing level of transmission capacity is equal to $K = K\left(\tilde{\alpha}^{*}\right)$. So when $C_T(K) > 0$ the optimal transmission capacity is less than $K\left(\tilde{\alpha}^{*}\right)$.

4. A Three-Node (Loop Flow) Network

In this section we analyze the more general three-node case. In the case of multiple interconnected links, the networks exhibit what are called *loop flows*, which are an essential characteristic of electricity networks. For example, in a three-node network, electricity transmitted from one node to another not only impacts the flow on the line connecting these two nodes, but also impacts the flow on the other two lines.

As in Joskow and Tirole (2000) we study a simple three-node network with two generation nodes (the private firm located on one and the regulated firm on the other) and one consumption node. We only consider the case where the transmission line between two generation nodes is capacity constrained (see Figure IV-4).

Figure IV-4: Three-Node Network



4.1 More Efficient Regulated Firm

We first consider the case where the regulated firm is more efficient, i.e. $c_R = 1$ and $c_P = c > 1$. The response functions of the private and the regulated firm in this case, given by

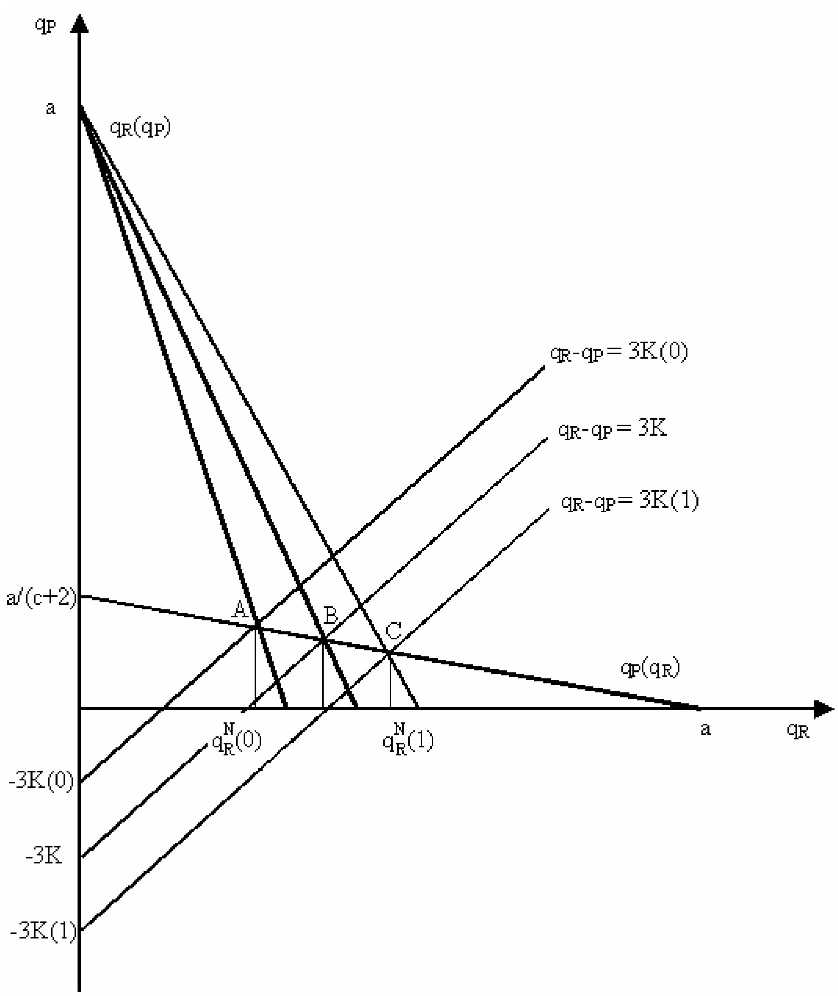
$$q_P(q_R) = \frac{a - q_R}{c+2} \tag{4.39}$$

and

$$q_R(q_P) = \frac{(1+\alpha\eta)\left[a - q_P\right]}{3(1+\alpha\eta) - \alpha}, \tag{4.40}$$

respectively, are the same as in Section 3.1.[58] As before, the response function of the regulated firm $q_R(q_P)$ depends on α, which changes the nature of equilibrium attained. Figure IV-5 displays the response functions of the two firms for a given K. The response function of the regulated firm becomes flatter (in a continuous manner) as α increases. The response function that passes through point A in Figure IV-5 corresponds to $\alpha = 0$, and the one that passes through point C corresponds to $\alpha = 1$.

Figure IV-5: Response Functions with a More Efficient Regulated Firm



[58] The objective functions of the private and the regulated firm are as in Section 3.1 (expressions (4.5) and (4.7), respectively.)

The line between the two generators has capacity K. Assuming that there are no losses on the lines, $q_P + q_R$ equals the quantity consumed at the demand node. Electricity flowing from the generators to the consumers follow the path of least resistance. This, in our case, translates into the following constraint on q_P, the amount of electricity produced by the private firm, and q_R, the amount produced by the regulated firm:

$$\left| \frac{q_R}{3} - \frac{q_P}{3} \right| \le K. \qquad (4.41)$$

Given that in this case we are considering a more efficient regulated firm, which in equilibrium leads to a higher output for the regulated firm than that of the private one, this constraint becomes

$$q_R - q_P \le 3K. \qquad (4.42)$$

Let $\overline{q}_R^N(\alpha)$ and $\overline{q}_P^N(\alpha)$ be the respective unconstrained equilibrium output levels of the regulated and the private firm for a given α. Thus $\overline{K}(0) > 0$ is the capacity level such that $\overline{q}_R^N(0) - \overline{q}_P^N(0) = 3\overline{K}(0)$. Similarly, let $\overline{K}(1) > 0$ be the capacity level such that $\overline{q}_R^N(1) - \overline{q}_P^N(1) = 3\overline{K}(1)$. Figure IV-5 depicts the capacity constraint for both $K = \overline{K}(0)$ and $K = \overline{K}(1)$. Thus, for a given level of $K \in \left[\overline{K}(0), \overline{K}(1)\right]$, there exists an $\alpha = \overline{\alpha}(K)$ such that the capacity constraint $q_R - q_P = 3K$ is just binding in equilibrium. Figure IV-5, where the capacity constraint line $q_R - q_P = 3K$ and the corresponding response function for the regulated firm both pass through point B, depicts such a case. For a given K, if $\alpha \le \overline{\alpha}(K)$ then the capacity constraint is never binding, whereas for $\alpha > \overline{\alpha}(K)$ it is always binding. Observe that if $K < \bar{K}(0)$ then the capacity constraint is binding regardless of the value of α, and if $K \geq \bar{K}(1)$ then it is not binding for any α.

For a given K, suppose that $\alpha \leq \bar{\alpha}(K)$. Respective (unconstrained) equilibrium output choices of the regulated and the private firm are

$$\bar{q}_R^N(\alpha) = \frac{(c+1)(1+\alpha\eta)a}{(3c+5)(1+\alpha\eta)-(c+2)\alpha} \tag{4.43}$$

$$\bar{q}_P^N(\alpha) = \frac{\left[2(1+\alpha\eta)-\alpha\right]a}{(3c+5)(1+\alpha\eta)-(c+2)\alpha} \tag{4.44}$$

Note that $\bar{q}_R^N(\alpha) > \bar{q}_P^N(\alpha)$.

The corresponding total output and price are:

$$\bar{Q}^N(\alpha) = \frac{\left[(c+3)(1+\alpha\eta)-\alpha\right]a}{(3c+5)(1+\alpha\eta)-(c+2)\alpha} \tag{4.45}$$

$$\bar{P}^N(\alpha) = \frac{(c+1)\left[2(1+\alpha\eta)-\alpha\right]a}{(3c+5)(1+\alpha\eta)-(c+2)\alpha} \tag{4.46}$$

Note that $\bar{\alpha}(K)$ can be computed from expressions (4.43) and (4.44) as

$$\bar{\alpha}(K) = \frac{3(3c+5)K-(c-1)a}{(c-1)\eta a+1-3\left[(3c+5)\eta-(c+2)\right]K}\,. \tag{4.47}$$

We restrict our attention to the space of parameters where $\bar{\alpha}(K) \in [0,1]$ for all K.

For a given K, suppose now that $\alpha > \bar{\alpha}(K)$. Take, for example, $\alpha = 1$ and consider the capacity level K shown in Figure IV-5. The unconstrained equilibrium, which would occur at point C, is not attainable in this case. The constrained equilibrium occurs at point B (at the intersection of the private firm's response function and the capacity constraint equation $q_R - q_P = 3K$.)

When the capacity constraint is binding, respective equilibrium output levels of the regulated and the private firm are

$$\bar{q}_R^B = \frac{a + 3(c+2)K}{c+3} \qquad (4.48)$$

$$\bar{q}_P^B = \frac{a - 3K}{c+3}, \qquad (4.49)$$

Resultant total output and price, respectively, are

$$\bar{Q}^B = \frac{2a + 3(c+1)K}{c+3}$$

$$\bar{P}^B = \frac{(c+1)(a-3K)}{c+3}$$

We assume as before that there is an Independent System Operator, tasked with ensuring the reliability of the network, that strictly enforces the capacity constraint where it is binding in equilibrium.

4.1.1 Optimal Regulatory Policy

Expression (4.18) also gives the total surplus for the current case. As in the two-node case, we first consider the optimal choice of the policy variable α when the capacity constraint is not binding in equilibrium. In fact, observe that the welfare analysis of the three-node case when the capacity constraint is not binding is going to be exactly the same as the welfare analysis of the unconstrained two-node case. Without the capacity constraint the features of the two-node and the three-node network configurations we study become identical. Thus, the optimal regulatory policy in the three-node network when the regulated firm is more efficient and the capacity of the line connecting the two generators is sufficiently large is

$$\bar{\alpha}^* = \frac{c^2 + 3c + \eta(c+1)}{c^2 + 3c + 1 - \eta^2(c+1) + 2\eta} \in \left[\frac{4}{5}, 1\right], \tag{4.50}$$

as given in expression (4.19) in Section 3.1.1 where we studied the corresponding two-node case. Note again that for $\bar{\alpha}^*$ to fall in the interval [0,1], as per its definition, it has to be the case that $\eta \leq \bar{\eta}$, where $\bar{\eta} = \frac{\left(1 - c + \sqrt{c^2 + 2c + 5}\right)}{2(c+1)}$.

Let $\bar{K}(\alpha) \equiv \bar{\alpha}^{-1}(K) \equiv \frac{1}{3}\left[\bar{q}_R^N(\bar{\alpha}(K)) - \bar{q}_P^N(\bar{\alpha}(K))\right]$. For a given α, $\bar{K}(\alpha)$ is the capacity level that is just binding in the unconstrained equilibrium, and it is computed by using expression (4.47). If $K \geq \bar{K}(\bar{\alpha}^*)$, i.e. if K is sufficiently large so that the equilibrium output of the regulated firm induced by $\bar{\alpha}^*$ is not constrained, then the optimal regulatory policy is to set $\alpha = \bar{\alpha}^*$. If, on the other hand, $K < \bar{K}(\bar{\alpha}^*)$, i.e. if K is not sufficiently large so that the equilibrium output of the regulated firm is constrained when $\alpha = \bar{\alpha}^*$, then the optimal regulatory policy is to set $\alpha = \bar{\alpha}(K)$. Since total surplus is strictly increasing in α for $\alpha < \bar{\alpha}^*$, it is optimal to set α at least equal to $\bar{\alpha}(K)$. Setting $\alpha > \bar{\alpha}(K)$ would lead to jeopardizing the reliability of the transmission network as it would lead to a violation of the capacity constraint on the line connecting the two generators.

The following proposition summarizes the optimal regulatory policy when there is competition in a three-node network with a transmission capacity constraint between a private generator and a more efficient regulated generator.

Proposition 3: If $K \geq \bar{K}(\bar{\alpha}^*)$, then the optimal regulatory policy is to set $\alpha = \bar{\alpha}^*$. If $K < \bar{K}(\bar{\alpha}^*)$, then the optimal regulatory policy is to set $\alpha = \bar{\alpha}(K)$.

Proposition 3 states that when α is set at its optimal value $\bar{\alpha}^*$, there exists a capacity level $K = \bar{K}^*$ such that $q_R^N(\bar{\alpha}^*) - q_P^N(\bar{\alpha}^*) = 3\bar{K}^*$, i.e. a capacity level that is just binding at the optimal value of α. As in the two-node case, since $\bar{\alpha}^* \in \left[\frac{4}{5}, 1\right]$, the optimal policy does not involve total surplus maximization when the network is not congested. When the capacity of the line is sufficiently small so that it is congested in equilibrium, the optimal regulatory policy again does not involve total surplus maximization.

4.1.2 Optimal Choice of Transmission Capacity

Noting once again that the total surplus maximizing ex-ante choice of capacity is the one that leaves no unused capacity in equilibrium, the optimal ex-ante optimal choice of K is the solution to the following maximization problem:

$$\max_K \bar{W}^B(K) - C_T(K) \tag{4.51}$$

where $\bar{W}^B(K) \equiv W(\bar{q}_R^B, \bar{q}_P^B; K, \alpha)$ and $C_T(K) > 0$ is the total cost of installing a transmission line with capacity K, with $C_T'(\cdot) \geq 0$ and $C_T''(\cdot) > 0$. If $C_T(K) = 0$, i.e. if capacity can be installed at no cost, then total surplus maximizing level of transmission capacity is $K = K(\bar{\alpha}^*)$. So when $C_T(K) > 0$ the optimal transmission capacity is smaller than $K(\bar{\alpha}^*)$.

4.2 More Efficient Private Firm

In this section we examine the case where the private firm is more efficient, i.e. $c_P = 1$ and $c_R = c > 1$. Respective response functions of the private and the regulated firm,

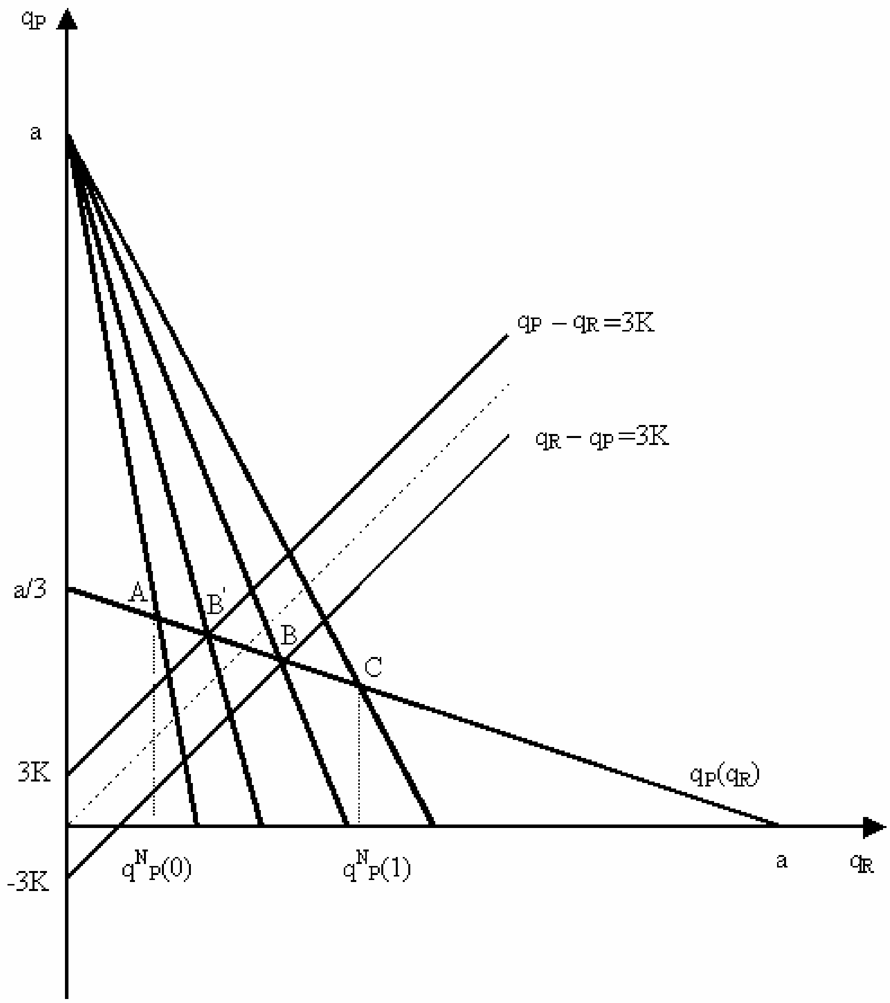
$$q_P(q_R) = \frac{a - q_R}{3} \tag{4.52}$$

$$q_R(q_P) = \frac{(1+\alpha\eta)\left[a - q_P\right]}{(2+c)(1+\alpha\eta) - \alpha}, \tag{4.53}$$

are the same as in Section 3.2.[59] As before, the response function of the regulated firm $q_R(q_P)$ depends on α, which changes the nature of equilibrium attained. Figure IV-6 shows the response functions of the two firms for a given K. As in Figure IV-5, the regulated firm's response functions passing through points A and C correspond to $\alpha = 0$ and $\alpha = 1$, respectively. The response function of the regulated firm gets flatter as α increases from 0 to 1, i.e. the more welfare conscious the regulated firm is, the more responsive it is to changes in the private firm's output.

Note from Figure IV-6 that, unlike in the previous case where the more efficient regulated firm always produces more than the private firm in the unconstrained equilibrium, in this case the unconstrained equilibrium output of the regulated firm may be greater or smaller than that of the private firm. When $\alpha = 0$, i.e. when both firms are pure profit maximizers, the unconstrained equilibrium is always above the 45° line in Figure IV-6, as a consequence of the fact that a more efficient private firm always produces more than a less efficient private firm in the equilibrium of a quantity-setting game. When $\alpha = 1$, the unconstrained equilibrium may occur above or below the 45° line depending on the parameter values.

Figure IV-6: Response Functions with a More Efficient Private Firm



Let $\tilde{\tilde{q}}_R^N(0)$ and $\tilde{\tilde{q}}_P^N(0)$ be the unconstrained equilibrium output levels of the regulated and the private firm, respectively, when $\alpha = 0$. Let $\tilde{\tilde{K}}(0) > 0$ be the capacity level such that $\tilde{\tilde{q}}_P^N(0) - \tilde{\tilde{q}}_R^N(0) = 3\tilde{\tilde{K}}(0)$ and let $\tilde{\tilde{K}}(1) > 0$ be the capacity level such that

[59] The objective functions of the private and the regulated firm will be as in Section 3.1 (expressions

$\left|\tilde{\tilde{q}}_P^N(1)-\tilde{\tilde{q}}_R^N(1)\right|=3\tilde{\tilde{K}}(1)$.[60] A capacity constraint line that passes through point A in Figure IV-6 corresponds to the capacity level $\tilde{\tilde{K}}(0)$ and one that passes through point C corresponds to the capacity level $\tilde{\tilde{K}}(1)$. If $K>\tilde{\tilde{K}}(0)$, then the capacity constraint is not binding for any value of α, whereas if $K<\frac{1}{3}\left|\tilde{\tilde{q}}_P^N(1)-\tilde{\tilde{q}}_R^N(1)\right|$, then the capacity constraint is binding for any value of α. Then, for a given level of $K\in\left[\tilde{\tilde{K}}(1),\tilde{\tilde{K}}(0)\right]$, there exist two values of α, $\tilde{\tilde{\alpha}}_1(K)$ and $\tilde{\tilde{\alpha}}_2(K)$, both of which make the capacity constraint $\left|q_P-q_R\right|=3K$ just binding. In Figure IV-6, points B and B' correspond to two distinct equilibria at two such values of α. Let $\tilde{\tilde{\alpha}}_1(K)$ be the value of α that results in point B being the equilibrium outcome, and let $\tilde{\tilde{\alpha}}_2(K)$ be the value of α that results in point B' being the equilibrium outcome. Observe that $\tilde{\tilde{q}}_P^N(\tilde{\tilde{\alpha}}_1(K))>\tilde{\tilde{q}}_R^N(\tilde{\tilde{\alpha}}_1(K))$ and $\tilde{\tilde{q}}_R^N(\tilde{\tilde{\alpha}}_2(K))>\tilde{\tilde{q}}_P^N(\tilde{\tilde{\alpha}}_2(K))$ so that, for the case depicted in Figure IV-6, we have $\tilde{\tilde{\alpha}}_2(K)>\tilde{\tilde{\alpha}}_1(K)$.

For a given K, suppose that $\alpha\in\left[\tilde{\tilde{\alpha}}_1(K),\tilde{\tilde{\alpha}}_2(K)\right]$. In this case the equilibrium output choices of the regulated and the private firms are unconstrained and are given respectively by

$$\tilde{\tilde{q}}_R^N=\frac{2(1+\alpha\eta)a}{(3c+5)(1+\alpha\eta)-3\alpha} \tag{4.54}$$

$$\tilde{\tilde{q}}_P^N=\frac{\left[(c+1)(1+\alpha\eta)-\alpha\right]a}{(3c+5)(1+\alpha\eta)-3\alpha} \tag{4.55}$$

(4.21) and (4.23), respectively.)

[60] From the previous paragraph we know that $\tilde{\tilde{q}}_P^N(0)>\tilde{\tilde{q}}_R^N(0)$.

Resulting total output and price are

$$\tilde{\tilde{Q}}^N = \frac{\left[(c+3)(1+\alpha\eta)-\alpha\right]a}{(3c+5)(1+\alpha\eta)-3\alpha} \quad (4.56)$$

$$\tilde{\tilde{P}}^N = \frac{2\left[(c+1)(1+\alpha\eta)-\alpha\right]a}{(3c+5)(1+\alpha\eta)-3\alpha} \quad (4.57)$$

It is easily checked from expressions (4.54) and (4.55) that $\tilde{\tilde{q}}_P^N \geq \tilde{\tilde{q}}_R^N$ if and only if $c-1 \geq \frac{\alpha}{1+\alpha\eta}$. Note that $\tilde{\tilde{\alpha}}(K) \in \left\{\tilde{\tilde{\alpha}}_1(K), \tilde{\tilde{\alpha}}_2(K)\right\}$ can be computed from expressions (4.54) and (4.55) as

$$\tilde{\tilde{\alpha}}(K) = \left| \frac{3(3c+5)K-(c-1)a}{(c-1)\eta a - 1 - 3\left[(3c+5)\eta-3\right]K} \right|. \quad (4.58)$$

Suppose now that either $\alpha < \tilde{\tilde{\alpha}}_1(K)$ or $\alpha > \tilde{\tilde{\alpha}}_2(K)$. In either of these cases the capacity constraint is binding. When $c-1 \geq \frac{\alpha}{1+\alpha\eta}$ so that $\tilde{\tilde{q}}_P^N > \tilde{\tilde{q}}_R^N$, the resulting equilibrium level of output produced by the regulated and the private firms respectively are as follows:

$$\tilde{\tilde{q}}_R^B = \frac{(1+\alpha\eta)(a-3K)}{(1+\alpha\eta)(c+3)-\alpha} \quad (4.59)$$

$$\tilde{\tilde{q}}_P^B = \frac{(1+\alpha\eta)a + 3K\left[(1+\alpha\eta)(c+2)-\alpha\right]}{(1+\alpha\eta)(c+3)-\alpha} \quad (4.60)$$

Consequent total output and price are

$$\tilde{\tilde{Q}}^B = \frac{2a(1+\alpha\eta) + 3K\left[(1+\alpha\eta)(c+1)-\alpha\right]}{(1+\alpha\eta)(c+3)-\alpha} \quad (4.61)$$

$$\tilde{\tilde{P}}^B = \frac{\left[(1+\alpha\eta)(c+1)-\alpha\right](a-3K)}{(1+\alpha\eta)(c+3)-\alpha}. \tag{4.62}$$

When, on the other hand, $c-1<\dfrac{\alpha}{1+\alpha\eta}$ so that $\tilde{\tilde{q}}_P^N < \tilde{\tilde{q}}_R^N$, the resulting equilibrium level of output produced by the regulated and the private firms respectively are

$$\tilde{\tilde{q}}_R^B = \frac{a+9K}{4} \tag{4.63}$$

$$\tilde{\tilde{q}}_P^B = \frac{a-3K}{4} \tag{4.64}$$

Resulting total output and price are

$$\tilde{\tilde{Q}}^B = \frac{a+3K}{2} \tag{4.65}$$

$$\tilde{\tilde{P}}^B = \frac{a-3K}{2} \tag{4.66}$$

4.2.1 Optimal Regulatory Policy

Total surplus for the current case is given by (4.34). As in the previous cases, we first consider the choice of the policy variable α when the capacity constraint is not binding in equilibrium, which provides a useful benchmark in analyzing the cases where the constraint is binding. Following the same steps as in the optimal policy analysis in previous sections, the optimal regulatory policy in the three-node network when the private firm is more efficient and the capacity of the line connecting the two generators is sufficiently large is to set α equal to

$$\tilde{\tilde{\alpha}}^* = \frac{5+2\eta-c}{5+(c+1)\eta-2\eta^2} \in \left[0, \frac{4}{5}\right]. \tag{4.67}$$

Note that this is the same as expression (4.35) in Section 3.2.1 where we studied the corresponding two-node case. For $\tilde{\tilde{\alpha}}^* \in [0,1]$, as per its definition, we have to have $\eta \le \tilde{\eta}$, where $\tilde{\eta} = \frac{\left(c - 1 + \sqrt{c^2 + 6c + 1}\right)}{4}$. Note that $\tilde{\tilde{\alpha}}^*$ is increasing in η.

Let $\tilde{\tilde{K}}(\alpha) \equiv \tilde{\tilde{\alpha}}^{-1}(K) \equiv \frac{1}{3}\left|\tilde{\tilde{q}}_R^N(\tilde{\tilde{\alpha}}(K)) - \tilde{\tilde{q}}_P^N(\tilde{\tilde{\alpha}}(K))\right|$. For a given α, $\tilde{\tilde{K}}(\alpha)$ is the capacity level that is just binding in unconstrained equilibrium, and it can be computed from (4.58). If $K \ge \tilde{\tilde{K}}\left(\tilde{\tilde{\alpha}}^*\right)$, i.e. if K is large enough so that the equilibrium output of the regulated firm induced by $\tilde{\tilde{\alpha}}^*$ is not constrained, then the optimal regulatory policy is to set $\alpha = \tilde{\tilde{\alpha}}^*$. If, on the other hand, $K < \tilde{\tilde{K}}\left(\tilde{\tilde{\alpha}}^*\right)$, i.e. if K is not sufficiently large so that the equilibrium output of the regulated firm is constrained at $\alpha = \tilde{\tilde{\alpha}}^*$, then the optimal regulatory policy depends on the sign of $(\tilde{\tilde{q}}_P^N - \tilde{\tilde{q}}_R^N)$. If $c - 1 \ge \frac{\alpha}{1 + \alpha\eta}$ so that $\tilde{\tilde{q}}_P^N \ge \tilde{\tilde{q}}_R^N$, then the total surplus is computed using (4.59)-(4.62). If $c - 1 < \frac{\alpha}{1 + \alpha\eta}$ so that $\tilde{\tilde{q}}_P^N < \tilde{\tilde{q}}_R^N$, then the equilibrium lies at the intersection of the private firm's reaction function and the capacity constraint line and the total surplus is computed using (4.63)-(4.66).

The proposition below summarizes the optimal regulatory policy in a three-node network with a binding transmission capacity constraint and a more efficient private firm.

Proposition 4: If $K \ge \tilde{\tilde{K}}\left(\tilde{\tilde{\alpha}}^*\right)$, then the optimal regulatory policy is to set $\alpha = \tilde{\tilde{\alpha}}^*$. If $K < \tilde{\tilde{K}}\left(\tilde{\tilde{\alpha}}^*\right)$, then the optimal regulatory policy variable α belongs to the set

$\left\{0, \frac{a(c+1)-6K(c+2)}{2a-9K-\eta\left[a(c+1)-6K(c+2)\right]}, 1\right\}$ when $c-1 \geq \frac{\alpha}{1+\alpha\eta}$, and the optimal regulatory policy is to set α equal to $\tilde{\tilde{\alpha}}(K)$ when $c-1 < \frac{\alpha}{1+\alpha\eta}$.

4.2.2 Optimal Choice of Transmission Capacity

Total surplus maximizing ex-ante choice of capacity in this case is the solution to the following maximization problem:

$$\max_{K} \tilde{\tilde{W}}^{B}(K) - C_T(K) \tag{4.68}$$

where $\tilde{\tilde{W}}^{B}(K) \equiv W(\tilde{\tilde{q}}_R^B, \tilde{\tilde{q}}_P^B; K, \alpha)$ and $C_T(K) > 0$ is the total cost of installing a transmission line with capacity K, with $C_T'(\cdot) \geq 0$ and $C_T''(\cdot) > 0$. In contrast to the previous sections, the optimal ex-ante choice of K in this case depends on whether at the constrained equilibrium it is total surplus maximizing to have the regulated firm produce more than the private firm or not. If $\tilde{\tilde{q}}_P^N(\tilde{\tilde{\alpha}}^*) \geq \tilde{\tilde{q}}_R^N(\tilde{\tilde{\alpha}}^*)$, then total surplus maximizing level of transmission capacity is $K = K(\tilde{\tilde{\alpha}}^*)$ when $C_T(K) = 0$; so when $C_T(K) > 0$ the optimal transmission capacity is less than $K(\tilde{\tilde{\alpha}}^*)$ in this case.

5. Conclusion

In this chapter we analyzed the optimal regulatory policy in the context of a mixed oligopolistic wholesale electricity market. The only regulatory tool at hand is the choice of the public firm's objective function while there are no restrictions on the operation of the private firm. Our results show that the optimal regulatory policy in both a two-node (no loop flow) network and a three-node network (with loop flows) depends on whether the regulated firm or the private firm has cost advantage in production, as well as on the capacity of the line linking the two generators. Our results indicate that in many instances it will not be optimal (in terms of total surplus or welfare) to instruct the regulated firm to maximize total surplus. However, except only in one case, it is not optimal to instruct the regulated firm to maximize profits, either.

First, we study a two-node network in which the less efficient generator is located in the South where consumers are located and the more efficient generator is located in the North (where there is no demand). When the private firm is located in the South, the optimal regulatory policy depends on the capacity of the line, K. If K is sufficiently large, then the public firm is instructed to maximize, not welfare or profits, but a strict convex combination of the two, given that the shadow cost of public funds is below a threshold. When K is below a threshold level, then any objective function that gives a sufficiently high weight to welfare so as to cause the line to be congested, is part of the optimal regulatory policy, including pure total surplus maximization.

When the regulated firm is located in the South, provided that the line capacity K is sufficiently large, the optimal regulatory policy never involves pure total surplus maximization. The weight given to total surplus in the objective function increases with the shadow cost of public funds and decreases with the cost efficiency gap between the two generators. However, profits are always part of the objective function of the regulated firm and under some parameter values, the only part. The intuition behind this result is that since the public firm is not constrained by the transmission link, instructing it to give too big a weight to total social surplus results in overproduction. Due to its relative inefficiency and increasing marginal cost technology, it may produce where losses from cost inefficiencies outweigh consumer surplus gains. On the other hand, when transmission capacity is small and thus the line is congested in equilibrium, the public firm is instructed either to maximize total social surplus only, or a strict mix of profits and total social surplus, depending on the parameter values. However, in this case pure profit maximization is not part of the optimal regulatory policy.

Second, we examine a three-node network where generators are located on different nodes and consumers are located on the remaining node. When the private firm is less efficient, provided that K is sufficiently large, the optimal regulatory policy is to give most, and in some cases all, of the weight to total surplus maximization; and under no circumstance is pure profit maximization the optimal instruction. When the private firm is the more efficient and K is sufficiently large, the optimal regulatory policy is exactly the same as the optimal regulatory policy under a two-node network with an efficient private firm and a sufficiently large K.

Chapter V: **Optimal Regulatory Policy in a Duopolistic Mixed Electricity Market with Market-Based Congestion Management**

1. Introduction

In this chapter we attempt to answer the same question as the previous chapter, which is what the choice of the non-private firm's (used synonymously with "public firm" and "regulated firm") objective function should be when a non-private generator competes with a private generator in an imperfectly competitive wholesale electricity market on a capacity constrained transmission network. The model we employ in this chapter appears to be similar to the one(s) in the previous chapter.

As in the previous chapter, we model the workings of a mixed duopolistic wholesale electricity market as a two stage game. In the first stage, the public authority (government or regulator) assigns an objective function to the non-private firm. This objective function takes the form of a weighted average of consumers' surplus and profits of the non-private firm. The weight of the consumers' surplus is the regulatory policy tool and it's set by the public authority in the first stage. In the second stage the non-private generator engages in a Cournot competition (i.e. simultaneous quantity-setting game) with a private generator. The private generator chooses its output to maximize its own profits, whereas the non-private generator makes its output decision to maximize the objective function assigned to it in the first stage, i.e. the weighted average of its own profits and consumers' surplus.

Despite their apparent similarities, there are marked differences between this chapter and Chapter 4 that significantly change the nature of decision making of the actors and the competition between them. The first and most notable modeling difference from the previous chapter is the assignment of property rights, and an associated pricing structure, for the use of transmission network by the generators in this chapter. In the previous chapter we assumed the transmission network to be a freely congestible public good subject only to safe line flow limits. In this chapter each generator is required to pay a nodal transmission congestion charge for each unit of injection and withdrawal of electricity on each node. The congestion charge on a node can be positive, zero or negative, depending on the impact of the injection (or withdrawal) on the transmission constraint. The nodal transmission prices are determined based on the principle that all participants pay proportionally for their contribution to a binding transmission line constraint the Independent System Operator ("ISO") has to control for. Another (and equivalent) way to look at the same principle is that all participants pay (or get paid) for the externality they cause on the other participants, in terms of exacerbating or relieving the congestion on the constrained transmission facility.

This explicit modeling and pricing of transmission congestion rights changes the nature of the optimization problems faced by the generators. Now the generators account for payments to and from transmission congestion rights directly in their objective functions. In this model, the ISO utilizes a market-based congestion management system where reliability is achieved via explicit nodal transmission price signals to the generators.

The model we employ in this chapter is consistent with the congestion management and pricing methods used in most U.S. ISO/RTO markets (PJM, Midwest ISO, ISO New England, New York ISO, California ISO) called "Locational Marginal Pricing", better known with its acronym "LMP". The price at each node is comprised of two separate components, energy and congestion.[61] The energy price is the "system lambda", or the would-be marginal clearing price in the system in the absence of a transmission constraint. The congestion component is the charge reflecting the node's contribution to the transmission congestion being controlled for. The total effective price on a node is the sum of the two and applies to every participant equally.

Introduction of a market for transmission congestion rights into the model requires a modification in our equilibrium concept. Now the equilibrium of the system is defined as generation levels, an energy price and nodal transmission congestion prices such that the transmission congestion rights market is in equilibrium, as well as the energy market. We assume the electricity market is characterized by Cournot competition between the generators whereas the transmission congestion rights market is competitive. That is, the generators take the nodal transmission prices as given when they make their optimal short-run production decisions. The formal definition of the equilibrium concept we employ in this chapter is presented in Section 3 below.

The second major modeling difference from the previous chapter is the objective function of the non-private generator. In this chapter, we model the non-private firm as maximizing a weighted average of its own profits and consumers' surplus, whereas in

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[61] LMP in ISO regions consist of three components: energy, congestion and losses. However, since we ignore transmission losses in our model, total nodal prices comprise of energy and congestion only.

the previous chapter it is modeled to be maximizing a weighted average of own profits and total surplus. Total surplus is the sum of consumers' surplus and the producers' surplus, where the latter in the previous chapter is approximated as short-run profits of the generators. Since own profits is already a component of the non-private generator in both models, the only difference is that the non-private generator takes the private generator's profits also into account in the previous chapter, whereas it has no regard for its competitor's profits in this model. The question then is whether one approach is superior to the other from a modeling or a realism point of view?

On the one hand, using total surplus, rather than consumers' surplus, seems to be the standard approach in the literature (reviewed in the previous chapter) that deals with the issue that we tackle in this and the previous chapter, which is the choice of optimal objective function for a public firm that is engaged in imperfect competition with private firm(s). So using total surplus in our model would be preferred from the perspective of comparing our findings with those of the relevant literature. On the other hand, consumers' surplus maximization is significantly easier to instruct or implement institutionally than total surplus maximization, making it a more realistic model of reality.

For example, in the case of a publicly-owned company, consumers' surplus can be made a part of the public firm's objective by appointing a number of consumer representatives to the board of managers or to the upper management. However, there does not seem to be an obvious way of representing the private firm's financial interests in the public firm's objective, as it may look inappropriate or create a conflict of interest to place, say, a large shareholder of the private firm in the public firm's board or upper management. In the case of a regulated private firm, like the vertically integrated utilities in the U.S. serving customers on cost of service regulated bundled rates, the state utility regulatory commission can achieve a representation of both consumers' surplus and profits of the regulated firm by allowing the regulated firm to keep a share of the profits from off-system sales. This way, the regulated firm still has an incentive to increase its profits, but not to the extent a purely private unregulated firm does, as well as an incentive to be concerned about the consumers' surplus. The bigger share of profits from off-system sales the regulated firm can keep, the larger is the weight of profits in the objective of the regulated firm is.

As in the case of a publicly-owned firm, there is no simple or apparent way to represent the financial interests of the unregulated private firm in the objective of the regulated firm. In fact, this is outright impossible in most circumstances because most state utility regulatory commissions are explicitly required by law to represent the interests of ratepayers or to balance the interests of ratepayers and the regulated firms. Therefore, such a regulatory framework does not allow representation of unregulated private firm profits, and thus total surplus, in the regulated firm's objective.

As a result, we concluded that there is no single best way to model the objective of the non-private generator and there are legitimate arguments for and against both approaches outlined above. The direction we took was to use one approach in the previous chapter and the other approach in this chapter, to examine the impact of this choice on the results. Although there is no direct comparison, due to other differences between the models, the exact specification of the non-private firm's objective function does not appear to impact our qualitative results.

The third major difference in modeling between the previous and this chapter is the specification of cost functions. In the previous chapter, cost of production is a quadratic function of the total output of a generator, whereas in this chapter we model cost of production for a generator as a linear function of its output. In other words, we assume in this chapter that marginal cost of production is constant, whereas it is assumed to be increasing in output in the previous chapter. There are plenty of examples of both (constant and increasing marginal costs) in the literature on wholesale electricity market competition, so neither one is an obvious choice.

Use of constant marginal costs was preferable in this chapter for two reasons. First, since previous chapter used increasing marginal costs, we wanted to examine whether the cost function specification was single-handedly driving the results. Given that the results are qualitatively similar, that does not appear to be the case. Secondly, the model is significantly more complicated now with the introduction of transmission congestion rights prices, so using constant marginal costs makes it easier to solve the model.

Our qualitative results for the optimal regulatory policy are almost identical to our results from the previous chapter. Under the vast majority of the parameter combinations, the optimal policy is to instruct the non-private generator to maximize a strictly convex combination of own profits and consumer surplus. Under no circumstance is pure consumers' surplus maximization the optimal instruction. On the other hand, profit maximization is the optimal instruction only in the limiting case where the capacity of the line between the generators is sufficiently large *and* the efficiency gap between the private and the non-private generator is above a threshold level (private generator being more efficient).

This chapter is organized as follows. In Section 2 we introduce the general features of the loop flow network model we study. In Section 3 we analyze the equilibria both when the transmission constraint is not binding and when it is binding. In Section 4 we study the profits of the ISO and the non-private generator in each type of equilibrium and discuss how we use these for equilibrium selection when there are multiple equilibria. In Section 5 we analyze the optimal choice of objective function for the non-private generator as a regulatory policy. In Section 6 we provide a summary of our results and offer some concluding remarks. Proofs of all of the propositions and the results on the profits of the ISO and the non-private generator are relegated to the two appendices at the end.

2. The Model

We consider a simple model of the electricity sector where there are two generators supplying electricity to a single market.[62] One of these generators, denoted by P, is purely private and its objective is to maximize its profit. The other one, which we call "non-private"[63] and denote by R, is assumed to maximize a weighted average of consumers' surplus and its own profits. That is, the non-private generator's objective function is assumed to be

$$\gamma CS(\cdot)+(1-\gamma)\Pi_R(\cdot) \tag{5.1}$$

[62] The configuration of the electricity network is similar to the model studied in Joskow and Tirole (2000).

where $CS(\cdot)$ is the total consumers' surplus, $\Pi_R(\cdot)$ is its own profit, and $\gamma \in [0,1]$ is the weight on consumers' surplus. Note that the case of $\gamma = 0$ refers to a pure private generator and $\gamma = 1$ to a generator concerned solely with maximizing consumers' surplus.

We assume that the network is a three-node network, which is the simplest model of electricity network that involves loop-flows in electricity transmission (see Figure V-1). In this case electricity sent from one node to the other not only affects the flow on the line connecting these two nodes, but also the congestion on the other two lines. We study a simple three-node network with two generation nodes and one consumption node. The non-private generator is located on node 1, the private generator is located on node 2, and consumers are located on node 3.[64] There is no generation on node 3 and no consumption on node 1 or node 2.

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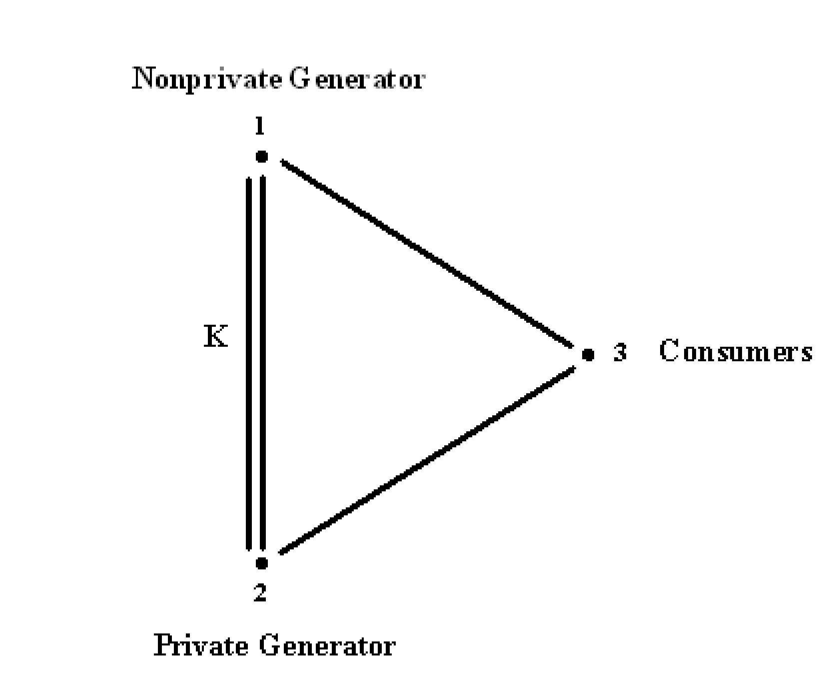
[63] Non-private can be interpreted either as publicly owned or as private but subject to some sort of public regulation.

[64] There are multiple reasons for connecting the two generation nodes, even if this creates a loop flow. First, to increase the reliability of the network; in case of an outage of one of the lines connecting the generators directly to the consumers, both generators continue to supply electricity through the indirect line. In fact, a reliable operations dispatch procedure employed by all dispatchers (utility or ISO) called "n-1 contingency dispatch" is a reflection of this fact. Second, the market we are modeling can be interpreted as a sub-market in a larger interconnection with fixed available transmission capacities or transmission reservations on the lines, in which case the line connecting the two generators serves other transactions in other sub-markets and thus our ISO does not have the discretion to dismantle it.

Figure V-1: Transmission Network Representation



The transmission line between two generation nodes is assumed to have a given capacity of K. The feasibility in the TCR market has to do with the constrained capacity of the line between the two generators, i.e. K. Electricity flowing from the generators to the consumers follows the path of least resistance. This, in our model, translates into a constraint on q_R and q_P given by

$$|q_R - q_P| \leq 3K . \qquad (5.2)$$

The grid is operated by an Independent System Operator (ISO) that is in charge of ensuring the safe and reliable utilization of the grid by auctioning transmission congestion rights, or Transmission Capacity Reservations (TCRs), as in Smeers and Wei (1997). The nodal transmission rights allow the generators to withdraw and inject up to a specific amount of electricity from and into the transmission network at a specified transmission node. As in Smeers and Wei (1997), it is assumed that transmission rights are actively traded at pre-dispatch time. Let λ_1, λ_2 and λ_3 be the prices of the TCRs at nodes 1,2 and 3, respectively. λ_i is the price of withdrawing a unit of electricity from node *i*, i.e. an entity would have to pay λ_i to withdraw from (and pay $-\lambda_i$ to inject into) node *i* a unit of electricity, in addition to the price of electricity itself. Without loss of generality, we normalize the TCR prices by setting $\lambda_1 = 0$.

Generators compete in two markets; the electricity generation market and the TCR market. In the electricity generation market generators are assumed to engage in Cournot competition, i.e. they compete by simultaneously choosing output levels. The quantities they choose are pre-dispatch quantities submitted to the ISO that is in charge of the reliable operation of the transmission network. They also purchase and sell transmission rights at the TCR market, which is also operated by the ISO. Both generators are assumed to take TCR prices as given in making their decisions.

The equilibrium condition in the TCR market takes into account the externality each generator imposes on the other when transmitting a unit of electricity. When the grid is not congested, the production by a generator does not impose any positive or negative externality on the other, implying TCR prices of $\lambda_2 = \lambda_3 = 0$ in equilibrium. However, when the grid is congested, an additional unit of production by one generator creates a positive externality on the other by decongesting the line connecting them. The private generator, located on node 2, receives λ_2 at node 2 and pays λ_3 at node 3 for each unit of electricity it sends from node 2 to node 3. Hence the marginal transmission cost for the private generator is $\lambda_3 - \lambda_2$. Similarly, the non-private generator located at node

1 receives $\lambda_1 (\equiv 0)$ at node 1 and pays λ_3 at node 3 for each unit of electricity it sends from node 1 to node 3, implying that the non-private generator is willing to pay up to λ_3 to benefit from the positive externality created by the additional unit of production by the private generator. In equilibrium we must have $\lambda_3 - \lambda_2 = -\lambda_3$ (marginal cost = marginal benefit), or

$$\lambda_2 - 2\lambda_3 = 0. \qquad (5.3)$$

In equilibrium no generator wants to hold more or fewer TCRs than it already has.

Throughout this chapter we study the short-run output decisions of the generators and assume a constant returns to scale short-run production technology of $C_i(q_i) = c_i q_i$, where q_i is the output of generator $i = R, P$.

The consumers' demand for power is represented by an affine inverse demand function, $p(Q) = a - Q$, where $Q \equiv q_R + q_P$. Defining $\alpha_i = a - c_i$, $i = R, P$, as the *grade of efficiency* for generator i, we assume the following conditions on the demand and cost parameters:

Assumption 1: $\alpha_i > 0, i = R, P$.

Assumption 2: $2\alpha_i - \alpha_j > 0, i, j \in \{R, P\}, i \neq j$.

Assumption 1 states that each generator would find it profitable to serve the whole market on its own. Assumption 2 posits that the marginal cost differential between the two generators is not “too large” and it guarantees that when both generators are pure profit maximizers, the equilibrium is an interior one when the transmission capacity constraint is not binding.

With the above cost and demand specifications, the private generator's maximization problem becomes

$$\underset{q_P \geq 0}{Max}\, \Pi_P = \left[\alpha_P - (q_R + q_P)\right] q_P - (\lambda_3 - \lambda_2) q_P \, .$$

Note that the profits of the private generator involve a separate component, namely $(\lambda_3 - \lambda_2) q_P$, which arises from payments due to having to acquire TCRs for each unit of electricity generated and delivered. On the other hand, the non-private generator's maximization problem becomes

$$\underset{q_R \geq 0}{Max}\, \Phi_R = \gamma \left[\frac{1}{2} (q_R + q_P)^2 \right] + (1-\gamma) \left\{ \left[\alpha_R - (q_R + q_P)\right] q_R - \lambda_3 q_R \right\} .$$

Note that the first term (weighted by γ) involves the effect of consumers' surplus on the non-private generator's objective function, while the second term (weighted by (1-γ)) shows its profit arising from production and transmission.

3. Analysis of Equilibria

Given the above description of equilibrium in the TCR market, equilibrium in the overall system is characterized by the following conditions:

- Equilibrium in the electricity generation market:

$$\begin{aligned} &\gamma(q_R + q_P) + (1-\gamma)(\alpha_R - 2q_R - q_P) - \lambda_3 \leq 0 \\ &q_R \geq 0 \text{ and } q_R \left[\gamma(q_R + q_P) + (1-\gamma)(\alpha_R - 2q_R - q_P) - \lambda_3 \right] = 0 \end{aligned} \qquad (5.4)$$

$$\begin{aligned} &\alpha_P - 2q_P - q_R - \lambda_3 + \lambda_2 \leq 0 \\ &q_P \geq 0 \text{ and } q_P \left[\alpha_P - 2q_P - q_R - \lambda_3 + \lambda_2 \right] = 0 \end{aligned} \qquad (5.5)$$

- Feasibility in the TCR market:

$$|q_R - q_P| \leq 3K \qquad (5.6)$$

- Equilibrium in the TCR market:

$$\lambda_2 - 2\lambda_3 = 0 \qquad (5.7)$$

Expressions in (5.4) and (5.5) above are the first order conditions for the non-private and private generators, respectively, in the (constrained) maximization problem they face when they compete by choosing their quantities independently, while taking the TCR prices λ_2 and λ_3 as given. As we show below, for a given γ and K, there may exist an "unconstrained" equilibrium where the transmission capacity constraint in (5.6) is not binding in equilibrium, as well as a "constrained" equilibrium where it is binding in equilibrium (each equilibrium involving different λ_2 and λ_3.)

3.1 Unconstrained Equilibria

We first look at the case where the capacity of the line connecting the two generators, K, is sufficiently large so that the grid is not congested for any value of γ.[65] As discussed in Section 2 above, in this case we have $\lambda_2 = \lambda_3 = 0$ in equilibrium. The non-private generator's response function is

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[65] In fact, a sufficient condition for there to be no congestion for any γ is $K \geq \frac{a}{3}$, as shown in the analysis below.

$$q_R(q_P;\gamma)=\begin{cases}\dfrac{(1-\gamma)\alpha_R-(1-2\gamma)q_P}{2-3\gamma} & \text{for } q_P\in\left[0,\dfrac{(1-2\gamma)\alpha_R+(2-3\gamma)c_R}{(1-\gamma)}\right)\\ a-q_P & \text{for } q_P\in\left[\dfrac{(1-2\gamma)\alpha_R+(2-3\gamma)c_R}{(1-\gamma)},a\right)\\ 0 & \text{for } q_P\in[a,\infty)\end{cases}\quad(5.8)$$

while the private generator's response function becomes

$$q_P(q_R)=\begin{cases}\dfrac{\alpha_P-q_R}{2} & \text{if } q_R\in[0,\alpha_P)\\ 0 & \text{if } q_R\in[\alpha_P,\infty)\end{cases}\quad(5.9)$$

Note that the ("unconstrained") response function of the non-private generator depends on γ. When both γ and q_P are large enough, the non-private generator's best response is to produce just enough to complete the total output to a (at which point the market is saturated and consumers' surplus reaches its maximum value).[66] For $\gamma<\frac{1}{2}$ the non-private generator's and the private generator's outputs are strategic substitutes while the negative slope changes beyond $q_P=\frac{(1-2\gamma)\alpha_R+(2-3\gamma)c_R}{(1-\gamma)}$. For $\gamma=\frac{1}{2}$ the non-private generator's response function is vertical at $q_R=\alpha_R$ until $q_R+q_P=a$, at which point the slope changes to -1. For $\gamma>\frac{1}{2}$, non-private and private generators' outputs become strategic complements. This is due to the fact that the non-private

[66] For $\gamma<\frac{c_R}{a+c_R}$, there is no kink in the response function.

generator puts a relatively larger weight on consumer surplus than on its profits when $\gamma > \frac{1}{2}$.

When the private generator increases its output at a given level of non-private generator's output, price decreases. This leads to an increase in the consumers' surplus and a decrease in the non-private generator's profit. The optimal response for the non-private generator is to increase its output until the increase in consumer surplus weighted by γ is just equal to the decrease in marginal profit weighted by $1-\gamma$. The fact that γ, the weight on consumer surplus, is greater than $\frac{1}{2}$ results in an increase rather than a decrease in non-private generator's output as an optimal response to an increase in private generator's output. On the other hand, a decrease in the private generator's output will lead to a decrease in the non-private generator's output as the optimal response for the same reason.

Let $q_R^U(\gamma)$ and $q_P^U(\gamma)$ be the unconstrained equilibrium output levels of the non-private and private generators, respectively, for a given γ. The (unconstrained) equilibrium output choices by the non-private and private generators are

$$q_R^U(\gamma) = \begin{cases} \dfrac{2(1-\gamma)\alpha_R - (1-2\gamma)\alpha_P}{3-4\gamma} & \text{if } 0 \le \gamma < \underline{\gamma} \\ \dfrac{(1-\gamma)\alpha_R}{2-3\gamma} & \text{if } \underline{\gamma} \le \gamma < \overline{\gamma} \\ a & \text{if } \overline{\gamma} \le \gamma \le 1 \end{cases} \qquad (5.10)$$

and

$$q_P^U(\gamma)=\begin{cases}\dfrac{(2-3\gamma)\alpha_P-(1-\gamma)\alpha_R}{3-4\gamma} & \text{if } 0\le\gamma<\underline{\gamma} \\ 0 & \text{if } \underline{\gamma}\le\gamma\le 1\end{cases}, \tag{5.11}$$

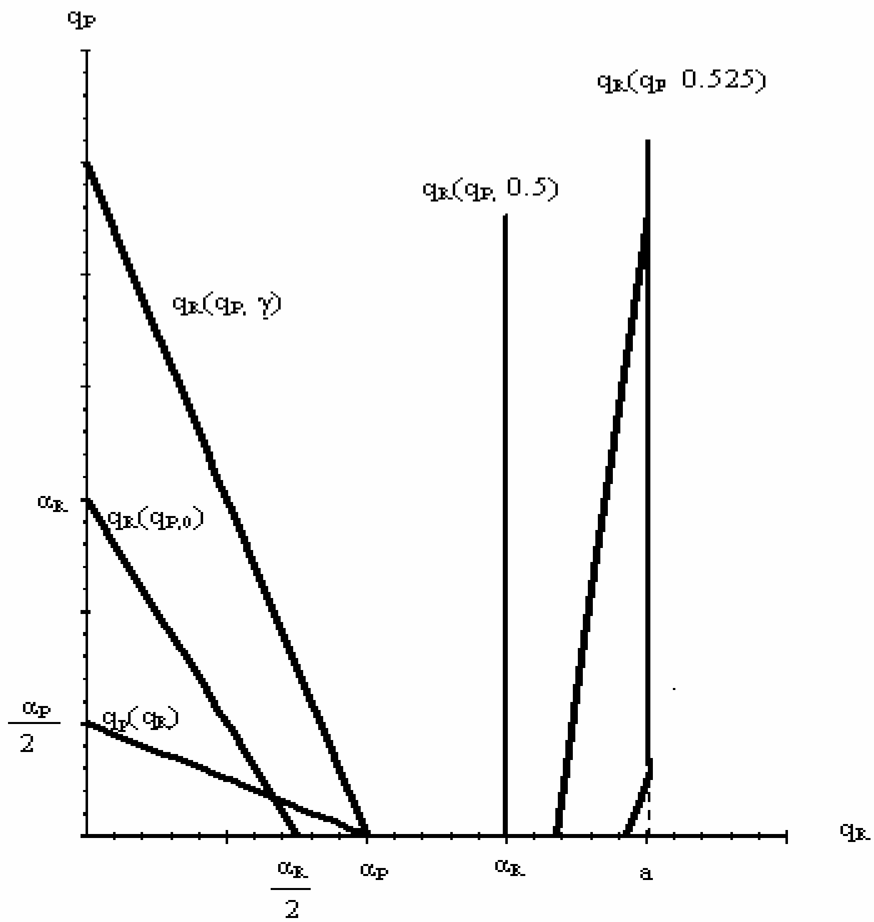
respectively, where

$$\underline{\gamma}=\frac{2\alpha_P-\alpha_R}{3\alpha_P-\alpha_R} \tag{5.12}$$

is the value of γ beyond which the private generator is ousted from the market and $\overline{\gamma}=\dfrac{2a-\alpha_R}{3a-\alpha_R}$ is the value of γ beyond which the market is saturated by the non-private generator's output. The total output therefore is

$$Q^U(\gamma)=\begin{cases}\dfrac{(1-\gamma)(\alpha_P+\alpha_R)}{3-4\gamma} & \text{if } 0\le\gamma<\underline{\gamma} \\ \dfrac{(1-\gamma)\alpha_R}{2-3\gamma} & \text{if } \underline{\gamma}\le\gamma<\overline{\gamma} \\ a & \text{if } \overline{\gamma}\le\gamma\le 1\end{cases}. \tag{5.13}$$

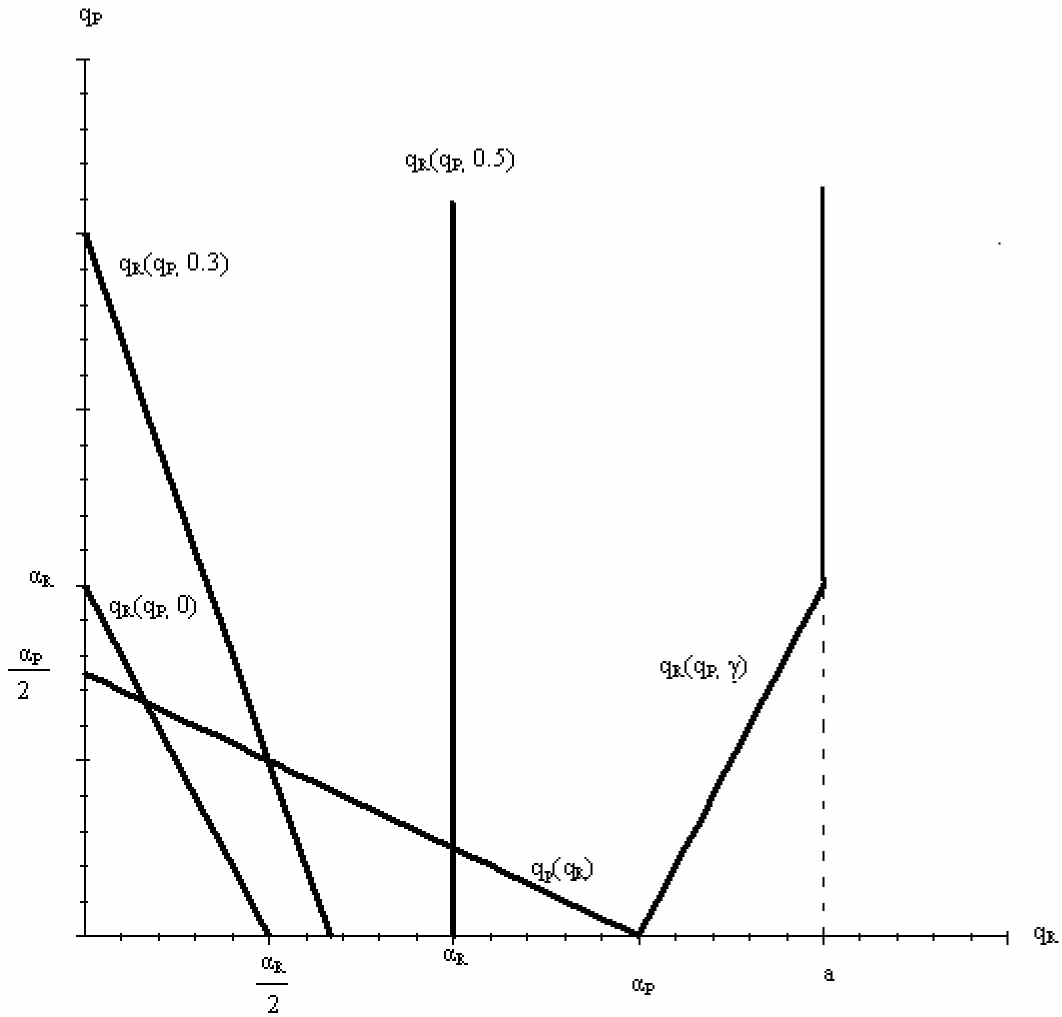
Figure V-2: Response Functions with a Less Efficient Private Generator



Note that in Figure V-2, where the non-private generator has a lower marginal cost, we have $\underline{\gamma} < \frac{1}{2}$. When the non-private generator has a higher marginal cost, we have $\underline{\gamma} > \frac{1}{2}$ (see Figure V-3). That is, it takes a higher γ for the non-private generator to oust the private one from the market when the non-private generator is the higher cost producer.[67]

[67] Such a high level of production by the non-private generator may entail losses on its part.

Figure V-3:Response Functions with a More Efficient Private Generator



Equations (5.10) and (5.11) reveal that there are two types of unconstrained equilibria. In the first case, both the non-private and the private generators produce a positive amount. This case corresponds to small values of γ, the weight on consumer's surplus in the non-private generator's objective function. We denote such interior unconstrained equilibria as type U^1 equilibria. Whether or not the non-private generator is the more efficient producer impacts the characterization of U^1 type equilibria. It is therefore useful to differentiate between U^1 type equilibria where the non-private generator produces more, which we call U_R^1 type, and where the private generator produces more, which we call U_P^1 type. When γ is large enough, only the non-private generator produces a positive amount, and we denote such equilibria as type U_R^2.

As a direct result of Assumption 2, the non-private generator always produces a positive amount, even when $\gamma = 0$, in an unconstrained equilibrium. As shown below, the non-private generator's equilibrium output is increasing in γ in the unconstrained case, therefore, there does not exist an unconstrained equilibrium where the non-private generator produces zero output.

From Equation (5.2) we know that whether there is congestion on the grid depends on the difference between the generators' output levels. To facilitate the characterization of the constrained equilibria, consider the difference between the unconstrained equilibrium output levels of the two generators. Letting $\Delta q^U(\gamma) \equiv q_R^U(\gamma) - q_P^U(\gamma)$, this difference is

$$\Delta q^U(\gamma) = \begin{cases} \alpha_R - \alpha_P + \dfrac{\gamma(\alpha_R + \alpha_P)}{3-4\gamma} & \text{if } 0 \le \gamma < \underline{\gamma} \\ \dfrac{(1-\gamma)\alpha_R}{2-3\gamma} & \text{if } \underline{\gamma} \le \gamma < \overline{\gamma} \\ a & \text{if } \overline{\gamma} \le \gamma \le 1 \end{cases} . \quad (5.14)$$

To analyze the impact of γ on the nature of equilibria, define $K(\gamma)$ as the capacity level that makes the unconstrained equilibrium, characterized by equations (5.10) and (5.11), just binding for a given γ:

$$K(\gamma) \equiv \frac{1}{3}\left|\Delta q^U(\gamma)\right| \quad (5.15)$$

When the non-private generator's objective is solely to maximize profit, i.e. when $\gamma = 0$, the difference between the two output levels depends only on the marginal cost differential, as long as both generators' production levels are strictly positive. It is easily shown that $\frac{\partial \Delta q^U(\gamma)}{\partial \gamma} \geq 0$ for all $\gamma \in [0,1]$, regardless of the relative efficiency of the generators. If $\alpha_R \geq \alpha_P$, then $\Delta q^U(\gamma) \geq 0$ for all $\gamma \in [0,1]$. If $\alpha_R < \alpha_P$, then $\Delta q^U(0) < 0$ and $\Delta q^U(1) = a > 0$. Since $\Delta q^U(\gamma)$ is continuous in γ in the relevant region, there must exist a $\hat{\gamma} \in [0,1]$ such that for $\gamma \in [0,\hat{\gamma}]$, $\Delta q^U(\gamma) \leq 0$ and for $\gamma \in (\hat{\gamma},1]$, $\Delta q^U(\gamma) > 0$. This threshold level of γ is calculated as

$$\hat{\gamma} = \frac{3(\alpha_P - \alpha_R)}{5\alpha_P - 3\alpha_R}. \tag{5.16}$$

Note that $\hat{\gamma}$ is always less than $\frac{1}{2}$. Thus, the relative magnitudes of the unconstrained equilibrium output levels depend on the relative cost efficiency of the generators and the weight attached to the consumer surplus in the non-private generator's objective function. If the non-private generator is more efficient than the private one, then the non-private generator produces more for any γ. If, on the other hand, the private generator is more efficient, then the private generator produces more for smaller levels of γ, i.e. for $\gamma < \hat{\gamma}$, while the non-private generator's output is higher as γ increases beyond $\hat{\gamma}$. Therefore, as the weight attached to consumers' surplus in the objective of the non-private generator increases beyond a threshold, the non-private generator produces more than its private counterpart despite its cost inefficiency.

Figure V-4:Threshold Capacity Levels with a Less Efficient Private Generator

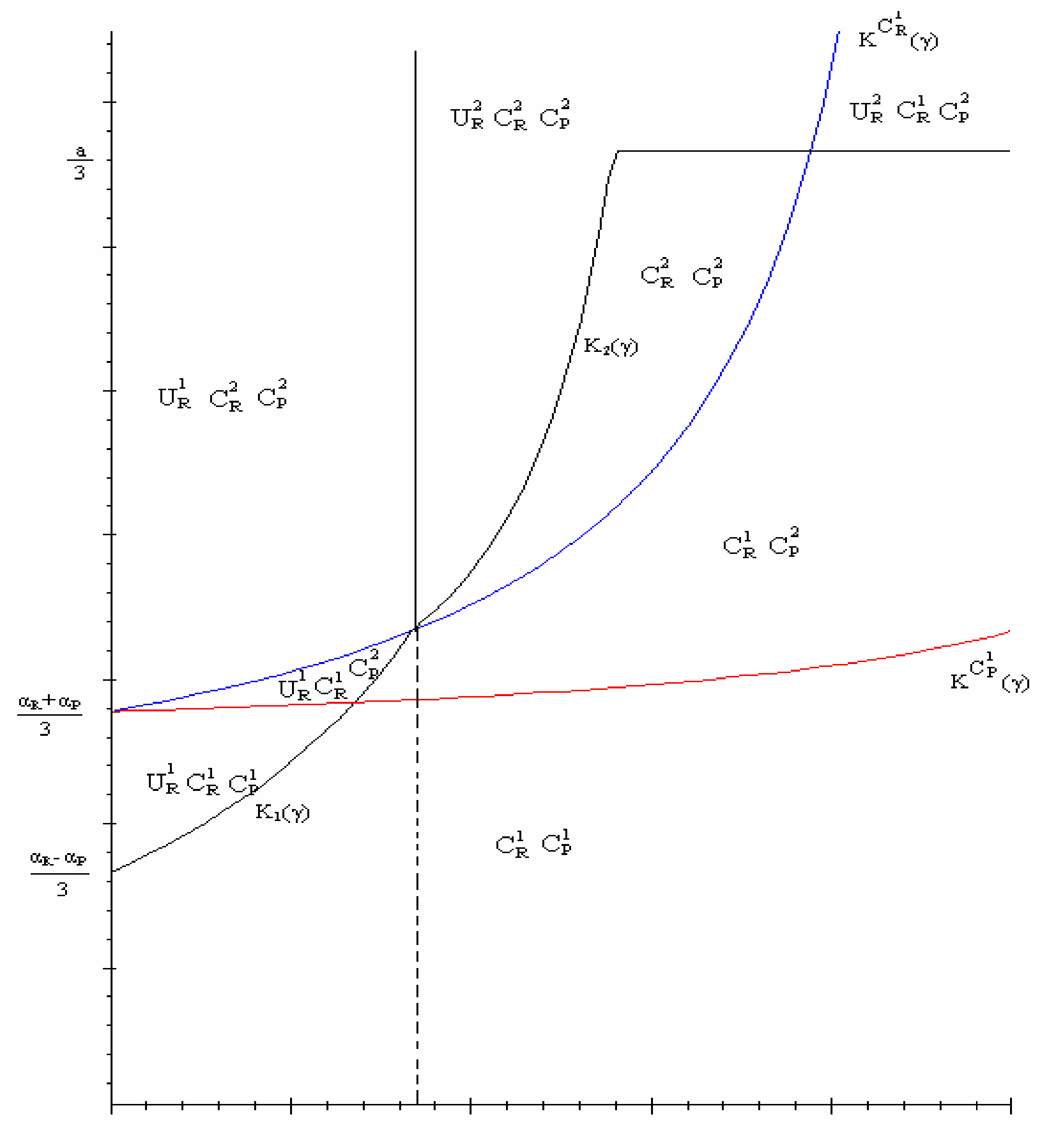
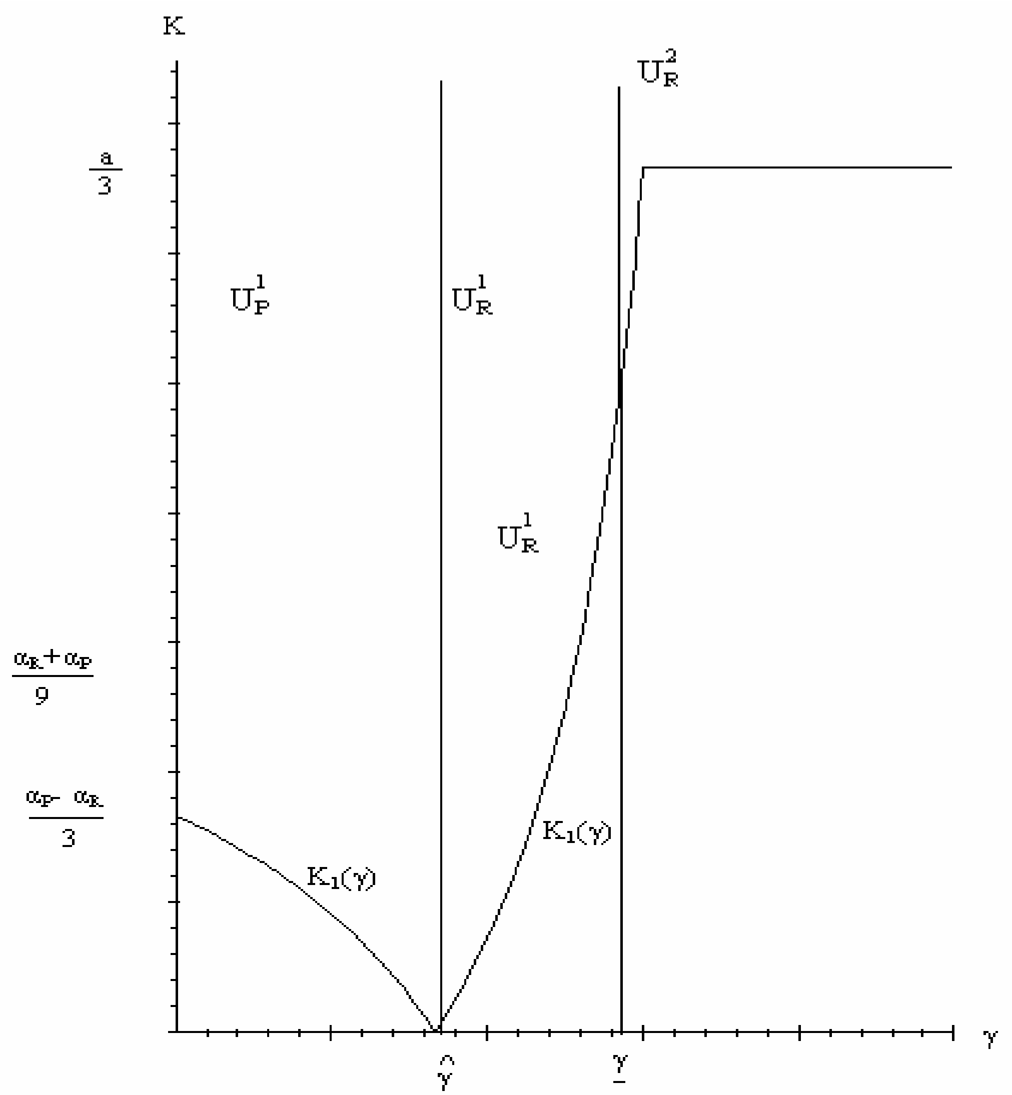


Figure V-4 depicts $K(\gamma)$ for $\alpha_R > \alpha_P$. Note that (5.14) implies that $K(\gamma)$ lies within the interval $\left[\frac{\alpha_R - \alpha_P}{3}, \frac{a}{3}\right]$. For a given $\gamma \in [0,1]$, if $K \geq K(\gamma)$, then the equilibrium output levels are the unconstrained output levels characterized by Equations (5.10) and (5.11) above. Unconstrained equilibria, of type U_R^1 and U_R^2, that arise for given combinations of K and γ when $\alpha_R > \alpha_P$ are depicted in Figure V-4. Note that U_P^1 type equilibrium does not exist when $\alpha_R > \alpha_P$. Figure V-5 shows $K(\gamma)$ for $\alpha_R < \alpha_P$. In this case $K(\gamma)$ resides in the interval $\left[0, \frac{a}{3}\right]$. Unconstrained equilibria for given combinations of K and γ are shown in Figure V-5. The proposition below summarizes the results on unconstrained equilibria for both cases.

Proposition 1: Let $K \geq Min\left\{K(\gamma), \frac{a}{3}\right\}$ for a given γ. Then

1. If $\alpha_R > \alpha_P$, then the unconstrained equilibrium will be of type U_R^1 for $\gamma \in \left[0, \underline{\gamma}\right]$, and of type U_R^2 for $\gamma \in \left[\underline{\gamma}, 1\right]$;
2. If $\alpha_R < \alpha_P$, then the unconstrained equilibrium will be of type U_P^1 for $\gamma \in \left[0, \hat{\gamma}\right]$, of type U_R^1 for $\gamma \in \left[\hat{\gamma}, \underline{\gamma}\right]$, and of type U_R^2 for $\gamma \in \left[\underline{\gamma}, 1\right]$.

Figure V-5:Threshold Capacity Levels with a More Efficient Private Generator



3.2 Constrained Equilibria

For a given γ, if $K < K(\gamma)$, then the equilibrium necessarily involves congestion on the grid. Since the capacity constraint involves the absolute value of the difference between output levels, there are potentially two equilibria for each level of $K < K(\gamma)$. That is, with congestion the TCR prices λ_2 and λ_3 are no longer zero, and there are two sets of λ_2 and λ_3 that satisfy (5.4), (5.5), (5.2) and (5.3).

Figure V-6:Generator Response Functions for a Given γ'

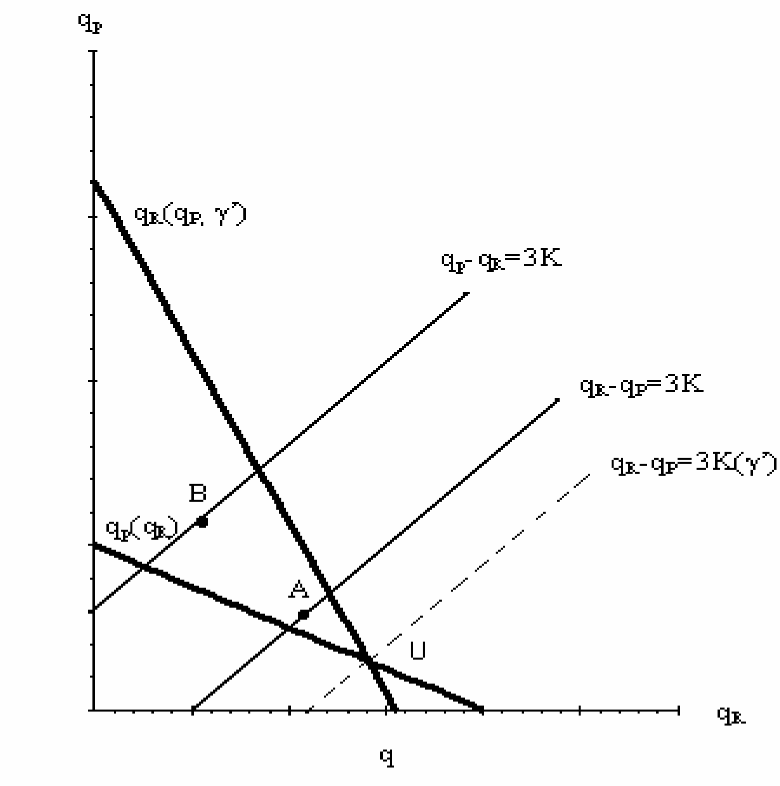


Figure V-6 displays the response functions of the generators for a given γ'. In this case point U is an (unconstrained) equilibrium for a capacity level $K' \geq K(\gamma')$. Take a $K < K(\gamma')$. The lines implied by $|q_R - q_P| = 3K$ correspond to the capacity constraint in this case. In the TCR market nodal transmission rights are traded, and the equilibrium TCR prices shift the best response functions of the two generators such that equilibrium in the electricity market occurs at either point A or point B, where the response functions (5.8) and (5.9), the TCR market equilibrium condition $\lambda_2 - 2\lambda_3 = 0$ and the capacity constraint lines $|q_R - q_P| = 3K(\gamma)$ are satisfied simultaneously for $\gamma = \gamma'$.

3.2.1 Example

We present the following simple example to illustrate the role of TCRs. Consider the case where $\gamma = 0$ and $\alpha_R > \alpha_P$. In this case, the unconstrained equilibrium output levels of the non-private and the private generators are

$$q_R^{U_R^1}(0) = \frac{2\alpha_R - \alpha_P}{3} \tag{5.17}$$

and

$$q_P^{U_R^1}(0) = \frac{2\alpha_P - \alpha_R}{3}, \tag{5.18}$$

respectively. Since $\alpha_R > \alpha_P$, at the unconstrained equilibrium the non-private generator produces more than the private generator and $\Delta q^{U_R^1}(0) = \alpha_R - \alpha_P$. Now suppose that $\alpha_R - \alpha_P > 3K$, i.e. the unconstrained equilibrium is not attainable. In order to bring production in line with the capacity constraint the effective cost of production to the non-private generator needs to be increased while the effective cost of production to the private generator needs to be decreased. The constrained equilibria outcomes are

$$q_R^C = \frac{\alpha_R + \alpha_P \pm 9K}{6} \tag{5.19}$$

$$q_P^C = \frac{\alpha_R + \alpha_P \mp 9K}{6} \tag{5.20}$$

$$\lambda_2^C = (\alpha_R - \alpha_P) \mp 3K > 0 \tag{5.21}$$

$$\lambda_3^C = \frac{(\alpha_R - \alpha_P) \mp 3K}{2} > 0 \qquad (5.22)$$

In one of the constrained equilibria the non-private generator produces more, and in the other it produces less. In both cases the non-private generator pays λ_3^C (a different positive amount in each case) at the margin for each unit of electricity transmitted, thus raising its effective marginal cost to $c_R + \lambda_3^C$. The private generator, on the other hand, receives λ_2^C and pays λ_3^C for each unit of electricity it transmits, bringing its effective marginal cost to $c_P + \lambda_3^C - \lambda_2^C < c_P$ in each case. With the introduction of these congestion prices, the response function of each generator moves accordingly. One could also interpret this "adjustment" in terms of prices rather than costs. The effective price the non-private generator receives from the sale of a unit of electricity would then be $p^C - \lambda_3^C < p^C$, while the private generator would be selling the same good at an effective price of $p^C - \lambda_3^C + \lambda_2^C > p^C$.

As in the case of unconstrained equilibria, there is a type of constrained equilibrium where both generators produce strictly positive levels of output, as well as another type of constrained equilibrium where only the non-private generator produces. We denote the constrained equilibria where both generators produce strictly positive amounts as equilibria of type C^1, and the equilibria where only the non-private generator produces as equilibria of type C^2. An equilibrium where $q_R - q_P = 3K$ holds is denoted as C_R^1, and an equilibrium where $q_P - q_R = 3K$ holds is denoted as C_P^1. In other words, C_R^1 is a constrained equilibrium where the non-private generator produces more, whereas C_P^1 is a constrained equilibrium where the private generator produces more. We now turn to the characterization of each type of equilibrium.

3.2.2 C^1 Type Equilibria

The following proposition characterizes the C_R^1 type equilibrium.

Proposition 2: A C_R^1 type equilibrium exists if and only if

$$K \leq K^{C_R^1}(\gamma) \equiv \frac{\alpha_P + (1-\gamma)\alpha_R}{9(1-\gamma)}. \tag{5.23}$$

The equilibrium values for the variables under consideration in this case are:

$$q_R^{C_R^1}(\gamma) = \frac{\alpha_P + (1-\gamma)\alpha_R + 3K(3-2\gamma)}{6-5\gamma} \tag{5.24}$$

$$q_P^{C_R^1}(\gamma) = \frac{\alpha_P + (1-\gamma)\alpha_R - 9K(1-\gamma)}{6-5\gamma} \tag{5.25}$$

$$\lambda_3^{C_R^1} = \frac{3(1-\gamma)\alpha_R - (3-5\gamma)\alpha_P - 3K(3-4\gamma)}{6-5\gamma} \tag{5.26}$$

$$\lambda_2^{C_R^1} = 2\lambda_3^{C_R^1} \tag{5.27}$$

Proof: See Appendix.

Thus, C_R^1 type equilibrium exists if K is sufficiently small, i.e. when $K < K^{C_R^1}(\gamma)$. Note from Equation (5.25) that when K exceeds $K^{C_R^1}(\gamma)$, the private generator runs losses and hence chooses not to produce. Figure V-7 and Figure V-8 display the equilibria for the cases where $\alpha_R > \alpha_P$ and $\alpha_P > \alpha_R$, respectively. Observe from these Figures that C_R^1 type equilibrium may exist in regions where unconstrained equilibrium also exists.

Figure V-7:Types of Equilibrium with a Less Efficient Private Firm

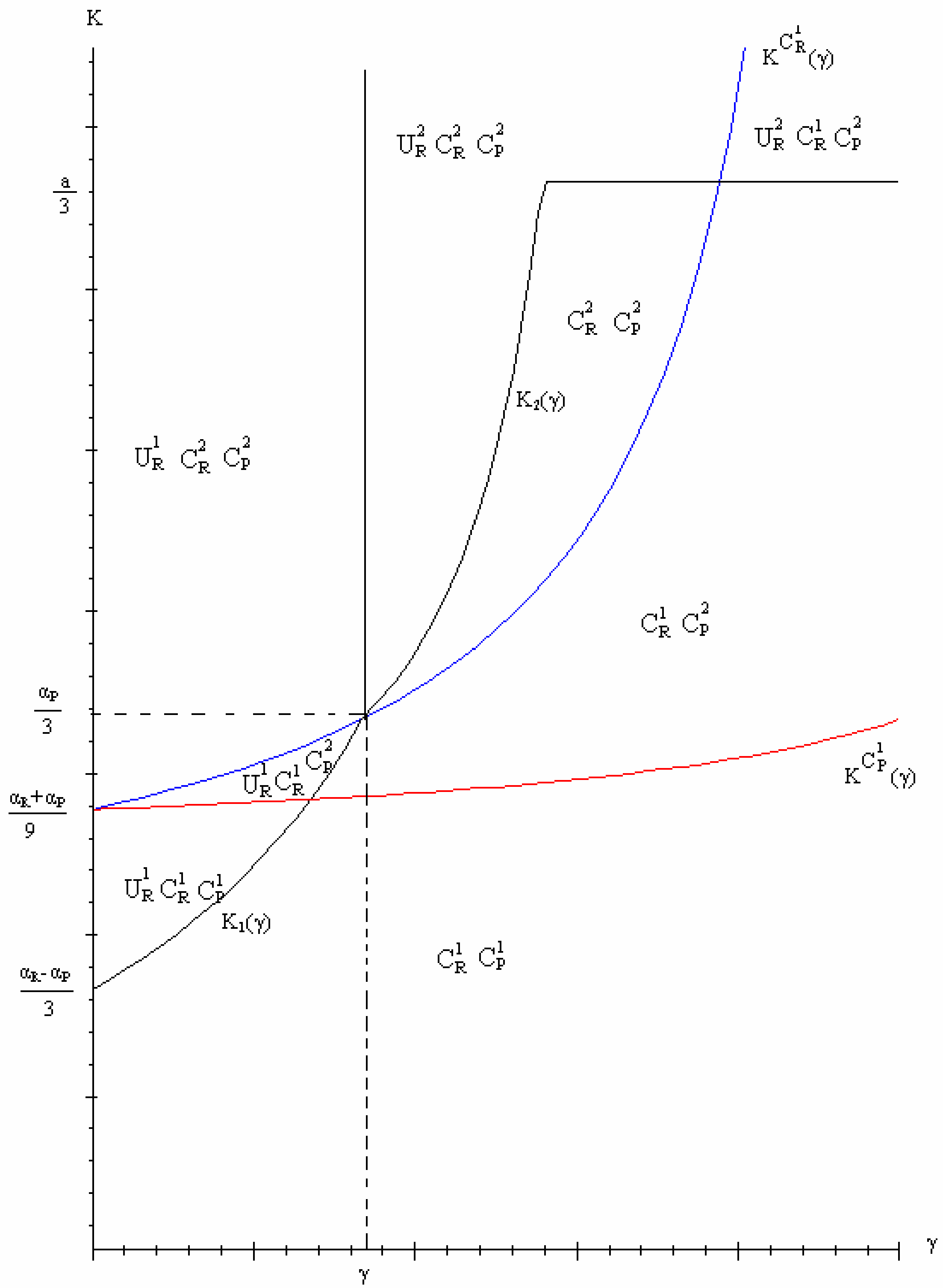
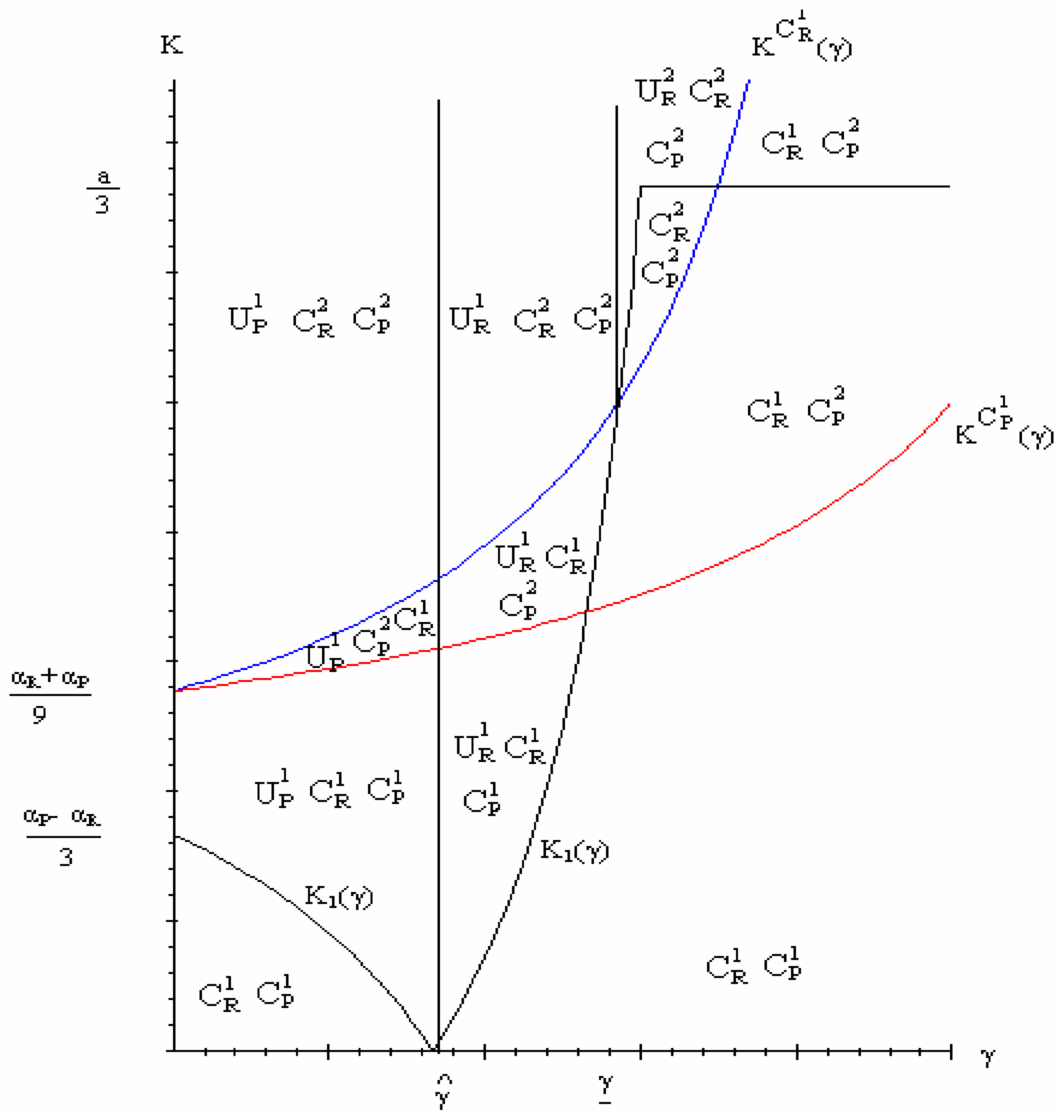


Figure V-8:Types of Equilibrium with a More Efficient Private Firm



The following proposition characterizes C_P^1 type equilibria.

Proposition 3: C_P^1 type equilibria exist if and only if

$$K \le K^{C_P^1}(\gamma) \equiv \frac{\alpha_P + (1-\gamma)\alpha_R}{3(3-2\gamma)}. \tag{5.28}$$

The equilibrium values for the variables under consideration in this case are:

$$q_R^{C_P^1}(\gamma) = \frac{\alpha_P + (1-\gamma)\alpha_R - 3K(3-2\gamma)}{6-5\gamma} \tag{5.29}$$

$$q_P^{C_P^1}(\gamma) = \frac{\alpha_P + (1-\gamma)\alpha_R + 9K(1-\gamma)}{6-5\gamma} \tag{5.30}$$

$$\lambda_3^{C_P^1} = \frac{3(1-\gamma)\alpha_R - (3-5\gamma)\alpha_P + 3K(3-4\gamma)}{6-5\gamma} \tag{5.31}$$

$$\lambda_2^{C_P^1} = 2\lambda_3^{C_P^1} \tag{5.32}$$

Proof: See Appendix.

Thus, C_P^1 type equilibria exist if K is sufficiently small, this time when $K < K^{C_P^1}(\gamma)$. Note from Equation (5.29) that when K exceeds $K^{C_P^1}(\gamma)$, the non-private firm chooses not to produce. Figure V-7 and Figure V-8 also display $K^{C_P^1}(\gamma)$ and show on the (γ, K) space the regions where C_P^1 type equilibrium is obtained. Note again that C_P^1 type equilibrium may exist in regions where unconstrained equilibrium also exists.

3.2.3 C^2 Type Equilibria

A C_R^2 type equilibrium is characterized in the following proposition.

Proposition 4: C_R^2 type equilibrium exists if and only if

$$K \geq K^{C_R^1}(\gamma) \equiv \frac{\alpha_P + (1-\gamma)\alpha_R}{9(1-\gamma)}. \tag{5.33}$$

The equilibrium values for the variables under consideration in this case are:

$$q_R^{C_R^2}(\gamma) = 3K \tag{5.34}$$

$$q_P^{C_R^2}(\gamma) = 0 \tag{5.35}$$

$$\lambda_3^{C_R^2} = (1-\gamma)\alpha_R - 3K(2-3\gamma) \quad (5.36)$$

$$\lambda_2^{C_R^2} = 2\lambda_3^{C_R^2} \quad (5.37)$$

Proof: See Appendix.

Thus, C_R^2 type equilibrium exists in regions where C_R^1 does not exist (except along the $K^{C_R^1}(\gamma)$ curve on which they coincide). Figure V-7 and Figure V-8 display the regions where C_R^2 type equilibrium is attained. Observe again that C_R^2 type equilibrium may exist in regions where unconstrained equilibrium also exists.

The following proposition characterizes C_P^2 type equilibria.

Proposition 5: C_P^2 type equilibrium exists if and only if

$$K \geq K^{C_P^1}(\gamma) \equiv \frac{\alpha_P + (1-\gamma)\alpha_R}{3(3-2\gamma)}. \quad (5.38)$$

The equilibrium values for the variables under consideration in this case are:

$$q_R^{C_P^2}(\gamma) = 0 \quad (5.39)$$

$$q_P^{C_P^2}(\gamma) = 3K \quad (5.40)$$

$$\lambda_3^{C_P^2} = 6K - \alpha_P \quad (5.41)$$

$$\lambda_2^{C_P^2} = 2\lambda_3^{C_P^2} \quad (5.42)$$

Proof: See Appendix.

Thus, C_P^2 type equilibria exist in regions where C_P^1 type equilibria do not exist (except along the $K^{C_P^1}(\gamma)$ curve on which they coincide). Figure V-7 and Figure V-8 display the regions where C_P^2 type equilibria are attained. Note once more that C_P^2 type equilibria may exist in regions where unconstrained equilibrium also exists.

Some of our results may seem counter-intuitive at first glance; in particular, existence of an equilibrium where the private firm produces more than, or even ousts from the market, the non-private generator even when the non-private firm is the more efficient generator. It's worth noting that such counter-intuitive outcomes happen only in constrained equilibria and they are never the only possible outcomes; there are always other equilibria for the same parameter values with the "expected" outcome. However, as we discuss in detail below, in any equilibrium where the non-private generator is ousted from the market, the ISO runs a loss. That is, to support an equilibrium where the private generator is the only firm that produces, the ISO effectively has to "subsidize" the private generator (or a penalty to the non-private generator, or both) via generous transmission rights prices favoring the private generator. As we show below, once some reasonable constraints on the profits of the ISO are imposed for equilibrium selection, such counter-intuitive outcomes are eliminated.

4. Profits of the ISO and the Non-private Generator

The profits of the ISO and the non-private generator may be of concern for a number of reasons. The ISO is in charge of administering the TCR market and operating the transmission network. The TCR market is assumed to operate much like a competitive market, each generator taking the transmission prices it faces as given and equilibrium prices being those that equate demand and supply for transmission rights at each node.

We have not ascribed a separate objective function to the ISO other than perhaps allowing it to act like a "Walrasian auctioneer" in the TCR market, announcing the final prices that will drive the TCR market into equilibrium. In our model, as in the operation of any ISO that uses market-based congestion management, TCR pricing involves transfers to and from the ISO depending on the signs of λ_2 and λ_3, as well as the relative magnitudes of q_R and q_P. The profits of the ISO are given by

$$\Pi_{ISO} = \lambda_3 q_R + (\lambda_3 - \lambda_2) q_P$$

and given that $\lambda_2 = 2\lambda_3$ in equilibrium, the equilibrium level of ISO profits will be

$$\Pi_{ISO} = \lambda_3 (q_R - q_P)\,. \tag{5.43}$$

Note that when the equilibrium is unconstrained, we have $\lambda_2 = \lambda_3 = 0$, and hence $\Pi_{ISO} = 0$. However, in the case of constrained equilibria, profits of the ISO can be positive or negative, as indicated by Equation (5.43) above.

It may very well be the case that the public authority (government) requires that the ISO runs no losses. Recall also from our characterization of constrained equilibria in Section 3.2 above that for each given pair of K and γ, there will be one set of λ_2 and λ_3 that corresponds to the constraint $q_R - q_P = 3K$ in equilibrium, and another that corresponds to $q_P - q_R = 3K$. It may be the case that the ISO profits are positive for one case and negative for the other. We may then use the non-negative ISO profit requirement as an equilibrium selection criterion.

In the Appendix, we present a detailed analysis of the profits of the ISO in constrained equilibria. As to be expected, the sign of the ISO profits in a constrained equilibrium (be it of C_R^1, C_P^1, C_R^2 or C_P^2 type) depends, among other things, on the relative efficiency of the non-private generator versus the private one. Figure V-9 depicts the ISO profits in the (γ, K) space for the case where $\alpha_R > \alpha_P$, and Figure V-10 does the same for the case $\alpha_R < \alpha_P$.

Figure V-9: Profits of the ISO with a Less Efficient Private Generator

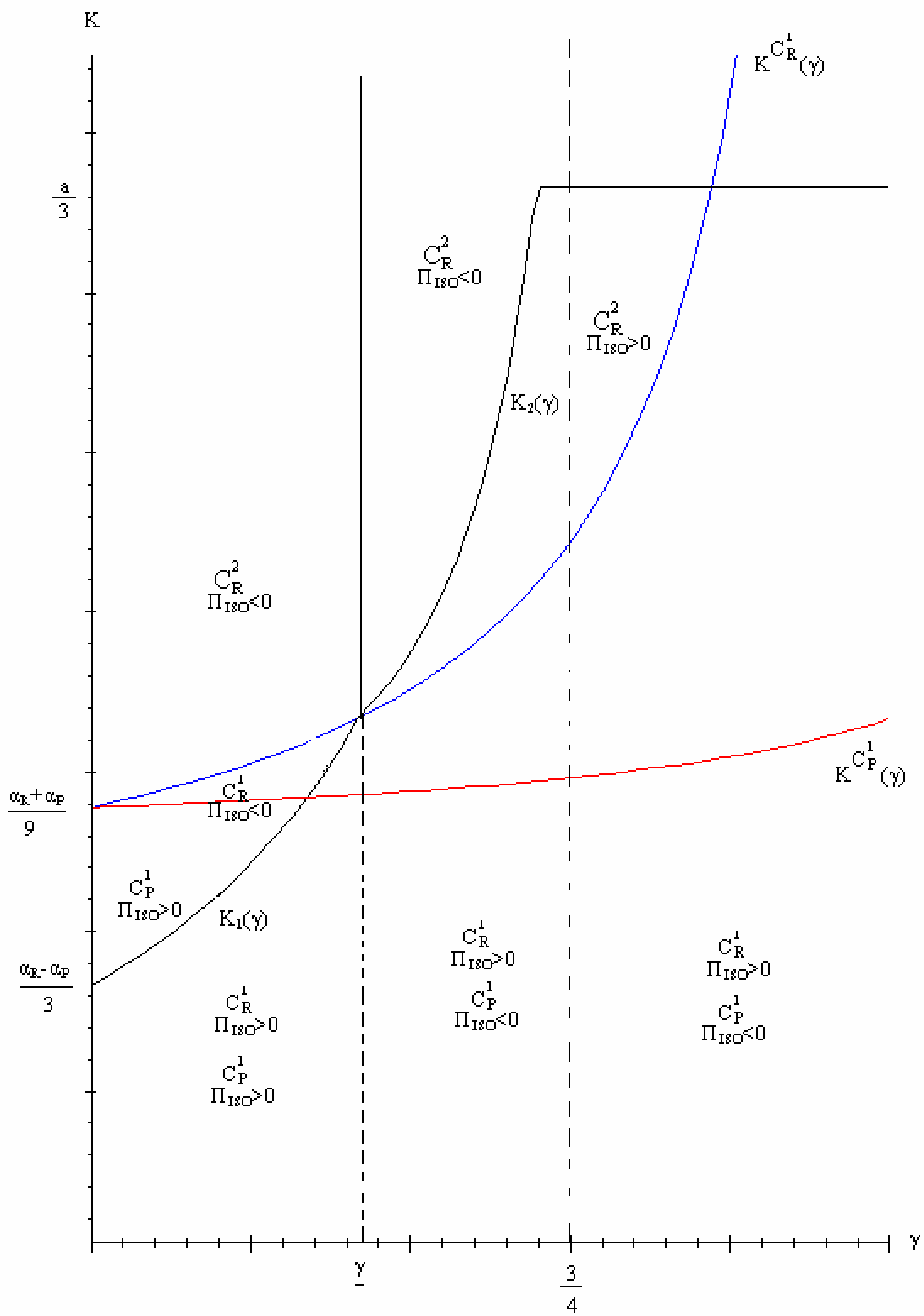
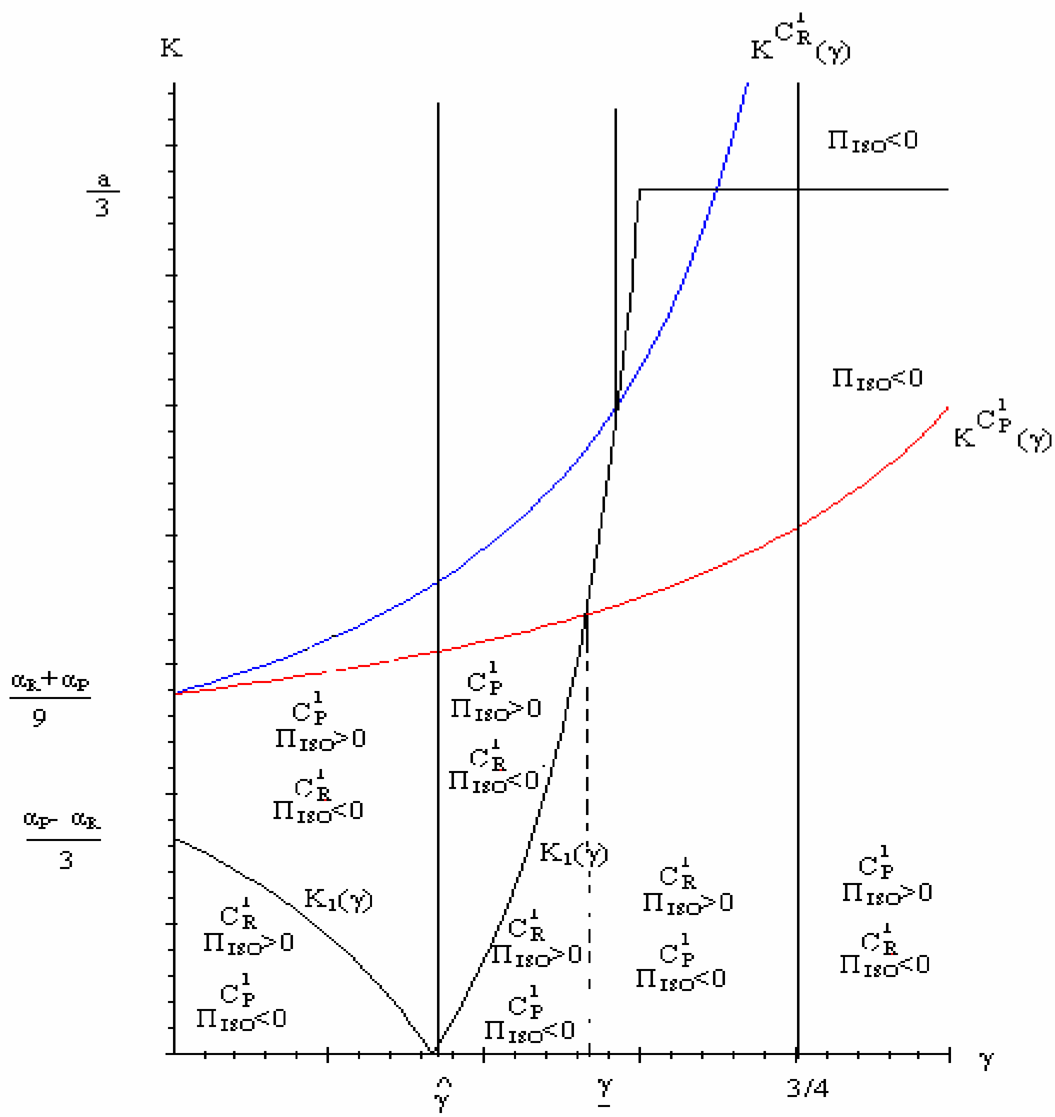


Figure V-10: Profits of the ISO with a More Efficient Private Generator



As for the profits of the non-private generator, recall that the non-private generator's objective may involve concern for consumers' surplus. In cases where a large enough weight is placed on consumers' surplus in relation to profits, i.e. for a large γ, a constrained equilibrium outcome may involve negative profits for the non-private generator. Perhaps more so than the case for ISO, it is again plausible that the non-private generator faces a nonnegative profit constraint. As in the case of the ISO profits, the sign of non-private generator's profits can also be used as an equilibrium selection criterion when there are multiple equilibria for a given pair of K and γ.

In the Appendix, we also present a detailed analysis of the profits of the non-private generator in all types of constrained and unconstrained equilibria, although we do not impose any constraints on the non-private firm's profits for equilibrium selection in the model. Unlike the case for the ISO profits, non-private generator's profits can be negative or positive in unconstrained equilibria as well in constrained equilibria. We note here that profits of the non-private generator are always nonnegative for U_R^1 type equilibrium. In a U_R^2 type equilibrium, where $\gamma \in \left[\underline{\gamma}, \overline{\gamma}\right]$, the non-private generator's profits are positive when $\alpha_R > \alpha_P$, and they are negative when $\alpha_R < \alpha_P$. In the region where $\gamma \in \left[\overline{\gamma}, 1\right]$, its profits are also strictly negative.

5. Choice of γ as a Regulatory Policy

The equilibrium levels of production calculated above are for a given K and γ. Observe that γ, the weight given to consumers' surplus in the non-private generator's objective function, can be viewed as a policy tool. This brings out the question of choosing γ optimally. We take the total surplus

$$W(q_R, q_P; K, \gamma) = \int_0^{q_R+q_P} P(Q)dQ - P(Q)Q + \Pi_P(q_R, q_P) + \Pi_R(q_R, q_P) + \Pi_{ISO}(q_R, q_P)$$

as the measure of welfare, which, given the specifications of our model, becomes

$$W(q_R, q_P; K, \gamma) = \alpha_R Q - \frac{Q^2}{2} - (\alpha_R - \alpha_P) q_P . \tag{5.44}$$

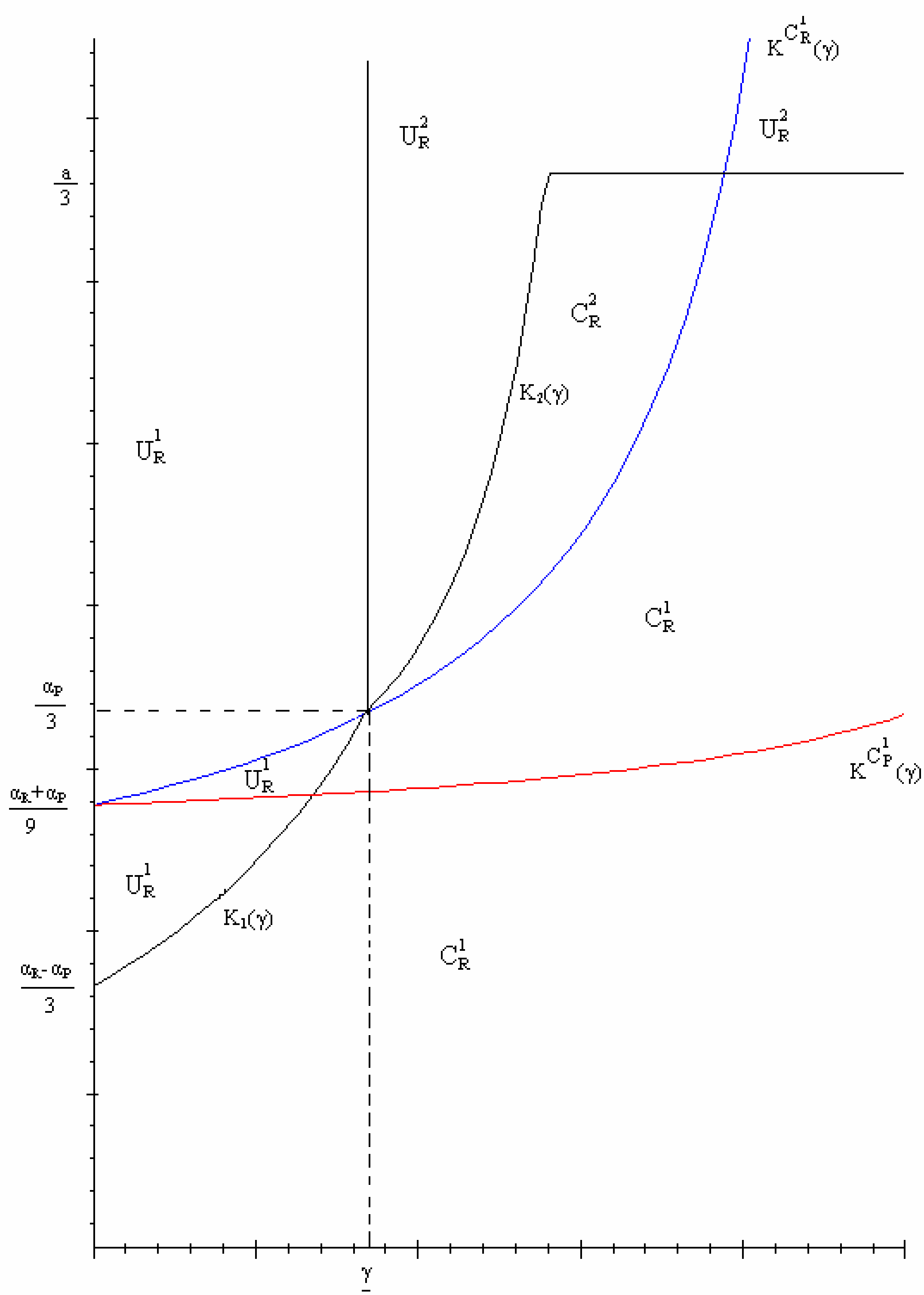
Recall that for a given K and γ, there will exist multiple equilibria. In order to carry out welfare analysis of any sort we have to deal with the multiplicity of equilibria. As argued in Section 4 above, a plausible criterion to select among equilibria in our case is to look at the profits of the ISO as well as those of the non-private generator. Using the analysis for that section (presented in the Appendix), we first eliminate equilibria that involve negative profits for the ISO. If after this elimination there still remain multiple equilibria with nonnegative profits for the ISO, we choose the one that leaves the ISO with zero profits. The ISO has a rather neutral role in the way we modeled the operation of the transmission network. In fact, the ISO simply coordinates the functioning of the TCR market. While it is plausible to insist that the ISO does not run any losses, it is also plausible to assume that it is left with minimum profits (in our case zero profits.) This approach is also consistent with the operation of major U.S. ISOs (PJM, Midwest ISO, ISO New England, New York ISO, California ISO), which are private companies that are required to operate at zero profits.

Applying these selection criteria on Figure V-7 and Figure V-8, we arrive at Figure V-11 and Figure V-12, which display the single equilibrium selected in relevant regions of the (γ, K) space for the cases of $\alpha_R > \alpha_P$ and $\alpha_R < \alpha_P$, respectively. In computing the optimal value of γ, we consider the cases where the non-private generator is more efficient than the private generator, and where it is less efficient, separately for the sake of clarity of exposition.

5.1 Optimal Policy with a More Efficient Non-private Generator

For the case of $\alpha_R > \alpha_P$, the equilibrium selection process just outlined shows that when the transmission capacity K exceeds $\frac{a}{3}$ the equilibrium is unconstrained for any γ, being of the U_R^1 type for $\gamma \in \left[0,\underline{\gamma}\right]$ and of the U_R^2 type for $\gamma \in \left[\underline{\gamma},1\right]$. For $\gamma \in \left[0,\underline{\gamma}\right]$ and $K \in \left[K_1(\gamma),\frac{a}{3}\right]$, we have a U_R^1 type equilibrium. For $\gamma \in \left[0,\underline{\gamma}\right]$ and $K \in \left[0,K_1(\gamma)\right]$, we have a C_R^1 type equilibrium. For $\gamma \in \left[\underline{\gamma},\overline{\gamma}\right]$ and $K \in \left[K_2(\gamma),\frac{a}{3}\right]$, we have a type U_R^2 equilibrium. For $\gamma \in \left[\underline{\gamma},\gamma^{**}\right]$, where γ^{**} is such that $K^{C_R^1}(\gamma^{**}) = \frac{a}{3}$, and $K \in \left[K^{C_R^1}(\gamma), Min\left\{K_2(\gamma),\frac{a}{3}\right\}\right]$ we have a C_R^2 type equilibrium. Finally, for $\gamma \in \left[\underline{\gamma},1\right]$ and $K \leq Min\left\{K^{C_R^1}(\gamma),\frac{a}{3}\right\}$ we have a C_R^1 type equilibrium. (See Figure V-11)

Figure V-11: Equilibrium Selection with a Less Efficient Private Firm



Define $\gamma_2(K) \equiv (K_1)^{-1}(K)$ and $\gamma^{C_R^1}(K) \equiv \left(K^{C_R^1}\right)^{-1}(K)$ as the γ at which equilibrium selected changes from U_R^1 to C_R^2, and from C_R^2 to C_R^1, respectively. The proposition below characterizes the optimal regulatory policy for different levels of K when the non-private generator is more efficient than the private one.

<u>Proposition 6:</u> Suppose $\alpha_R > \alpha_P$. Then the optimal regulatory policy is to set

$$\gamma^* = \begin{cases} \dfrac{2(\alpha_P + \alpha_R)}{\alpha_R + 5\alpha_P + 6K} & \text{if } K \in \left(0, \dfrac{\alpha_P + \alpha_R}{6}\right] \\ \left[\dfrac{6K - \alpha_R}{9K - \alpha_R}, \dfrac{9K - \alpha_R - \alpha_P}{9K - \alpha_R}\right] & \text{if } K \in \left[\dfrac{\alpha_P + \alpha_R}{6}, \dfrac{\alpha_R}{3}\right] \\ \dfrac{1}{2} & \text{if } K \in \left[\dfrac{\alpha_R}{3}, \infty\right) \end{cases}$$

Proof: See Appendix.

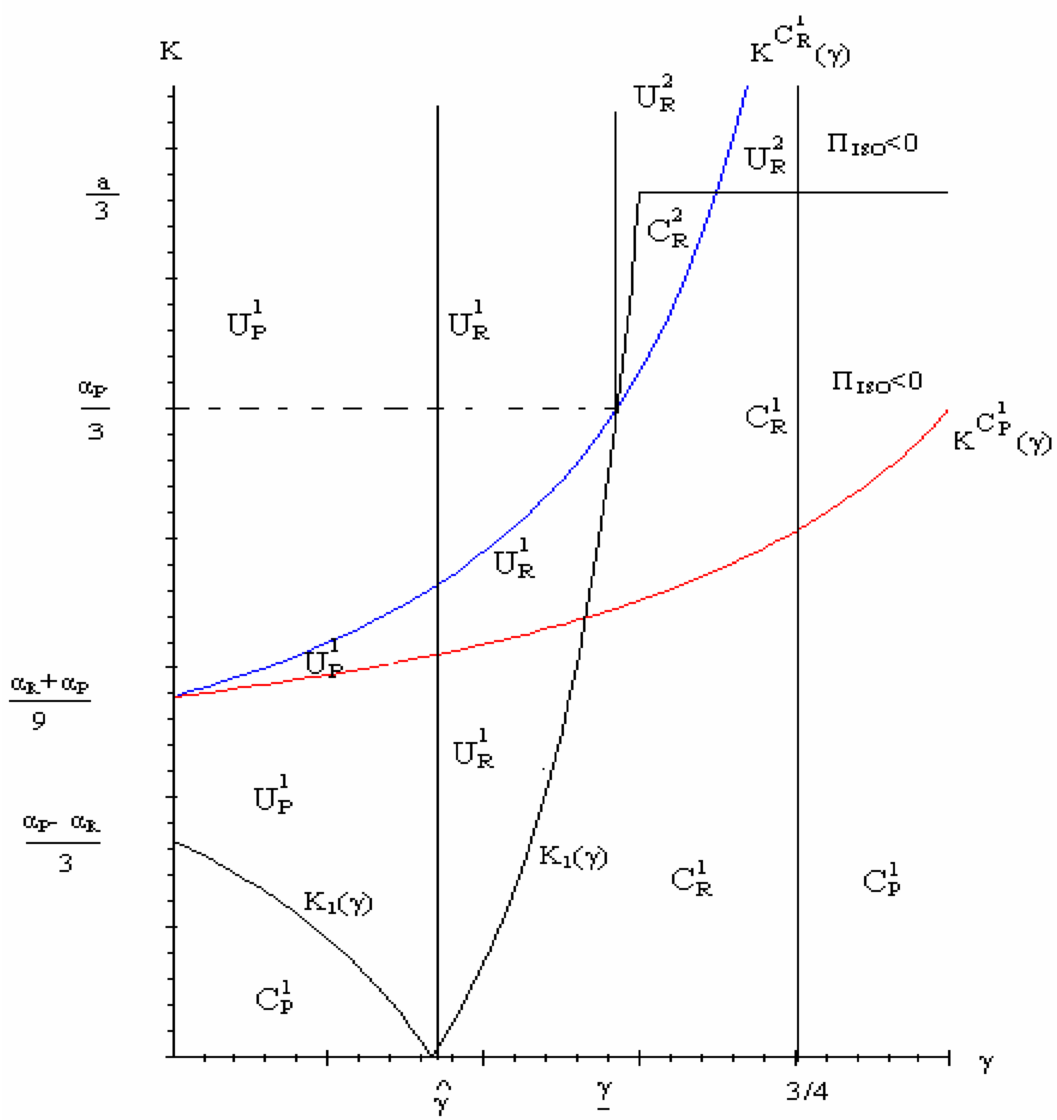
It's easy to see that the optimal γ in this case is never less than half. In other words, when the non-private generator is more efficient, the optimal regulatory policy always gives (equal or) more weight to the consumers' surplus in the non-private generator's objective. When the transmission line capacity is high enough, the optimal instruction is to give equal weights to profits and consumers' surplus. Weight of the consumers' surplus increases (γ rises from half) as the transmission line capacity falls below a threshold. However, optimal γ never reaches 1, that is, optimal policy stops short of instructing pure consumers' surplus maximization. Profits of the non-private firm are always part of optimal regulatory policy.

5.2 Optimal Policy with a Less Efficient Non-private Generator

For the case of $\alpha_R > \alpha_P$, the equilibrium selection process outlined above implies the following choice of equilibria in the (γ, K) space (see Figure V-12): for $\gamma \in [0, \hat{\gamma}]$, U_P^1 type for $K \geq K_1(\gamma)$ and C_P^1 type for $K < K_1(\gamma)$; for $\gamma \in [\hat{\gamma}, \underline{\gamma}]$, U_R^1 type when $K \geq K_1(\gamma)$ and C_R^1 type when $K < K_1(\gamma)$; for $\gamma \in \left[\underline{\gamma}, \frac{3}{4}\right]$, U_R^2 type for $K \geq Min\left\{K_2(\gamma), \frac{a}{3}\right\}$, C_R^2 type for $K \in \left[K^{C_R^1}(\gamma), Min\left\{K_2(\gamma), \frac{a}{3}\right\}\right]$, and C_R^1 for $K \leq Min\left\{K^{C_R^1}(\gamma), \frac{a}{3}\right\}$; for $\gamma \in \left[\frac{3}{4}, 1\right]$, U_R^2 type for $K \geq \frac{a}{3}$, C_R^1 type and C_P^2 type for $K \in \left[K^{C_P^1}(\gamma), \frac{a}{3}\right]$,[68] and C_P^1 type for $K < K^{C_P^1}(\gamma)$.

[68] Note that the profits of the ISO are negative for both the C_R^1 and C_P^2 type equilibria when $\gamma \in \left[\frac{3}{4}, 1\right]$ and $K \in \left[K^{C_P^1}(\gamma), \frac{a}{3}\right]$, thus our equilibrium selection criteria will not apply here. However, as will be seen in Proposition 7, the optimal γ never falls in this region

Figure V-12: Equilibrium Selection with a More Efficient Private Firm



Define

$$\tilde{\gamma} = \begin{cases} \dfrac{5\alpha_R - 4\alpha_P}{7\alpha_R - 5\alpha_P} & \text{if } 5\alpha_R > 4\alpha_P \\ 0 & \text{otherwise} \end{cases}.$$

<u>Proposition 7:</u> Suppose $\alpha_R < \alpha_P$. Then the optimal regulatory policy is to set

$$\gamma^* = \begin{cases} \dfrac{3(\alpha_P - \alpha_R) - 3K}{5\alpha_P - 3\alpha_R - 4K} & \text{if } 5\alpha_R > 4\alpha_P \text{ and } K \in \left(0, \dfrac{6\alpha_R - 5\alpha_P}{3}\right] \\ \dfrac{5\alpha_R - 4\alpha_P}{7\alpha_R - 5\alpha_P} & \text{if } 5\alpha_R > 4\alpha_P \text{ and } K \in \left(\dfrac{6\alpha_R - 5\alpha_P}{3}, \infty\right] \\ \dfrac{3(\alpha_P - \alpha_R) - 3K}{5\alpha_P - 3\alpha_R - 4K} & \text{if } 5\alpha_R < 4\alpha_P \text{ and } K \in \left(0, \dfrac{\alpha_P - \alpha_R}{3}\right] \\ 0 & \text{if } 5\alpha_R < 4\alpha_P \text{ and } K \in \left(\dfrac{\alpha_P - \alpha_R}{3}, \infty\right] \end{cases}$$

Proof: See Appendix.

If, on the other hand, the private generator is more efficient, then there is a tradeoff between allocative efficiency and productive efficiency when the less efficient non-private generator gets to increase its output with higher γ. After a point, it does not pay, in terms of total surplus, to have the less efficient non-private generator displace production by the more efficient private generator, and the optimal objective policy stops short of maximizing consumers' surplus (note that $\tilde{\gamma}$ is always less than $\frac{1}{2}$.)

It's easily checked that $\frac{1}{2}$ is the highest possible optimal choice of γ in this case, therefore optimal regulatory policy always puts more weight on profits than on consumers' surplus when the private generator is more efficient. In fact, if both the transmission line capacity and the efficiency gap between the two generators (private generator being more efficient) are high enough, then the optimal regulatory policy is to instruct the non-private firm to maximize profits only.

6. Discussion and Conclusions

In this chapter we examined the optimal choice of regulatory policy, in terms of the objective function of a public or a regulated generator, in a mixed wholesale electricity market where a private and a public generator engage in Cournot competition. In a marked difference from the previous chapter, where the transmission grid is assumed to be a freely congestible public good subject only to safe line flow limit, in this chapter we used a competitive nodal transmission congestion rights (TCR) market as the congestion management and pricing tool where each generator has to pay an explicit congestion charge in the amount of its contribution to congestion on the constrained facility.

Introduction of such transmission rights brings complications, as well as benefits, to the model. The main complication we need to deal with is the multiplicity of equilibrium. For a given level of transmission capacity and a given regulatory policy, sometimes there is an equilibrium where the line is congested, as well as an equilibrium where there is no congestion on the grid. In other instances, for the same model parameters, there is an equilibrium where the line is congested in one direction, as well as an equilibrium where the line is congested in the other direction. This complication is primarily due to the flexibility that the transmission rights prices bring into the model, despite the fact that these prices cannot be set arbitrarily but they have to be such that marginal transmission price a generator faces equals to the marginal foregone profits in the electricity market. Even with this rationality restriction on them, different sets of transmission rights prices can be used to support multiple equilibrium outcomes in the electricity market and the corresponding congestion patterns.

To make any kind of a welfare analysis and choose optimal regulatory policy, the multiplicity of equilibrium issue has to be resolved. We use the profits of the ISO as the criterion for equilibrium refinement. The profits of the ISO are simply the difference between what it collects and pays out in the operation of the transmission congestion rights market. We assume that the ISO operates under a breakeven constraint, that is, its payouts in the TCR market cannot exceed its revenues. If there are still multiple equilibria after imposing the breakeven condition, we used a second refinement that the ISO set prices such that it operates with zero profits. The second refinement amounts to selecting an unconstrained equilibrium when there is also a constrained equilibrium (with different production levels and TCR prices) where the ISO makes positive profits. After imposing these two criteria on the ISO’s profits, there is a unique equilibrium for each given set of parameters.

The optimal regulatory policy, weight of the consumers’ surplus in the non-private generator’s objective function, depends on the capacity of the transmission line, as well as the relative cost efficiencies of the two generators. If the non-private generator is more efficient, optimal regulatory policy never puts more weight on profits than on consumers’ surplus. When transmission line capacity is sufficiently large, profits and consumers’ surplus are equally weighted. As the line capacity falls below a threshold, optimal policy puts more weight on consumers’ surplus. However, regardless of model parameters, including the line capacity, the optimal instruction is never to maximize only consumers’ surplus. Therefore, when the non-private generator is more efficient, optimal regulatory policy is a strictly convex combination of profits and consumers' surplus; pure profit maximization or pure consumers' surplus maximization is never the optimal instruction for the non-private generator.

If, on the other hand, the private generator is more efficient, then pure profit maximization is part of the optimal policy, though only under limiting conditions. When the cost efficiency gap is sufficiently large in favor of the private firm and the transmission line capacity is above a threshold, it is indeed optimal to instruct the non-private firm to maximize only profits. Aside from this limiting case, optimal regulatory policy again is always a strictly convex combination of profits and consumers' surplus. Under no circumstance is pure consumers' surplus maximization the optimal instruction. In fact, when the private generator is more efficient, profits always have a larger weight than consumers' surplus in the optimal regulatory policy. Intuitively, this is because after a point marginal welfare losses from replacing low cost private generation with high cost non-private generation starts to outweigh marginal gains from increasing consumers' surplus.

One might wonder, in the case of a more efficient non-private generator, why the optimal policy is not simply to set the weight of consumers' surplus in the non-private generator's objective function that will induce an equilibrium where the price of electricity is equal to the non-private generator's (constant) marginal cost and the non-private generator supplies the whole market. The reason is that such a high level of production by the non-private generator is not feasible due to the transmission line capacity constraint without some production from the private generator. Private generator's output is required to create counter-flow on the congested transmission line;

otherwise the flow on the line exceeds safe flow limits, which cannot be tolerated by the ISO that is in charge of reliable operations of the grid. In other words, there are no market prices to support that seemingly optimal configuration simply because the physical configuration of the grid cannot support the resulting line flows. In a nutshell, this constraint is the contribution of transmission congestion to the model, and the contribution of our results to the literature on mixed oligopolies.

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Appendix to Chapter V

1. Omitted Proofs in Chapter V

1.1 Proof of Proposition 2

C_R^1 type equilibrium is characterized by the simultaneous solution to the following equations:

$$\begin{gathered}\gamma(q_R + q_P) + (1-\gamma)(\alpha_R - 2q_R - q_P) - \lambda_3 = 0 \\ \alpha_P - 2q_P - q_R - \lambda_3 + \lambda_2 = 0 \\ q_R - q_P = 3K \\ \lambda_2 - 2\lambda_3 = 0\end{gathered}$$

which results in the equilibrium quantities for the variables as stated. Note that we have $q_P^{C_R^1}(\gamma) > 0$ and $q_R^{C_R^1}(\gamma) > q_P^{C_R^1}(\gamma)$ if and only if $K \le K^{C_R^1}(\gamma) \equiv \dfrac{\alpha_P + (1-\gamma)\alpha_R}{9(1-\gamma)}$, as stated in the proposition.

1.2 Proof of Proposition 3

C_P^1 type equilibrium is characterized by the simultaneous solution to the equations

$$\begin{gathered}\gamma(q_R + q_P) + (1-\gamma)(\alpha_R - 2q_R - q_P) - \lambda_3 = 0 \\ \alpha_P - 2q_P - q_R - \lambda_3 + \lambda_2 = 0 \\ q_P - q_R = 3K \\ \lambda_2 - 2\lambda_3 = 0\end{gathered}$$

which results in the equilibrium quantities for the variables as stated in the proposition. Note that we have $q_P^{C_P^1}(\gamma) > q_R^{C_P^1}(\gamma)$ and $q_R^{C_P^1}(\gamma) > 0$ if and only if $K \le K^{C_P^1}(\gamma) \equiv \frac{\alpha_P + (1-\gamma)\alpha_R}{3(3-2\gamma)}$ as stated in the proposition.

1.3 Proof of Proposition 4

C_R^2 type equilibrium is characterized by the simultaneous solution to the equations

$$\begin{gathered}\gamma(q_R + q_P) + (1-\gamma)(\alpha_R - 2q_R - q_P) - \lambda_3 = 0 \\ \alpha_P - 2q_P - q_R - \lambda_3 + \lambda_2 \le 0 \\ q_R = 3K \\ \lambda_2 - 2\lambda_3 = 0\end{gathered}$$

which results in the equilibrium quantities for the variables as stated in the proposition. Note that the inequality $\alpha_P - 2q_P - q_R - \lambda_3 + \lambda_2 \le 0$ is satisfied if and only if $K \ge K^{C_R^1}(\gamma)$, as stated in the proposition.

1.4 Proof of Proposition 5

C_P^2 type equilibrium is characterized by the simultaneous solution to the equations

$$\begin{gathered}\gamma(q_R + q_P) + (1-\gamma)(\alpha_R - 2q_R - q_P) - \lambda_3 \le 0 \\ \alpha_P - 2q_P - q_R - \lambda_3 + \lambda_2 \le 0 \\ q_P = 3K \\ \lambda_2 - 2\lambda_3 = 0\end{gathered}$$

which results in the equilibrium quantities for the variables as stated in the proposition. Note that the inequality $\gamma(q_R + q_P) + (1-\gamma)(\alpha_R - 2q_R - q_P) - \lambda_3 \le 0$ is satisfied if and only if $K \ge K^{C_P^1}(\gamma)$, as stated in the proposition.

1.5 Proof of Proposition 6

Let $\alpha_R > \alpha_P$. We first show that in this case $\gamma = \frac{1}{2}$ will be the optimal choice if the total surplus maximization is to be attained at an unconstrained equilibrium.

Note that for each γ we have a unique unconstrained equilibrium with the corresponding values for q_R and q_P. We perform the welfare optimization in the (q_N, q_P) space. As γ increases, the equilibrium moves along the reaction function of the private generator up to $\underline{\gamma}$ (i.e. the point where the private generator ceases production). Beyond $\underline{\gamma}$, the equilibrium moves along $q_P = 0$ until $q_R = a$ (see Figure V-2.) Using (5.44) and substituting the private generator's reaction function, the total surplus can be expressed as

$$W(q_R) = \begin{cases} \alpha_R(q_R + \frac{\alpha_P - q_R}{2}) - \frac{(q_R + \frac{\alpha_P - q_R}{2})^2}{2} - (\alpha_R - \alpha_P)(\frac{\alpha_P - q_R}{2}) & \text{if } q_R \in [0, \alpha_P) \\ \alpha_R q_R - \frac{(q_R)^2}{2} & \text{if } q_R \in [\alpha_P, a) \end{cases}$$

Differentiating with respect to q_R we get

$$\frac{\partial W(q_R)}{\partial q_R} = \begin{cases} \alpha_R - \frac{1}{4}q_R - \frac{3}{4}q_P & \text{if } q_R \in [0, \alpha_P) \\ \alpha_R - q_R & \text{if } q_R \in [\alpha_P, a) \end{cases}$$

Noting that the second order condition is satisfied, observe that $\frac{\partial W(q_R)}{\partial q_R}$ evaluated at α_P is positive. Hence total surplus is maximized by setting either $q_R = \alpha_P$ or $q_R = \alpha_R$. Observe that total surplus with $q_R = \alpha_R$ exceeds that with $q_R = \alpha_P$. Therefore, it is optimal to choose γ that will induce $q_R = \alpha_R$, i.e. to set $\gamma = \frac{1}{2}$. Note that the unconstrained equilibrium induced by $\gamma = \frac{1}{2}$ is not attainable if $K < \frac{\alpha_R}{3}$.

We now determine the optimal choice if the optimum surplus is to be attained at a constrained equilibrium. For a given K, if the equilibrium is to be a constrained one, then we have $q_R - q_P = 3K$.[69] Then the maximum total surplus is achieved at q_R^* and q_P^* such that the isowelfare curve with q_R^* and q_P^* is tangent to the constraint line $q_R - q_P = 3K$. This is so because welfare decreases if the equilibrium moves along $q_R - q_P = 3K$ past this point of tangency (given that $\alpha_R > \alpha_P$ in this case). The slope of the isowelfare curve is

$$\frac{dq_R}{dq_P} = \frac{Q - \alpha_P}{\alpha_R - Q}.$$

Setting this equal to 1 (slope of the constraint line) we get $Q = \frac{\alpha_R + \alpha_P}{2}$, which gives us the locus of total surplus maximizing constrained equilibria for different levels of K. For C_R^1 type equilibrium the value of γ that induces the total surplus maximizing allocation is given by the simultaneous solution to $q_R^{C_R^1}(\gamma)$, $q_P^{C_R^1}(\gamma)$ and $Q = \frac{\alpha_R + \alpha_P}{2}$, resulting in

$$\gamma^* = \frac{2(\alpha_R + \alpha_P)}{\alpha_R + 5\alpha_P + 6K}.$$

[69] Note that with $\alpha_R > \alpha_P$, $q_R - q_P = 3K$ is the only relevant constraint line.

Thus, it is optimal to set γ equal to this value, provided that the equilibrium is of C_R^1 type. That is the case if $K < \frac{\alpha_R + \alpha_P}{6}$. For $K > \frac{\alpha_R + \alpha_P}{6}$, there exists a C_R^2 type equilibrium for an appropriate choice of γ. With $\alpha_R > \alpha_P$ it is optimal to have only the non-private generator produce in this region where K is sufficiently high. Observe from Figure V-9 that for all $\gamma \in \left[\frac{6K-\alpha_R}{9K-\alpha_R}, \frac{9K-\alpha_R-\alpha_P}{9K-\alpha_R}\right]$ we have C_R^2 type equilibria, all of which involve the same output levels and hence the same total surplus.[70] Observe also that total surplus decreases if $Q^* = q_R^*$ increases beyond α_R. Therefore, for $K \in \left(\frac{\alpha_P + \alpha_R}{6}, \frac{\alpha_R}{3}\right)$ the optimal policy is to set $\gamma \in \left[\frac{6K-\alpha_R}{9K-\alpha_R}, \frac{9K-\alpha_R-\alpha_P}{9K-\alpha_R}\right]$. For $K \geq \frac{\alpha_R}{3}$, since the unconstrained equilibrium outcome with $\gamma^* = \frac{1}{2}$ is attainable, it is optimal to set γ equal to $\frac{1}{2}$.

1.6 Proof of Proposition 7

Following the same argument as in the proof of Proposition 6, for a sufficiently large K we observe that total surplus is maximized by setting either $q_R = 4\alpha_R - 3\alpha_P$ or $q_R = \alpha_R$. Observe that $4\alpha_R - 3\alpha_P < \alpha_P$ and $\alpha_R < \alpha_P$, implying that the total surplus with $q_R = 4\alpha_R - 3\alpha_P$ exceeds that with $q_R = \alpha_R$. Hence it is optimal to choose the γ that

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[70] Note that $\frac{6K-\alpha_R}{9K-\alpha_R} = \left(K_2\right)^{-1}(K)$ and $\frac{9K-\alpha_R-\alpha_P}{9K-\alpha_R} = \left(K^{C_R^1}\right)^{-1}(K)$.

induces $q_R = 4\alpha_R - 3\alpha_P$ and the corresponding $q_P = 2(\alpha_P - \alpha_R)$. Simple calculations show that these output levels are induced by setting γ equal to $\frac{5\alpha_R - 4\alpha_P}{7\alpha_R - 5\alpha_P}$. Note that with $\alpha_R < \alpha_P$, $\frac{5\alpha_R - 4\alpha_P}{7\alpha_R - 5\alpha_P}$ can be positive or negative. If $5\alpha_R > 4\alpha_P$, then $\frac{5\alpha_R - 4\alpha_P}{7\alpha_R - 5\alpha_P} > 0$ and checking the relevant second order condition reveals that it is indeed the global maximum. If $5\alpha_R < 4\alpha_P$ and $7\alpha_R > 5\alpha_P$, then $\frac{5\alpha_R - 4\alpha_P}{7\alpha_R - 5\alpha_P} < 0$ and the total surplus is maximized at $\gamma = 0$. For the case $7\alpha_R < 5\alpha_P$, we have $\frac{5\alpha_R - 4\alpha_P}{7\alpha_R - 5\alpha_P} > 0$, but in this case $\frac{5\alpha_R - 4\alpha_P}{7\alpha_R - 5\alpha_P}$ is a global minimum and the total surplus is again maximized at $\gamma = 0$. Therefore, the total surplus is maximized at $\frac{5\alpha_R - 4\alpha_P}{7\alpha_R - 5\alpha_P}$ if $5\alpha_R > 4\alpha_P$, otherwise it is maximized at $\gamma = 0$. Note that the unconstrained equilibrium is attainable only if $K \geq \frac{\alpha_P}{3}$.

We now determine the optimal choice of q_R and q_P if the optimum surplus is to be attained at a constrained equilibrium. This is the case for $K < \frac{\alpha_P}{3}$. We first analyze the case where $5\alpha_R > 4\alpha_P$, i.e. $\frac{5\alpha_R - 4\alpha_P}{7\alpha_R - 5\alpha_P}$ is the total surplus maximizing value of γ in the unconstrained equilibrium. Observe that with $K = \frac{6\alpha_R - 5\alpha_P}{3}$ the equilibrium induced by $\gamma = \frac{5\alpha_R - 4\alpha_P}{7\alpha_R - 5\alpha_P}$ is just binding. Hence for $K \in \left[\frac{6\alpha_R - 5\alpha_P}{3}, \frac{\alpha_P}{3}\right]$ the equilibrium moves along the response function of the private generator for $\gamma \in \left[0, \frac{3(\alpha_R - \alpha_P) - 3K}{3\alpha_R - 5\alpha_P - 4K}\right]$ and along the constraint line $q_R - q_P = 3K$ for $\gamma \in \left[\frac{3(\alpha_R - \alpha_P) - 3K}{3\alpha_R - 5\alpha_P - 4K}, 1\right]$. As in the unconstrained case above, total surplus is maximized at $\gamma = \frac{5\alpha_R - 4\alpha_P}{7\alpha_R - 5\alpha_P}$. For $K \in \left(0, \frac{6\alpha_R - 5\alpha_P}{3}\right]$ the equilibrium moves along $q_P - q_R = 3K$ for $\gamma \in \left[0, \frac{3(\alpha_P - \alpha_R) - 3K}{5\alpha_P - 3\alpha_R - 4K}\right]$, it moves along the response function of the private generator for $\gamma \in \left[\frac{3(\alpha_P - \alpha_R) - 3K}{5\alpha_P - 3\alpha_R - 4K}, \frac{3(\alpha_R - \alpha_P) - 3K}{3\alpha_R - 5\alpha_P - 4K}\right]$, and it moves along $q_R - q_P = 3K$ for $\gamma \in \left[\frac{3(\alpha_R - \alpha_P) - 3K}{3\alpha_R - 5\alpha_P - 4K}, 1\right]$. Since the private generator is more efficient, the optimal outcome will involve the private generator producing more, implying that the optimal outcome will move along $q_P - q_R = 3K$. The total surplus maximizing output level for the private generator in this case is

$$q_P^* = \frac{\alpha_R + \alpha_P + 6K}{4}$$

and the value of γ that induces this output level for the private generator is

$$\frac{2(\alpha_R + \alpha_P)}{\alpha_R + 5\alpha_P - 6K}.$$

Since this is greater than $\frac{3(\alpha_P - \alpha_R) - 3K}{5\alpha_P - 3\alpha_R - 4K}$, it is optimal to increase γ in the interval $\left[0, \frac{3(\alpha_R - \alpha_P) - 3K}{3\alpha_R - 5\alpha_P - 4K}\right]$ until the point where the equilibrium becomes unconstrained, i.e., at $\gamma = \frac{3(\alpha_R - \alpha_P) - 3K}{3\alpha_R - 5\alpha_P - 4K}$. This is so because increasing γ further results in an unconstrained equilibrium with the less efficient non-private generator starting to displace production by the more efficient private generator.

If $5\alpha_R < 4\alpha_P$, which is the case where $\gamma = 0$ is the total surplus maximizing choice in the unconstrained equilibrium, then with $K = \frac{\alpha_P - \alpha_R}{3}$ the equilibrium induced by $\gamma = 0$ is just binding. The rest of the analysis is identical to the one in the previous case, except for the relevant intervals of K. For $K \in \left[\frac{\alpha_P - \alpha_R}{3}, \frac{\alpha_P}{3}\right]$ it is optimal to set γ equal to 0, whereas for $K \in \left[0, \frac{\alpha_P - \alpha_R}{3}\right]$ it is optimal to set γ equal to $\frac{3(\alpha_R - \alpha_P) - 3K}{3\alpha_R - 5\alpha_P - 4K}$, following similar arguments as above.

2. Profits of the ISO and the Non-private Firm

2.1 Profits of the ISO in Constrained Equilibria

2.1.1 C^1 type equilibria

When the equilibrium is of C_R^1 type, we have $q_R^{C_R^1}(\gamma) > q_P^{C_R^1}(\gamma)$, and thus $\Pi_{ISO} \geq 0$ if and only if $\lambda_3 \geq 0$. From Equation (5.26), this will be the case if and only if

$$K \leq K_1(\gamma) \equiv \frac{1}{3}\left[\alpha_R - \alpha_P + \frac{\gamma(\alpha_R + \alpha_P)}{3 - 4\gamma}\right].$$

Observe from Equations (5.14) and (5.15) that $K_1(\gamma)$ is the portion of $K(\gamma)$ for $\gamma \in \left[0, \underline{\gamma}\right]$. $K_1(\gamma)$ is thus the curve separating unconstrained equilibria from the constrained equilibria in this region. Note also that the sign of $K_1(\gamma)$ depends on the relative magnitudes of the grades of efficiency, α_P and α_N.

Figure V-9 shows the relationship between $K_1(\gamma)$ and $K^{C_R^1}(\gamma)$ when $\alpha_R > \alpha_P$. For $\gamma \in \left[0, \frac{3}{4}\right]$, $\Pi_{ISO} \geq 0$ if and only if $K \leq K_1(\gamma)$, and for $\gamma \in \left(\frac{3}{4}, 1\right]$ we have $\Pi_{ISO} \geq 0$ if and only if $K \geq K_1(\gamma)$. Thus, $\Pi_{ISO} < 0$ for C_R^1 type equilibrium in the region where $\gamma \in \left[0, \underline{\gamma}\right]$ and $K \in \left(K_1(\gamma), K^{C_R^1}(\gamma)\right]$, and $\Pi_{ISO} \leq 0$ elsewhere in the (γ, K) space.

Figure V-10 depicts $K_1(\gamma)$ and $K^{C_R^1}(\gamma)$ when $\alpha_R < \alpha_P$. In this case, for $\gamma \in [0, \hat{\gamma})$ we have $\Pi_{ISO} < 0$ for C_R^1 type equilibrium. In the region where $\gamma \in [\hat{\gamma}, \underline{\gamma}]$ and

$K \in \left(K_1(\gamma), K^{C_R^1}(\gamma)\right]$, we again have $\Pi_{ISO} < 0$ for C_R^1 type equilibrium. $\Pi_{ISO} \geq 0$ in the region where $\gamma \in \left[\hat{\gamma}, \frac{3}{4}\right]$ and $K \leq Min\left\{K_1(\gamma), K^{C_R^1}(\gamma)\right\}$. Finally, $\Pi_{ISO} < 0$ for $\gamma \in \left(\frac{3}{4}, 1\right]$.

When the equilibrium is of C_P^1 type, we have $q_P^{C_P^1}(\gamma) > q_R^{C_P^1}(\gamma)$, and thus $\Pi_{ISO} \geq 0$ if and only if $\lambda_3 \leq 0$. From Equation (5.31), this is the case if and only if

$$K \leq -K_1(\gamma)$$

Figure V-9 shows the relationship between $K_1(\gamma)$ and $K^{C_P^1}(\gamma)$ when $\alpha_R > \alpha_P$. For $\gamma \in \left[0, \frac{3}{4}\right]$, $\Pi_{ISO} \geq 0$ if and only if $K \geq K_1(\gamma)$; and for $\gamma \in \left(\frac{3}{4}, 1\right]$ we have $\Pi_{ISO} \geq 0$ if and only if $K \leq K_1(\gamma)$. Let γ^* be such that $K_1(\gamma^*) = K^{C_P^1}(\gamma^*)$. We observe that $\gamma^* < \underline{\gamma}$ and $\Pi_{ISO} \geq 0$ only in the region where $\gamma \in \left[0, \gamma^*\right]$ and $K \in \left(K_1(\gamma), K^{C_P^1}(\gamma)\right]$.

Figure V-10 depicts $K_1(\gamma)$ and $K^{C_P^1}(\gamma)$ when $\alpha_R < \alpha_P$. In this case we have $\Pi_{ISO} < 0$ for C_P^1 type equilibrium only in the region where $\gamma \in \left[\hat{\gamma}, \frac{3}{4}\right)$ and $K \leq Min\left\{K_1(\gamma), K^{C_P^1}(\gamma)\right\}$. Everywhere else in the (γ, K) space we have $\Pi_{ISO} \geq 0$ in a C_P^1 type equilibrium.

2.1.2 C^2 type equilibria

When the equilibrium is of C_R^2 type, we have $q_P^{C_R^2}(\gamma) = 0$ and $\Pi_{ISO} \geq 0$ if and only if $\lambda_3 \geq 0$. From Equation (5.36), this will be the case if and only if

$$K \leq K_2(\gamma) \equiv \frac{(1-\gamma)\alpha_R}{3(2-3\gamma)}.$$

Note that in the region where $K > Max\left\{K_2(\gamma), K^{C_R^1}(\gamma)\right\}$ we have $\Pi_{ISO} < 0$.

When the equilibrium is of C_P^2 type, we have $q_R^{C_P^2}(\gamma) = 0$ and $\Pi_{ISO} \geq 0$ if and only if $\lambda_3 \leq 0$. From Equation (5.41), this will be the case if and only if

$$K \leq \frac{\alpha_P}{6}.$$

Since $K^{C_P^1}(\gamma) > \frac{\alpha_P}{6}$, we have $\Pi_{ISO} < 0$ in C_P^2 type equilibrium, whenever it exists.

2.2 Profits of the Non-private Firm

Profits of the non-private generator are also of concern if it faces a break-even constraint. In this section we analyze the profits of the non-private generator under different types of equilibrium. The profits of the non-private generator is given by

$$\Pi_R = (\alpha_R - \lambda_3 - Q)q_R$$

2.2.1 Profits of the Non-private Firm in Unconstrained Equilibria

Note that $\Pi_R \geq 0$ if and only if the *marginal profit* $M\Pi_R \equiv (\alpha_R - \lambda_3 - Q) \geq 0$. Recall that in an unconstrained equilibrium all TCR prices are zero. In U_R^1 type equilibrium the marginal profit is given by

$$M\Pi_R^{U_R^1} = \frac{(2-3\gamma)\alpha_R - (1-\gamma)\alpha_P}{3-4\gamma}. \qquad (5.45)$$

Recall that U_R^1 type equilibrium exists for $\gamma \in [0, \bar{\gamma}]$, and from Equation (5.12) it can be easily checked that $\underline{\gamma} < \frac{3}{4}$, implying that the denominator in Equation (5.45) is always positive. Hence the sign of $M\Pi_R$ is identical to the sign of the numerator in Equation (5.45), which is also positive for $\gamma \in \left[0, \underline{\gamma}\right]$. Since this is the relevant range for U_R^1 type equilibrium, $M\Pi_R$ and thus the profits of the non-private generator are always nonnegative in U_R^1 type equilibrium.

U_R^2 type equilibrium exists only for $\gamma \geq \underline{\gamma}$. In the region $\gamma \in \left[\underline{\gamma}, \overline{\gamma}\right]$, the marginal profit for the non-private generator is

$$M\Pi_R^{U_R^2} = \frac{(1-2\gamma)\alpha_R}{2-3\gamma} \tag{5.46}$$

Recall from Section 3.1 that $\overline{\gamma} < \dfrac{2}{3}$ so the denominator of $M\Pi_R^{U_R^2}$, and hence the profit of the non-private generator, is nonnegative for $\gamma \in \left[\underline{\gamma}, \dfrac{1}{2}\right]$ and negative for $\gamma \in \left[\dfrac{1}{2}, \overline{\gamma}\right]$. For the case $\alpha_R < \alpha_P$, we have $\underline{\gamma} > \dfrac{1}{2}$, the numerator of $M\Pi_R^{U_R^2}$, and hence the profits of the non-private generator are negative for $\gamma \in \left[\underline{\gamma}, \overline{\gamma}\right]$, i.e., the whole region where U_R^2 type equilibrium exists in this case.

Note also that in U_R^2 type equilibrium, in the region where $\gamma \in \left[\overline{\gamma}, 1\right]$, the non-private generator produces a, which results in zero price for the electricity sold. Hence the profits of the non-private generator are strictly negative in this region (except when $\alpha_R = 0$).

2.2.2 Profits of the Non-private Firm in Constrained Equilibria

C^1 Type Equilibria: Using Equations (5.24), (5.25) and (5.26), we express the marginal profit for the non-private generator at C_R^1 type equilibria as follows:

$$M\Pi_R^{C_R^1} = \frac{\alpha_R + (1-5\gamma)\alpha_P + 3K(3-5\gamma)}{6-5\gamma} \qquad (5.47)$$

In the region where $\gamma \in \left[0, \frac{3}{5}\right]$, $M\Pi_R^{C_R^1}$ is positive if

$$K > K^{\Pi_R^1}(\gamma) \equiv \frac{\alpha_R + (1-5\gamma)\alpha_P}{3(5\gamma-3)}.$$

In the region where $\gamma \in \left(\frac{3}{5}, 1\right]$, $M\Pi_R^{C_R^1}$ is positive if $K < K^{\Pi_R^1}(\gamma)$. Figure V-11 shows that in the region where $\gamma \in \left[0, \frac{\alpha_R + \alpha_P}{5\alpha_P}\right]$ we have $K > K^{\Pi_R^1}(\gamma)$ for all K, and hence the profits of the non-private generator are positive wherever C_R^1 type equilibrium exists in this region.[71] In the region where $\gamma \in \left(\frac{\alpha_R + \alpha_P}{5\alpha_P}, \frac{3}{5}\right]$, the profits are positive for $K \geq K^{\Pi_R^1}(\gamma)$ and negative for $K < K^{\Pi_R^1}(\gamma)$. For $\gamma \in \left(\frac{3}{5}, 1\right]$, the profits are negative for all K.

For the case of C_P^1 type equilibrium, using Equations (5.29), (5.30) and (5.31), we express the marginal profit for the non-private generator in C_P^1 type equilibrium as

[71] Observe that $\frac{\alpha_R + \alpha_P}{5\alpha_P} < \frac{3}{5}$.

$$M\Pi_R^{C_P^1} = \frac{\alpha_R + (1-5\gamma)\alpha_P - 3K(3-5\gamma)}{6-5\gamma}. \qquad (5.48)$$

In the region where $\gamma \in \left[0, \frac{3}{5}\right]$, $M\Pi_R^{C_P^1}$ is positive if

$$K < K^{\Pi_R^1}(\gamma) \equiv \frac{\alpha_R + (1-5\gamma)\alpha_P}{3(5\gamma-3)}.$$

In the region where $\gamma \in \left(\frac{3}{5}, 1\right]$, $M\Pi_R^{C_P^1}$ is positive if $K > K^{\Pi_R^1}(\gamma)$. Figure V-11 shows that in the region where $\gamma \in \left[0, \frac{\alpha_R + \alpha_P}{5\alpha_P}\right]$, we have $K > K^{\Pi_R^1}(\gamma)$ for all K, and hence the profits of the non-private generator are negative wherever C_P^1 type equilibrium exists. In the region where $\gamma \in \left(\frac{\alpha_R + \alpha_P}{5\alpha_P}, \frac{3}{5}\right]$, the profits are negative for $K \geq K^{\Pi_R^1}(\gamma)$ and positive for $K < K^{\Pi_R^1}(\gamma)$. For $\gamma \in \left(\frac{3}{5}, 1\right]$, the profits are positive for all K.

C^2 Type Equilibria: Using Equations (5.34), (5.35) and (5.36), we write the marginal profit for the non-private generator in C_R^2 type equilibrium as

$$M\Pi_R^{C_R^2} = \gamma\alpha_R - 3K(3\gamma - 1). \qquad (5.49)$$

In the region where $\gamma \in \left[0, \frac{1}{3}\right]$, $M\Pi_R^{C_R^2}$ is positive if

$$K > K^{\Pi_R^2}(\gamma) \equiv \frac{\gamma\alpha_R}{3(3\gamma-1)}.$$

In the region where $\gamma \in \left[\frac{1}{3},1\right]$, $M\Pi_R^{C_R^2}$ is positive if $K < K^{\Pi_R^2}(\gamma)$. Figure V-12 shows that in the region where $\gamma \in \left[0,\frac{1}{3}\right]$ we have $K > K^{\Pi_R^2}(\gamma)$ for all K, and hence the profits of the non-private generator are positive wherever C_R^2 type equilibrium exists. In the region where $\gamma \in \left[\frac{1}{3},1\right]$, the profits are positive for $K \leq K^{\Pi_R^2}(\gamma)$ and negative for $K > K^{\Pi_R^2}(\gamma)$.