Entry and Externality: Hydroelectric Generators in Brazil

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Abstract

This work analyzes the entry problem in the hydroelectric generation industry. The operation of a generator upstream regularizes the river flow for generators located downstream on the same river, increasing the production capacity of the latter. This positive externality increases the attractiveness of the locations downstream whenever a generator decides to enter upstream. Therefore, the entry decision of a generator in a given location may affect all entry decisions in potential locations for plants downstream. I first model the problem of generators located in cascade on the same river to show the positive effect of the externality. Next, I develop a method to estimate an entry model specific to the hydro generation industry which takes into account the externality of the entry decisions. The specificity of the method derives from technological characteristics of hydro generation, and significantly simplify the estimation when compared to more standard entry models. Finally, I use a data set on investment decisions of Brazilian hydro-generators to estimate the model. The results show a positive incentive to locate downstream from existing plants and from locations where entry is likely to occur. Location characteristics also play an important role on the entrants' decisions. An interesting by-product of the analysis is that the year effects' estimates show an increase one year before the energy crisis of 2001, providing evidence that the market anticipated the crisis. It contradicts the governmental version that the crisis was due to an unexpected drought.

Keywords: Entry; electricity industry; externality; spatial logit.
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1 Introduction

This work analyzes the entry problem in the hydroelectric generation industry. The operation of a generator upstream regularizes the river flow for generators located downstream on the same river, increasing the production capacity of the latter.[1] This positive externality increases the attractiveness of the locations downstream whenever a generator decides to enter upstream. Therefore, the entry decision of a generator in a given location may affect all entry decisions in locations downstream. I first model the problem of generators located in cascade on the same river to show the positive effect of the externality. Next, I develop a method to estimate an entry model specific to the hydro generation industry which takes into account the externality of the entry decisions. The specificity of the method derives from technological characteristics of hydro generation, and significantly simplify the estimation when compared to more standard entry models. Finally, I use a data set on investment decisions of Brazilian hydro-generators to estimate the model.

The empirical results show that firms have a positive incentive to locate downstream and that location characteristics matter on the decision to enter. The externality has a positive effect on entry decisions and is an increasing function of the regularization of the river flow done by the upstream plants, and a decreasing function of the distance between them. In rivers with several available locations there is also an incentive to locate downstream, since entrants take into account the probability that entry occur in the locations upriver. The physical and geographical characteristics of each location also play a strong role in the entrant's decision. The model identifies a pattern on the entry dynamics of new hydro-generators: once someone enters in a given location, entry becomes more likely to happen on the downstream locations of that same river.

The year effects estimates of the entry model capture the variation in market conditions for the different years covered by the sample, and can be understood as an average for the non-observable prices of the bilateral contracts, that governs most of the electricity trade.

[1]In this context, regularization means a reduction in the variance of the river flow.

Interestingly, these estimates show an improvement in market conditions one year before the crisis of 2001, when spot prices reached unprecedent high levels (see Figure 3). It indicates that the market anticipated the net excess demand that would take place in the months to come. This conclusion has three strong implications. First, it contradicts the government's claim that the crisis was due to an unexpected drought. If the crisis was truly unexpected, no anticipation would exist. Second, despite high sunk costs and uncertainty about future market conditions, investments in hydro-generation did respond to an expected excess demand, which absolves the market design of any blame for ineffectiveness. In fact, the crisis happened due to the length of time required for new plants to begin operating. Last, despite the fact that the market anticipated the crisis, the centralized dispatch algorithm failed in preventing it. Few months before the crisis the ISO was still dispatching the hydro plants instead of turning on the thermo generators.

I take advantage of information on the entry order to analyze one commonly used assumption in the empirical literature on entry: that entry occurs at the same time. Since my data set has information on the entry order I estimate the model with both the entry order and without it. The results show that not taking the entry order into account, and estimating a one shot entry game where everyone enter at the same time, overestimates the externality effect and the interactions of the agents.

1.1 Background

The Brazilian electricity industry has undergone major reforms during the 90's. A broad privatization and deregulation process changed the industry from a state-owned vertically integrated monopoly to a private industry separated in the three different segments of generation, transmission and distribution. The main purposes of the reforms were to increase efficiency and to attract private capital to the sector.

Among the major changes was the creation of a market for long term contracts of electricity supply, as a way to introduce competition in the generation segment. Generators would be free to negotiate contracts with consumers, which would create competition for better deals. The market would provide incentive for efficient behavior on the firm's side and would have a price that would work as a signal for new investments in electricity generation.

In 2001, five years after the reforms took place, Brazil went through its most severe energy crisis ever. An unexpected dry Summer[2] caught the water levels of the dams of the Brazilian system at an already low level leading to a water shortage that culminated in a rationing of electricity consumption with penalties for over-consumption. Unclear market rules led to major lawsuits from different parties, leaving the electricity market in complete chaos.

The official government explanation for the crisis was the unexpected drought of the first months of 2001 that added to a series of unfavorable rain seasons in the previous years, leading to the acute water shortage of 2001. However, critics of the reforms argued that the crisis was in fact the consequence of mis-designed market rules. More specifically, they argued that the price from the market for contracts of electricity supply was not able to attract enough investments in new generation capacity. They also claimed that due to the high sunk costs and number of years required for the new plants to start operating, entry of new plants should be the result of a centralized decision and should not be left to a decentralized market.

In order to analyze how investments in new plants respond to different market conditions one would need information on prices and on the profitability of the plants and how investment in new plants followed. The problem is that even after the reforms, the electricity industry in Brazil (and mostly elsewhere) is characterized as being centralized and regulated (section 2 discusses the Brazilian market in more depth). The generation segment operates under centralized dispatch of an ISO (Independent System Operator) that calculates through the solution of a computer algorithm the cost of the water stored in each generation plant, and based on these results determines the production of each plant. Therefore, generators

[2]Summer is the rain season for most part of Brazil.

do not determine the quantity they produce. Also, generators are paid according to their long term production capacity (called assured energy) instead of their actual production. The spot market is a residual market that is used to adjust for short term fluctuations in demand and supply. Around 90 percent of the trade happens through bilateral contracts, which means that the spot price and quantity traded cannot be used to analyze the entry decisions of new plants, since they are not representative of the profitability of the plants.

The contract market is the only competitive segment in this industry. Unfortunately, the price of the contract is a strategic information for generators and distributors and hence are kept secret by the parties. However, the decision to enter the generation market is public information and well documented. The literature on empirical entry models in industrial organization (Bresnahan and Reiss [6] and [7], Berry [4] among others) provides a way to estimate the profit function of the entrant firms based solely on entry data, without having information on prices and quantities. This is the method I follow in this paper.

However, when using the entry decisions to identify the profit function one needs to take into account one characteristic specific of hydroelectric generation: the externality in production. The externality arises from the fact that the operation of a generation plant regularizes the river flow downstream, since it stores water during the rain season and release it while generating electricity during the dry season. Other generation plants located downstream on the same river benefit from this regularization, since the upstream plant is in fact storing water for all the other plants located downstream. A generator that otherwise would need a large reservoir to store water from one season to another, can have an equivalent production with a smaller reservoir if there is a plant operating upstream.

This paper develops an entry model that takes this interaction into account. In this context, the externality is well defined and it is a function of the decrease in the variance of the river flow. The technological characteristics of the production process gives rise to a well defined pattern of how the externality is generated and how it affects the other plants. I take advantage of these characteristics to propose a econometric method that is computationally simpler than more standard entry models and does not suffer from the common problem of multiplicity of equilibria in entry games (see Berry [4], Seim [16] or more recently Andrews et al [1] for more on the problem of multiplicity of equilibria).

This work relates to the empirical literature on entry models in industrial organization. There is a large literature on this field, most of them using entry decisions to access market power: Bresnahan and Reiss [6] and [7], Berry [4] etc. However, it has a closer analogy to the work of Seim [16] and Mazzeo [13], where the decision to enter is made together with a location decision. The location can refer either to a product or a geographical space. The location decision in their models is driven by the trade off between differentiating and locating closer to higher demand locations; the degree of competition among products depends on the distance between competitors. The analogy with the problem studied here is that firms also decide if enter and where to locate. However, the location choices here are with respect to production and costs, and they depend on the physical characteristics of the locations and on the externality of production among the generators.

Analyzing the externality of entry decisions, the paper by Gowrisankaran and Stavins [10] estimate the externality associated with the adoption of new technology by banks. In their paper, the adoption of the new technology influences other banks decisions; banks that do not adopt the new technology are not able to carry certain types of transactions with other banks. While similar to this work for dealing with the problem of entry and externality instead of market power, their paper does not deal with the location problem as done by Seim [16] and Mazzeo [13]. In this paper I combine the two problems, with the externality of one agent's entry decision influencing the location decisions of other agents.

This paper also relates to the literature in spatial competition. Case et al [8] analyze the continuous case where neighboring states compete in the amount of public expenditures. Dealing with a spatial discrete choice problem, or spatial logit, Murdoch et al [14] estimate a model where countries have to decide to join an environmental agreement, with the decision of a country having a negative externality on neighbor countries.[3]

Finally, there is a large literature about the actual performance of restructured electricity markets, with several papers trying to analyze different aspects of these markets. Borenstein et al [5] uses a method that decompose the wholesale price of the California market into costs, infra marginal rents, and market power gains to evaluate market inefficiencies during the energy crisis of the year 2000.[4] Wolfran [19] analyzes bid behavior in the British wholesale market to identify departures from the competitive price. Ishii and Yan [12] look at the effect of changes in regulatory institutions on the option value of investing on new plants. These and many other papers use methodologies that rely on information on price quantity and costs to quantify market inefficiencies. The method I use in this paper requires only data on entry decision to assess market performance.

The paper is organized as follows. Section 2 briefly describes the Brazilian electric system and how investments in new facilities are made. In section 3 I present a theoretical model of two generators located in cascade on the same river operating under decentralized dispatch, and show that under non-restrictive assumptions the operation of the generator upstream increases the profitability of the generator downstream.

Section 4 describes the econometric entry model. It also describes the functional form of the profit function and the likelihood function used in the estimation. Section 5 is a description of the data set. It is a panel containing data on the locations available for the installation of new plants, from 1995 until 2002, with the locations chosen at each year and the locations that remained available. Section 6 describes the econometric procedure and presents the econometric results. Section 7 compare the results of estimating a model that takes the entry order into account and one that does not. The last section concludes.

[3]Anselin [3] provides a survey on spatial econometrics and spatial discrete choice models.

[4]Numerous other papers try to analyze the California energy crisis. Refer to Borenstein et al [5] for more references on this topic.

2 Investment in Electricity Generation

The Brazilian system is a predominantly hydroelectric system with approximately 90% of all electricity generated hydrolically, with the remaining capacity generated thermally. The generation system is operated under centralized dispatch by an ISO (Independent System Operator) that is responsible for the dispatch of the generation plants. A computer algorithm calculates the optimal dispatch by minimizing the probability of future water shortages. As a result, the generators are dispatched in a merit order: the plants with the lowest opportunity cost of water are the first to be dispatched, and more plants are added to the process up to the point where supply meets demand.

There are 4 sub-markets within the Brazilian market: North, South, Southeast/West Central and Northeast. The sub-markets are defined due to significant restrictions on the transmission lines between the regions, compared to no significant restrictions within it. The sub-markets can have different prices due to transmission constraints on peak times.

Investment in hydroelectric generation is done through a concession process where investors submit bids for the right to explore the hydroelectric potential of a given location. The available locations come from a list of possible locations provided by ANA (*Agência Nacional de Água*), which is the government body that regulates the use of water resources. When investors show interest in a specific location, a public concession process takes place, with several investors submitting technical proposals and bids for that location. Among the technical proposals that qualify, the greatest bid wins the right to build and operate the plant for the next thirty or forty years.

The choice of maximum generation capacity and the size of the reservoir of the generation plant are limited by natural characteristics of the location, and determined by the regulatory agency. Investors are not allowed to build a small reservoir in a location with capacity for a large one. On the other hand it is usually very costly to expand the reservoir beyond some natural limits. The engineering parameters of each location (area and volume of the reservoir, maximum installed power etc) are given when a potential investor decides to bid for the right to explore a location.

Most of the electricity is traded through bilateral contracts between generators and consumers, usually distribution companies or large users, and only a small fraction on the spot market. The Brazilian system adopts a payment scheme called MRE (*Mecanismo de Realocacão de Energia*), Mechanism to Relocate Energy, where the energy produced by all plants is pooled together and allocated to generators in proportion to their long term production capacity, also called assured energy (*energia assegurada*). In this way, generators are not paid by their actual production but by their assured energy. The assured energy is also the maximum amount of electricity per period that a generator can contract with the distribution companies. The MRE works as a risk sharing mechanism to mitigate the risk of a plant not being dispatched by the ISO, say due to a drought, not being able to deliver the contracted energy and, consequently, have no revenue for long periods of time.

Each year the distribution companies forecast what is going to be the demand five years ahead, the average time of installation of a new plant. The positive difference between the forecasted demand and what they have already contracted is the potential demand for contracts with new entrants, assuming all energy supplied by the existing plants is already contracted.[5] Given these demand conditions, potential investors negotiate with distribution companies the price of the new energy. If we consider electricity an approximated homogeneous good that can be transmitted for long distances through the transmission network and that congestion happens only between different regions, we can assume that there is a unique contracted price within each region at each period.[6]

[5]More than 90% of the energy produced in Brazil is traded through contracts.

[6]Electricity can be considered a homogeneous good up to the fact that there are transmission losses when transmitting for long distances and congestions between regions.

2.1 The MRE and the Financial Closure of the System: An Example

In order to understand how the financial closure of the system operates under the MRE, consider a system composed of only two generators, A and B, and two distribution companies, D1 and D2. Table 1 shows the quantities and prices contracted among them.

Table 1: Contracts

	D1		D2	
	$\mathbf{q}^c$	$\mathbf{p}^c$	$\mathbf{q}^c$	$\mathbf{p}^c$
A	100	1	-	-
B	50	1.5	40	2

I assume that both generators contract all their assured energy, therefore A's assured energy is 100 and B's is 90. In the absence of the MRE, the revenue of a generator would be given by,

$$R = p^c q^c + p^s (q^g - q^c), \tag{1}$$

and the payment of a distributor would be,

$$Y = p^c q^c + p^s (q^d - q^c) \tag{2}$$

Where p^s is the spot price of the system and q^g and q^d are the generated and consumed quantities, respectively.

The MRE is a risk sharing mechanism that allocates the energy produced across the different plants, changing the quantity generated q_g in equation (1), by the quantity determined by the MRE, q_{MRE}. The quantity q_{MRE} for plant A, for example, is given by

$$q^A_{MRE} = \frac{AE^A}{AE^A + AE^B}(q^A + q^B) \tag{3}$$

Table 2 shows two different situations. On situation 1 the system as a whole produces a quantity that is equal to the assured (contracted) energy of the system. In this case, the

MRE allocation guarantees that both plants have the contracted energy as the produced energy, so the generators do not trade on the spot market. Situation 2 shows the system producing less than the assured energy. The MRE allocation is then proportional to the assured energy of each plant. In this situation everyone trades on the spot market. One feature of the MRE, in fact its main purpose, is that it reduces the variance of the generator's revenue, as can be seen in the last two columns of the table.

Table 2: MRE - quantities and revenue

	Prod/Cons q	MRE q	Spot Market q	Rev/Pay MRE	Rev/Pay without MRE
Situation 1	q=AE				
A	80,0	100,0	0,0	100,0	90,0
B	110,0	90,0	0,0	155,0	165,0
D1	100,0	-	-50,0	150,0	150,0
D2	90,0	-	50,0	105,0	105,0
Situation 2	q < AE				
A	50,0	57,9	-42,1	78,9	75,0
B	60,0	52,1	-37,9	136,1	140,0
D1	60,0	-	-90,0	130,0	130,0
D2	50,0	-	10,0	85,0	85,0

3 Externality in Production

Generation plants located on the same river have production externalities among each other, with generators located upstream regularizing the river flow for generators located downstream. Before trying to estimate the effect of this externality on the entry probability I present a theoretical model of two generators operating on the same river to show that the operation of the plant located upstream creates a positive externality, increasing the profitability of the plant located downstream. I also present some characteristics of this externality which will be used in the next section to define the functional form of the externality in the empirical estimation.

I consider the case of a generator that decides its own production, as opposed to operate under centralized dispatch. It simplifies the problem, since in the decentralized case each generator decides production by maximizing its own utility. The difference between the optimal policies of the two problems is due to the externality, that is taken into account in the centralized dispatch case.[7]

The generator's problem consists of deciding when to use the water it has stored in its reservoir to produce energy. Different market conditions, with different prices, and a varying stock of water is what poses the trade off between producing power today or in the future.

I assume that prices are given for the generators, ruling out any type of strategic behavior to try to affect prices and market conditions. This assumption is reasonable in the case of a sizable market with a large number of generators connected to a transmission grid that covers different regions without major transmission constraints. It approximates the conditions found in Brazil.[8]

The problem analyzed here consists of two generators located in cascade on the same river, with generator 1 located upstream from plant 2, as shown in Figure 1. I represent the river by D discrete points. The amount of rain that falls in each period at every point along the river is represented by a stochastic variable ϵ, with $f(\epsilon)$ being its probability density. For simplicity, rain is *iid* both geographically and across time.[9]

The amount of water that reaches the reservoir of generator 1 is given by the amount of rain that falls upstream from plant 1. Generator 2 is located at the end of the river with generator 1 located at a distance of d from generator 2. The river spring is at a distance D from plant 2, as shown in Figure 1. The amount of rain that reaches plant 1 is given by $r_1 = \sum_{i=d}^{D} \epsilon_i$. On the other hand, the water that reaches generator 2 is the sum of the water used by generator 1 to produce electricity and the amount of rain that falls on the stretch of

[7]The externality in production in hydroelectric systems is one of the reasons used to justify having centralized dispatch.

[8]An interesting case would be found in a small or isolated market, where the plants could affect the market price by strategic manipulating the supply of electricity. Garcia et al [9] analyze a duopoly game of hydroelectric generators managing their stock of water and selling electricity on the spot market.

[9]A more realistic assumption could be made about the rain pattern, such as following a Markov process, without changing the main results of the model.

river that lies between the two plants. The amount of water that reaches generator 2's dam is $r_2 = q_1 + \sum_{i=0}^{d-1} \epsilon_i$.

The chronological order of events is the following: it rains at the beginning of the period, at the end of the period electricity production takes place and the remaining water on the reservoir will be the initial stock in the next period. The water used by plant 1 reaches plant 2 on the same period.

To simplify the analysis, I assume a one to one relation between water and energy produced. It means that one unit of water stored in the reservoir produces one unit of energy. In fact, a more realistic production function is nonlinear in the height of the water surface relative to the turbine located at the base of the reservoir. Taking this into account implies that the productivity of a unit of water changes with the state of the dam. I abstract away from these technical consideration in this work.

The production of generators 1 and 2 is constrained by the amount of water they have in their reservoirs and by the amount of rain that falls in the period. The amount of water in the dam is constrained by the maximum storage capacity of the reservoir, as given by the following inequalities:

$$q_i \leq X_i + r_i, \text{ for } i = 1, 2 \tag{4}$$

$$X_i \leq \bar{X}_i, \text{ for } i = 1, 2 \tag{5}$$

Where q_i is the quantity produced, X_i is the amount of water stored in the dam, r_i is the amount of water that reaches the plant in one period and $\bar{X}_i$ is the maximum storage capacity of the reservoir. It is important to note that electricity can be produced by using both water stored in the reservoir and/or the river flow in location i given by r_i. It implies that a generation plant with a reservoir of size zero, $\bar{X}_i = 0$, must have $X_i = 0$ and $q_i \leq r_i$.

The law of motion of the amount of water stored in reservoir i is given by,

$$X_i' \leq X_i + r_i - q_i; \text{for } i = 1, 2 \tag{6}$$

where the inequality sign represents the possibility that the reservoir spills water if it is full, $X = \bar{X}$. In the law of motion of generator 2, r_2 depends on plant's 1 production plus the rain that falls between the two plants.

Let p be the price of electricity in a given period, and $g(p)$ its probability distribution. Also, let $C(q)$ be the cost function of the plant, with $C^{'} > 0$ and $C^{''} > 0$. A generator maximizes profit by solving the following dynamic programming problem:

$$V\left(X,p\right) = \max_{q} \left\{ p.q - C(q) + \beta EV\left(X^{'}, p^{'}\right) \right\} \tag{7}$$

Subject to equations (4) (5) and (6).

Equation (7) is the Bellman equation solved by the generator to determine its optimal policy. The expectation of the future value is taking with respect to the probability distribution of rain fall and price.

In order to show that the effect of the externality is positive, we need to verify that (i) the smaller variance (regularization) of the river due to the operation of plant 1 upstream increases the production of generator 2 and (ii) that the optimal production policy of generator 1 regularizes the river flow.

Proposition 1 *The regularization of the river flow by generator 1 (upstream) increases the value of generator 2 (downstream).*

Proof. In order to show that the value of generator 2 increases with the operation of generator 1, it is sufficient to show that a generator's value function is concave. Recall that the amount of water that flows through plant 2 is the same both with or without plant 1 upstream.

Define $\pi = pq - C(q)$, and the operator T such that

$$TV = \max_{q} \left\{ \pi + \beta EV\left(X^{'}, p^{'}\right) \right\}$$

subject to $\quad X^{'} \leq X + r - q$.

If π is real valued, continuous, concave and bounded, and the set

$$S = \left\{ X, X^{'}, q : X^{'} \leq X + r - q \right\}$$

is convex and compact, then the operator T maps a continuous bounded function V in to a continuous bounded function TV, and it satisfies the Blackwell's sufficient conditions to be a contraction mapping. Stokey and Lucas with Prescott [17] show that T maps concave functions into concave functions, and therefore the solution to $V = TV$ is a concave function. Therefore, we only need to show that these properties hold in these cases in order to be able to apply their results here.

Since $p, q \in \mathrm{R}$ and $C^{''} > 0$, we have that π is indeed a real valued, continuous and concave function. Boundedness comes from the fact that the monopoly profit bounds this function above and the possibility of shutting down in face of negative profit bounds it below. The set S is clearly convex and compact. ■

Proposition 2 *The optimal policy of generator 1 located upstream, regularizes (reduces the variance) the river flow.*

Proof. We want to show that the variance of the optimal policy q^* is smaller than the variance of rainfall r. For this purpose it is sufficient to show that $0 < \partial q^* / \partial r < 1$.

Considering the case where the law of motion binds and substituting it into the Bellman equation we have,

$$V\left(X, p\right) = \max_{q} \left\{ p.q - C(q) + \beta EV\left(X + r - q, p^{'}\right) \right\}$$

The first order condition gives,

$$p - C^{'} - \beta EV^{'}(X + r - q, p^{'}) = 0$$

Applying the implicit function theorem,

$$\frac{\partial q^*}{\partial r} = \frac{\beta EV''(X + r - q, p')}{\beta EV''(X + r - q, p') - C''}$$

Using the fact that the value function is concave and the cost function is convex we have $0 < \partial q^*/\partial r < 1$. ■

Theorem 1 *The production of electricity by a generator located in a given river has a positive externality on the generators located downstream on the same river.*

Proof. If the production of a generator upstream regularizes the river flow, it increases the value of generators downstream as long as their value functions are concave. Propositions 1 and 2 show that both conditions hold. ■

The idea is that the reservoir of generator 1 is in fact holding water for generator 2 as well. Generator 1 holds water in the rain season and release it during the dry season. This is a positive externality of the first generator's reservoir management. The regularization of the water inflow into generator 2, as compared to the greater variance of the occurrence of rains, is the externality of the operation of generator 1 upstream. It is important to note that as much as this result depends on the technological characteristics of production in this industry, it also depends on the fact that generators upstream are maximizing profits and on the assumption that the price is exogenous.

One corollary of this result is that the effect of the externality of the operation of 1 in 2 depends on the distance between the two plants. The closer plant 1 locates to plant 2 the higher the effect of the externality, since a smaller stretch of the river will be subject to the higher variance of the rain pattern. To see this consider the case where plant 1 can locate in two different points along the river, r and r', with r' more downstream than r. Since each distance measure along the river has a one to one relationship with the amount of rain that falls downstream from this point, without loss of generality, normalize the expected amount of rain that falls in each location to one, $\bar{\epsilon} = 1$. With this normalization r and r' now are also equal to the expected amount of rain that falls downstream from them. The following corollary states it formally.

Corollary 2 *The effect of the externality generated by a plant upstream decreases as the distance between the plants increase.*

Proof. Since $r' < r$ we want to show that $Var(r) + Var(q_r^*) > Var(r') + Var(q_{r'}^*)$. The water inflow into plant 2 when plant 1 is located in r is $q_r^* + r$, hence the variance of the water inflow in plant 2 is $Var(q_r^* + r) = Var(q_r^*) + Var(r)$, while if plant 1 locates in r' the variance is $Var(q_{r'}^* + r') = Var(q_{r'}^*) + Var(r')$. For a plant located in r we can write $Var(q_r^*) + Var(r) = Var(q_r^*) + V(r - r') + Var(r')$, so we only need to compare $Var(q_r^*) + V(r - r')$ with $Var(q_{r'}^*)$. The plant located in r' is located $r - r'$ closer to plant 2 than the plant in r. Proposition 2 states that the optimal policy has a smaller variance than the variance of the rain fall, hence the plant in r' is regularizing $r - r'$ more than the plant in r, therefore, $Var(q_r^*) + V(r - r') > Var(q_{r'}^*)$ ■

4 An Entry Model with Externality

I assume that at each available location there is a potential entrant that in a given period can choose between entering or not. If the agent decides to enter she will sign the contract that will set the price for the following years, build the plant, operate it and get the pay off of selling the electricity. If she decides not to enter she will not have the option to enter in the next period. In other words, agents have only one opportunity to enter.

This assumption greatly simplifies the problem since it avoids any dynamic consideration on the timing of the entry decision, and it is based on the fact that there is no real value of waiting to enter in this industry. This can be justified by two specificities of this industry. First, the value of waiting (also known as option value) derives from the fact that enter can be made in a subsequent period if market conditions improve. It requires an agent to be able to make the decision about entry in the next period. But it is not necessarily the case here, since a different entrant can enter at that specific location. The reason for this is the limited number of locations available for entry, and the impossibility of being the only possible entrant in a given location. It reduces the value of waiting to zero, since not entering now does not guarantee the right to make the same decision next period. The second reason is that the waiting value is based on the trade off between entering now or in the future. Since most of the entrants in this industry are large firms with several plants operating in different locations, entering now in a given location does not prevent entry in the future. Therefore, a more reasonable assumption is to assume that agents enter every time there exists a positive profit opportunity in a given location. Without the identity of the entrants, it is equivalent to assuming that agents last only for one period.

I also assume that entrants are differentiated in their ability to operate a plant and sell the electricity produced in a specific location. And that this ability is not observed by the other entrants or by the econometrician. In fact, entrants are identical in the observable characteristics but distinct in the unobservable characteristics. This unobserved characteristic is private information of the entrant, which introduces asymmetry of information into the problem. This assumption implies that the profit of a generator i is determined by two distinct components: an observable part Ω_{jt}, a function of the plant's characteristics and time, and an unobservable part $\mu_j + \varepsilon_{jt}$, that account both the unobserved characteristics of the location and the specific ability of the entrant to operate the plant. The unobserved characteristics of the locations are observed by the entrants but not by the econometrician. The profit function can then be written as

$$\pi_{jt} = \Omega_{jt} + \mu_j + \varepsilon_{jt} \tag{8}$$

It makes the entry problem an incomplete information game where players form expectations about the other players' profits and actions. The solution concept used is a Bayesian Nash equilibrium where strategies are ex-ante optimal. This is the same concept used in Seim's [16] study of the video retail industry. In this type of equilibrium there can be ex-post regret about the entry decision. This type of assumption is especially reasonable in industries with high sunk costs as electricity generation, due to the mispracticality of reverting investments in new facilities. Ex-post regret only occurs in entry games with complete information if players use mixed strategy.

The idiosyncratic ability of the entrants ε represents the type of the entrant in the asymmetric information problem, which is modeled as an *iid* random variable with probability density $h(\varepsilon)$. Agents will form expectation about other agent's actions based on the distribution $h(.)$.

There is a list of J different locations available $\{1, ...J\}$. The locations chosen in period t will not be available in $t+1$. Let π_{jt} be the long term profit of entering location j in period t. An agent will enter in location j if the profit of entering is greater than zero. The decision to enter in location j in period t is given by,

$$\begin{cases} \text{doesn't enter} & \text{if} \quad \pi_{jt} < 0 \\ \text{enter} & \text{if} \quad \pi_{jt} \geq 0 \end{cases} \tag{9}$$

4.1 The Functional Form of the Profit Function

The investment decision is based on the expected long term profit, as shown in equation 9. Two important institutional features of the Brazilian market imply a specific functional form for the profit function. First, most of the energy is traded through long term bilateral contracts, implying that the price used to calculate the discounted cash flow is fixed on the relevant time horizon. This is important since it excludes uncertainty about future prices. And second, under the MRE, generators do not get paid according to their productions but according to their assured energy, which is fixed for long periods of time. These features significantly simplify the analysis since the payments received by a generator do not depend on her current stock of water or on the expected rain.

The profit function of an agent entering in location j in period t is given by

$$\pi_{jt} = \pi(Z_j, Ext_{jt}, \phi_t, \mu_j, \varepsilon_{jt}) \tag{10}$$

Where Z_j is the set of characteristics that affect both the profitability and the investment cost of the plant, Ext_{jt} is the externality that generators upstream from j generate in period t, ϕ_t is the time effect on the profitability of the plants, μ_j is an unobserved by the econometrician characteristic of the plant and ε_{jt} is the unobserved type of the entrant that affects profit.

It is worth noting that the fact that the contract keeps the price fixed for the relevant time horizon, together with the generator receiving according to the assured energy and not by the quantity produced, simplify the problem faced by the generator. In this case the important variables are location (each location already has Z_j defined), the unobservable contract price and the externality Ext_{jt}. Based on these variables the agent decides whether to enter or not. This differs from the case where generators are paid according to the quantity produced and trade occurs in the spot market with prices changing over time. If this was the case, the expected cash flow would be the solution of the dynamic programming problem analyzed in the section 3, where generators allocate water across time to maximize profit.

The assured energy depends on the size of the reservoir, the maximum power capacity and on the water inflow and its variability. The latter depends on the operation of plants located upstream, and therefore is affected by the externality of being downstream. Since it is unknown how the hydrological regime and the externality affect the assured energy I choose to use a profit function where all the variables that affect the assured energy enter linearly in the equation. I assume the functional form of the investment cost to be linear since several variables that affect the assured energy also affect the investment cost such as maximum power generation capacity and volume of the dam. The drawback of this approach is that I am not be able to separate the effect of some of the variables on the revenue stream from the investment cost. The advantage is that I do not have to make strong assumptions about the technology of production and the investment cost function.

The contract price is strategic and highly secret information for the generators and, hence, unknown to the econometrician. The year dummies capture the market conditions for each year, therefore including the effect of price and risk on the profitability.

The functional form of the profit function becomes,

$$\pi_{jt} = Z_j\beta + Ext_{jt} + \phi_t + \mu_j + \varepsilon_{jt} \tag{11}$$

Note that ε_{jt} is indexed on t since on each period a different entrant with different ability can choose to enter the market. I also assume that ε_{jt} has a type I extreme value distribution and μ_j is distributed as a normal with mean c and variance σ^2, $N(c, \sigma^2)$.

To model the externality effect I separate it in two components: the first is the regularizations of the river flow done by the upstream plant and the second is the distance from the plant to the generator downstream. The regularization of the river flow over time by the upstream plant is defined by the storage capacity of the reservoir relative to the river flow. The higher the size of the dam relative to the river flow the higher the regularization. And how the regularization affects the plants located downstream depends on the distance between them. The general form for the externality effect on plant j when plant i operates upstream is $Ext_j = g(d_{ij})reg(vol_i, flow_i)$, where d_{ij} is the distance between the two plants and $g(.)$ is a decreasing function of the distance, and $reg(.)$ is a function that depends on the reservoir's volume and river flow.

For the first term of the externality equation I assume that $g(d_{ij}) = 1/d_{ij}$. For the second term I use the following specification:

$$reg_i = (vol_i/flow_i) \tag{12}$$

Generalizing to the case of several plants upstream, the externality of plant j becomes

$$Ext_j = \sum_{i \in \Delta_j} \frac{reg_i}{d_{ij}} \tag{13}$$

Where Δ_j is the set of locations upstream from location j.

Define P_{it} as the probability of an entrant entering in location i upstream in period t. The expected externality that generator j will have in period t is,

$$\mathrm{E}(Ext_{jt}) = \sum_{i \in \Delta_j} \frac{reg_i}{d_{ij}} P_{it} \tag{14}$$

If at the beginning of period t there is already a plant operating in one or more of the upstream locations, $P_{it} = 1$ for these locations.

After defining the functional form of the profit and the externality function, the next step is to calculate the entry probability which will be used in the estimation procedure.

4.2 The Entry Probability

In order to illustrate how the probability of entry is calculated and some features of the equilibrium of the entry game I first show the entry problem of one generator with no plants or locations upstream, then I show the case of a generator with only one plant upstream and then the generalization to the case of N plants.

In the case of a generator with no possible location for plants upriver, the decision to enter depends on its own profitability only. A potential entrant in location i enters in period t if $\pi_{it} > 0$. Given μ_i, the probability of entering is,

$$P_{it} = P_{it}(\text{enter}|\mu_i) = P(\pi_{it} > 0|\mu_i) = P(\Omega_{it} + \mu_i + \varepsilon_{it} > 0) = P(\varepsilon_{it} > -(\Omega_{it} + \mu_i)). \tag{15}$$

Where $\Omega_{it} = Z_i\beta + \phi_t$ is the observable part of profits. Since I assume ε to have a type 1 extreme value distribution, given the vector of parameters β the conditional entry probability becomes

$$P_{it} = \frac{e^{\Omega_{it}+\mu_i}}{1+e^{\Omega_{it}+\mu_i}} \tag{16}$$

The decision of a second generator between entering or not in a location j downstream depends on the decision of generator i upstream. Since the entrant in j does not know what the entrant in i will do in period t, her decision is based on her assessment of the probability that i enters and the expected profit derived from it. The expected profit of an entrant in j in time t becomes,

$$\mathrm{E}\pi_{jt} = \Omega_{jt} + Ext^i_j P_{it} + \mu_j + \varepsilon_{jt} \tag{17}$$

Therefore, the conditional entry probability in j is

$$P_{jt} = P(\mathrm{E}\pi_{jt}(P_{it}) > 0) \tag{18}$$

Consider now the case of N locations on the same river, and order the plants such that the most upstream plant is 1, the second most upstream is 2 and so on. Given the vector Z of plant characteristics, the year effects and the coefficients of the model we can write the probabilities of these plants as a system of equations:

$$\begin{aligned} P_{1t} &= P(\Omega_{1t} + \mu_1 + \varepsilon_{1t} > 0) \\ P_{2t} &= P(\Omega_{2t} + Ext^1_2 P_{1t} + \mu_2 + \varepsilon_{2t} > 0) \\ &\vdots \\ P_{Nt} &= P(\Omega_{Nt} + \sum_{i\in\Delta} Ext^i_N P_{it} + \mu_N + \varepsilon_{Nt} > 0) \end{aligned} \tag{19}$$

It is easy to see that this system can be solved in a recursive fashion: calculate P_{1t} first, then use P_{1t} to find P_{2t} and so on. The fact that the system can be solved in this way indicates that there is a unique solution to this problem, and therefore there is no multiplicity of equilibria in the entry game. Heckman [11] has shown that, if the distribution of the random component is continuous with support R^N, a necessary and sufficient condition for a discrete choice model with strategic interactions to have a unique solution is to have a recursive solution. The fact that the externality occurs from plants upstream to plants downstream makes the problem recursive, together with the assumption that the random components are *iid* and have a extreme value type I distribution guaranteed that the result holds in this case. The fact that the externality occurs in only one direction avoid the problem of multiplicity of equilibria.

For each different river basin I solve for the probabilities using the system described in (20). After solving for the conditional entry probabilities for all periods in the sample, the conditional probability of the observed sequence of entry decision in location j is defined as:

$$P_j = \prod_{t=1}^{T_j} P_{jt}^{y_{jt}} (1 - P_{jt})^{1-y_{jt}} \tag{20}$$

Since the ε's are *iid* over time, and y_{jt} takes value 1 if entry happens and 0 otherwise. The unconditional probability can be obtained by integrating out the probability distribution of μ:

$$L_j = \int P_j f(\mu) d\mu \tag{21}$$

Since I assume that μ is distributed as a normal N(c,σ^2), the integral in (21) needs to be numerically calculated.

Finally, the likelihood function that is taken to the data is:

$$L(\theta) = \prod_{j=1}^{N} L_j \tag{22}$$

It is important to note that the interaction among the firm's actions is limited to entry on the same river basin (the main river and subsidiaries) only. Entry in different rivers basins are independent. Also, the recursiveness of the model comes from the fact that entry decisions affect only generators downstream. It significantly reduces the computational burden of the estimation, since it avoids the task of of numerically solving a simultaneous system of equations to calculate the probabilities.

5 Data

I use data from two different sources. Data about the locations with geographical characteristics and technical parameters of the power plants comes from the SIPOT database. This is a broad dataset elaborated by Eletrobras, the state owned enterprise responsible for the identification of locations with hydroelectric generation potential. It contains data about all existing hydroelectric plants and possible locations for installation of new plants in Brazil, including locations where only a very preliminary analysis was made. In this work I consider as locations available for concession the places where the technical parameters such as maximum power capacity, volume, height and area of the reservoir are already defined. It excludes locations with viability studies at a very preliminary stage. The geographical position of the locations used in the sample are shown in Figure 2.

Data about the entry over the period analyzed comes from ANEEL, the body that regulates the electricity industry. They have a dataset containing all the concession contracts negotiated since 1993.[10] I use data from concessions realized from 1995 thereafter, since this year marks the beginning of the reforms in the Brazilian electric system. There is information about the year the entry occurred and the location of the plant.

I merge the two datasets to have characteristics of the locations together with information on entry. The data is organized as a panel of locations available for concession for hydroelectric generation. Once a location is chosen and entry occur, this place gets out of the sample. Further, since I do not have information when a location become available for concession I assume that all the available locations considered in the sample were available

[10]The concession contracts are available at ANEEL website http://www.aneel.gov.br/

in 1995. It makes the dataset an unbalanced panel that shrinks over time since locations drop out of the sample as they are chosen and no new locations enter the sample over this period.

The distance between plants/locations on the same river I calculated using the polar coordinates from each plant, an information contained in the SIPOT database. The fact that rivers wind around the landscape makes the distance between two plants when following the river to be significantly more than if measured as the distance of two points on the Earth surface. So to calculate these distances I marked the coordinates of the plants on Google Earth and draw paths following the river curse to find the distance between the plants.[11] Table 3 summarizes the main explanatory variables used in the estimation.

Table 3: Summary of Data

Variables	mean	median	max	min	stand dev
Power (MW)	460	140	11000	32	1147
Height (m)	72	50	594	9	73
Area (m^2)	197	33	6140	0	612
Flow (hm^3)	951	238	17926	5	2207
DistSIN (Km)	62	23	1000	0	127
N	0.1	0.0	1.0	0.0	0.3
NE	0.1	0.0	1.0	0.0	0.3
S	0.2	0.0	1.0	0.0	0.4
SE/WC	0.6	0.0	1.0	0.0	0.5

Power is the installed capacity of a generator and affects its maximum production capacity, as well as the installation costs. Height is the distance between the highest possible water level to the base of the water fall. Area is the area of the dam when it is full. N NE S and SE/WC are dummy for the different regions of the country, and they compare to the Southeast-West Central region, that I take to be the base region. The main demand centers are located on the Southeast, the more populated and industrialized region. I group together SE and WC since they are electrically well integrated, without transmission restrictions between the two regions. DistSIN is the distance between the generator and the

[11] A Google Earth file with all the locations from the sample marked on the Brazilian territory is available on my webpage, https://netfiles.uiuc.edu/moita/www/.

main transmission line. Since investors are required to build the connection to the main transmission lines, it accounts for the cost of building the connection.

Table 4 shows the distribution of the number of firms and entry over the years covered by the sample.

Table 4: Locations and Entry

	no. locations	no. entry
1995	146	2
1996	144	2
1997	142	6
1998	136	13
1999	123	2
2000	121	12
2001	109	18
2002	91	16
total	1012	71

6 Estimation

Table 5 gives the maximum likelihood estimates of the full model defined in equation (22). The table presents the results of the full model and the results from the model without the random effects. The full model has higher coefficients than the model with no random effects.

All coefficients have the expected sign. Power is related both to the production capacity of a generator and therefore to its revenue stream, as well as with the investment cost - larger plants have both a higher maximum power capacity and a higher cost. The coefficient can be interpreted as the net effect of power on profits, with the results showing a positive but not significant effect. The positive coefficient may indicate the existence of economies of scale and/or market power. With the available data it is not possible to distinguish between the two effects.

Height increases the generation capacity of the plants and it is a good indicator of the energetic efficiency of the location, as corroborated by the positive and significant coefficient obtained on both specifications. Everything else constant, deep dams are better than shallow ones for two reasons: first, they can generate more power using the same amount of water and second, they can have the same power capacity as larger and more shallow plants but flood a smaller area. The flooded area represents the main cost of installing a new plant. The acquisition of the land, together with the remotion of whole villages, farms, domestic and wild animal population, plus the environmental cost of flooding in many cases forested areas represents the main component of the installation cost. When controlling for power and height, the variable area captures this effect and gives a good approximation of the environmental cost of installing a plant. The coefficients are negative and significant in both models.[12]

The region dummies N NE and S also carry two effects: difference in installation costs and congestion risk across the regions. Since the main load centers are located in the Southeast, plants located in different regions are likely to contract with consumers located in the SE. There are significant restrictions on the transmission among the regions in peak times and consequently different market prices in these hours. A plant located in the North but contracted with a consumer in the SE has to buy electricity from a generator in the SE in case there is congestion between the North and the Southeast and not all the contracted electricity can be delivered from the North. This electricity will be bought at the spot price for the sub-market SE, which will be higher than the price for the North if the transmission lines are congested in the N-SE direction. Also, different regions can have different costs to install a new plant.

The coefficients obtained for N NE and S are in relation to the SE-CW region and are negative for the regions South and Northeast and positive for the North in the full model. The similar geographic characteristics of the South and the Southeast indicates that congestion may affect the profitability in the South. The same cannot be said about the Northeast.

[12]The construction of the dam's wall plus the installation of the turbines represents a smaller share of the investment cost.

Table 5: Full Model Estimation

	Full Model		No Random Effects	
	Coef.	*Std. Dev.*	*Coef.*	*Std. Dev.*
Power	0.0002	0.0003	0.0001	0.0001
Height	0.0068 **	0.0030	0.0031**	0.0015
Area	-0.0030 *	0.0021	-0.0021**	0.0010
DistSIN	-0.0093 **	0.0054	-0.0065**	0.0029
N	0.0038	0.8773	-0.0263	0.5241
NE	-2.0506 **	1.1589	-1.6232**	0.7688
S	-0.5596	0.5334	-0.4171*	0.3232
D96	0.0952	1.1019	-0.3492	0.9328
D97	1.6812 **	0.9090	0.9004	0.7232
D98	2.9157 **	0.9649	1.8772**	0.6484
D99	1.0889	1.2034	-0.1670	0.9401
D00	3.2357 **	1.1193	1.9886**	0.6701
D01	4.2090 **	1.2934	2.5172**	0.6231
D02	4.6992 **	1.4851	2.6771**	0.6273
Ext	0.3080 **	0.1346	0.2408**	0.0849
c	-5.4625 **	1.1358	-3.6370**	0.5708
σ	1.4779 **	0.8043		

** Significant at the 10 percent level.

* Significant at the 20 percent level.

However, none of them is significantly different than zero. DistSIN has a negative impact on profits through fixed costs, since generators have to build the connection from the plant to the main transmission system.

The variable Ext captures the effect of the externality and therefore estimate the interaction of the entry decisions. The entry probability depends on the probability of other generators entering upstream, and measures the effect of having plants operating upstream on the entry decision. As previously discussed, in theory the externality is expected to have a positive effect on profits and on the entry decision. The estimated coefficient is positive and significant as predicted by the theory. It means that the weighted sum of the volume per flow ratio of the plants upstream has a positive effect on the profitability.

The coefficients c and σ are the mean and variance of the random effect. The negative mean is due to the fact that there are more observations of no entry than entry in the dataset. The variance measures the unobserved heterogeneity of the plants, with the results indicating a significant degree of unobserved difference among the plants.

Since I am not including any information on the demand for electricity in the regression equation, the year dummies capture the effect of market conditions on profits, and consequently on entry. The high increase in the last three years of the sample matches with the severe water shortfall that occurred in Brazil in 2001 (see Figure 3), that culminated on a rationing of electricity consumption with penalties for household consumption above certain levels, and very high spot prices on the electricity wholesale market.

The high coefficient for the year 2000 can be interpreted as if the market anticipated the crisis of 2001, with a large number of plants entering the market one year before the crisis. This is a controversial point since the government at that time claimed that the crisis happened due to the unexpected low amount of rain in the summer of 2001. If this were the case the increase in entry would not had been happening already in the year 2000. This is in accordance to the argument made by Anuatti and Hochstetler [2] that deviations from the long term average amount of rain as the one in 2001 is not unusual and the system is designed to withstand large deviations from this average when operating within a safe margin. A closer inspection to Figure 3 shows a rising trend for the spot price after the early months of 1999. It was known for the players in the industry that water levels in the dams were getting unusually lower. The year dummies and the yearly average spot price have a correlation of 0.7 over the 1995 to 2001 period. Figure 4 plots the year effects and the spot price.

7 Discussion of Results and Assumptions

The externality has a positive effect on entry decisions and it is an increasing function of the regularization of the river flow done by the upstream plants. As a way to understand the meaning of the estimated coefficient of the externality I calculate the entry probability for the locations available on the Uruguay river basin in southern Brazil. Figure 5 is a picture of the

Table 6: Entry Probabilities - Uruguay Basin

Plant	Cascade Order*	Distance (next plant)	P(entry)$^{(1)}$ (without ext)	P(entry)$^{(2)}$ (with ext)	Ratio (2)/(1)
Pai Quere	1	102	0.178	0.178	0.00
Barra Grande	2	100	0.218	0.240	10.23
So Roque	1	38	0.142	0.142	0.00
Garibaldi	2	59	0.152	0.175	15.22
Campos Novos	3	87	0.298	0.300	0.87
Machadinho	6	141	0.238	0.250	4.69
Ita	7	132	0.225	0.231	2.50
Passo Fundo	1	55	0.240	0.240	0.00
Monjolinho	2	86	0.174	0.300	72.63
Quebra Queixo	1	151	0.210	0.210	0.00
Foz do Chapeco	11	120	0.144	0.186	29.57
Itapiranga	12	360	0.174	0.200	15.10
Sao Jose	1	70	0.145	0.145	0.00
Passo de S. Joao	2	130	0.153	0.154	0.09
Garabi	15	0	0.050	0.054	7.52

* The number on the cascade order column in fact refers to the numbers of plants upstream.

Uruguay Basin in southern Brazil with the plants marked on it. I assume that all locations are still available and therefore the entry decisions are based on the expected externality. The first three columns of table 6 show the name of the locations, their locations on the cascade order and the distance to the next downstream plant. The fourth column shows the entry probabilities without the effect of the externality, equivalent to set the coefficient of Ext to zero. The fifth column shows the probabilities with the externality and the last column is the percentage increase in the entry probability for the two cases. The entry probability is substantially larger for some of the downstream plants, getting as far as 73 percent higher for Monjolinho, showing that the externality effect is not negligible. There is clearly a bias toward entry in downstream locations.

An alternative explanation for the rise in the dummy coefficients of year 2000 and after is the fact that some institutional change brought credibility to the regulatory process and decreased the risk of investment. There were four important landmarks in his industry: the privatization and the creation of the regulatory agency in 1995 and 1996, the creation of wholesale market, MAE, in 2000 and the crisis of 2001. The timing of the events excludes the first two for being the reason of the high entry of the 2000's. The creation of MAE in 2000 can be the source of an increase in credibility that reduced the regulatory risk and attracted capital to the industry.

I argue that this was not the case. The first reason is that the MAE was officially created in 2000 but the set of rules that governs the market was created by its participants in 1999. Hence, if MAE's creation was the reason some anticipation would be expected to occur and investments would increase before 2000. The second point, following Anuatti and Hochstetler [2], is that there was a malfunctioning of the wholesale market in its infant years due to absence of dispute resolution procedures and governance problems in general. Also, the crisis created serious problems on the wholesale market that culminated in the government intervention in 2001. The malfunction of the market rules together with the intervention of 2001 indicates that the creation of the wholesale market was not enough to bring stability to the regulatory environment and reduce the risk on new investments.

The data set has information about the entry order among the years of the sample.[13] It allows me to estimate the model using the entry order or, alternatively, disconsidering the entry order and assuming that everyone enters at the same time. This assumption is made on several empirical papers on entry, such as Berry [4] and Seim [16]. The usual reason for this assumption is the fact that information on the entry order is not available.

The data set used in the estimation is an unbalanced panel, where an available location that is chosen in a given year does not appear on the sample in the next period. Ignoring the entry order is equivalent to getting rid of the panel structure of the data. Table 7 shows the results of three different estimations. The regression labeled 'Full Model' is the one already presented in the previous section. The 'Cross Sectional' model treats the entry problem as a one shot game, where everyone decides to enter at once. In this case, the temporal dimension of the data set is lost since all entrants are assumed to make the decision at the same time.

[13]There is no information on the entry order within a year.

Table 7: Cross Sectional and Panel Models

	Cross Sectional		Entry Order		Full Model	
	Coef.	*Std Dev*	*Coef.*	*Std Dev*	*Coef.*	*Std Dev*
Power	0.0000	0.0011	0.0000	0.0001	0.0002	0.0003
Height	0.0047	0.0024	0.0029	0.0015	0.0068	0.0030
Area	-0.0030	0.0076	-0.0017	0.0010	-0.0030	0.0021
DistSIN	-0.0069	0.0073	-0.0052	0.0026	-0.0093	0.0054
N	0.7140	2.1058	0.1391	0.5026	0.0038	0.8773
NE	-1.5766	2.6793	-1.2181	0.7343	-2.0506	1.1589
S	-0.1928	0.3236	-0.2427	0.2855	-0.5596	0.5334
D96					0.0952	1.1019
D97					1.6812	0.9090
D98					2.9157	0.9649
D99					1.0889	1.2034
D00					3.2357	1.1193
D01					4.2090	1.2934
D02					4.6992	1.4851
Ext	0.6737	0.2608	0.2304	0.0714	0.3080	0.1346
cte	0.0881	0.6625	-2.3800	0.2361	-5.4625	1.1358
σ			0.0000	0.2330	1.4779	0.8043

The model labeled 'Entry Order' takes into account the entry order but does not include the year dummies, to facilitate comparison with the cross sectional specification.

The results show that ignoring the entry order significantly change the coefficient of the externality. The value of the coefficient of Ext goes from 0.30 in the full model to 0.67 in the static model. This is not an artifact of the year dummies, since the model without the year dummies gives estimates close to the ones from the full model.

8 Conclusion

This work develops a method to use entry data of hydroelectric generators to estimate the profit function. The main distinction of this method is providing a way to deal with the externality in production that arise among plants operating on the same river. This externality arises from the dynamic nature of the hydroelectric generator's problem and follows a well defined pattern with generators upstream positively affecting the plants downstream, as shown by the theoretical model. This feature avoids the usual problem of multiplicity of equilibrium in entry games, and provides a natural way to recursively calculate the equilibrium probabilities.

The results obtained from the full model estimation are consistent with the theoretical model in that the effect of the externality is positive and statistically significant. The empirical results show that firms have a positive incentive to locate downstream from existing plants or locations where entry is likely to occur. An implication of this result is that entry is likely to happen first on the downstream locations of a river, and that once a generator enters a given location the likelihood that someone enter downstream increases significantly.

The characteristics of each location play a strong role in the decision to enter. Power and height represent the energetic efficiency of the location, and therefore have a positive correlation with profits, although power is not significant. The area of the reservoir is a proxy of the installation cost of the plant, and show the high cost of flooding large areas and its negative impact on profits. The region dummies capture the risk of congestion and the difference in installation costs across the different regions of the country. The results are not conclusive in that locating far from the load centers has a negative impact on profits. Distance from the main transmission lines implies the cost of building the connection to the main system, and it is an important factor on the location decision.

The model provides estimates of the change in market conditions for the different years covered by the sample. These estimates show a high coefficient already in year 2000, one year before the crisis of 2001, when spot prices reached unprecedent high levels (see Figure 3). It indicates that the contract market anticipated the excess demand that would be generated by the water shortage. This conclusion has three strong implications. First, as already mentioned it indicates that the crisis was not an unexpected event. Second, and more important, it points out that there was a response in new entry due to a rising expectation of a supply shortage in the future. It supports the effectiveness of the contract market as a decentralized mechanism to attract and allocate investments in new plants, going against the view that the crisis was a problem of misdesigned market institutions. In fact, the crisis happened due to the length of time that the new plants require to begin operating, since the length of time for a medium sized plant to start operating is 5 to 7 years. Third, despite the fact that the market anticipated the crisis the centralized dispatch algorithm failed in preventing it. Few months before the crisis the ISO was still dispatching the hydro plants instead of turning on the thermo generators.

Finally, ignoring the entry order and treating the problem as a one shot game gives rise to misleading coefficients of the underlying problem. The estimation of a static entry game overestimates the effect of the interaction among the generators when compared to the result obtained from the model which takes the sequential order of entry into account.

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Figure 1: Two Generators in Cascade

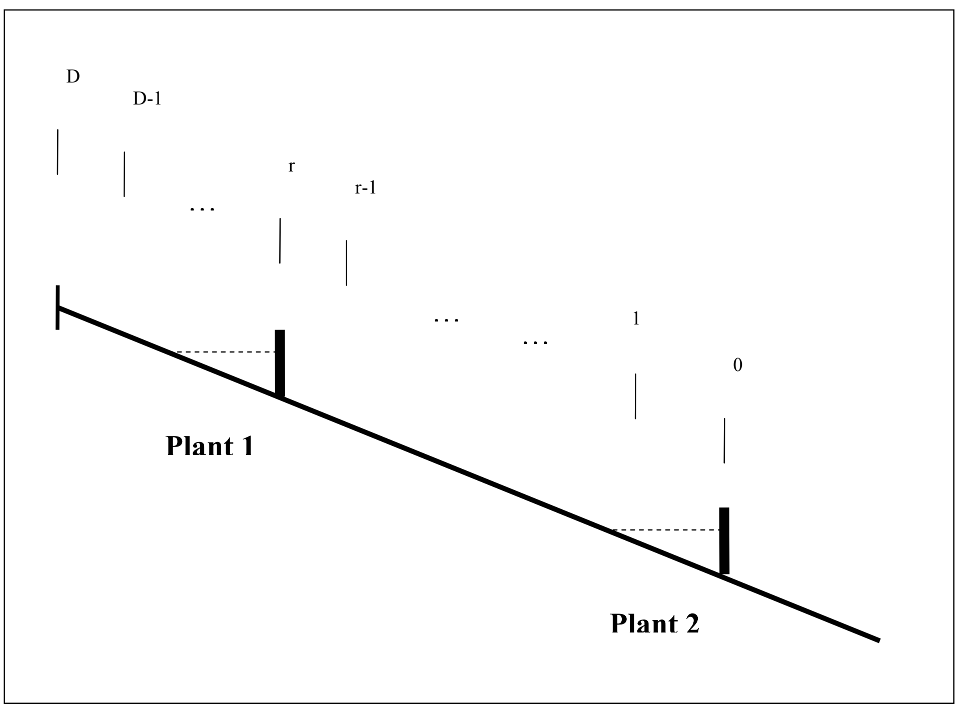

Figure 2: Locations Available in 1995

Figure 3: Spot Prices

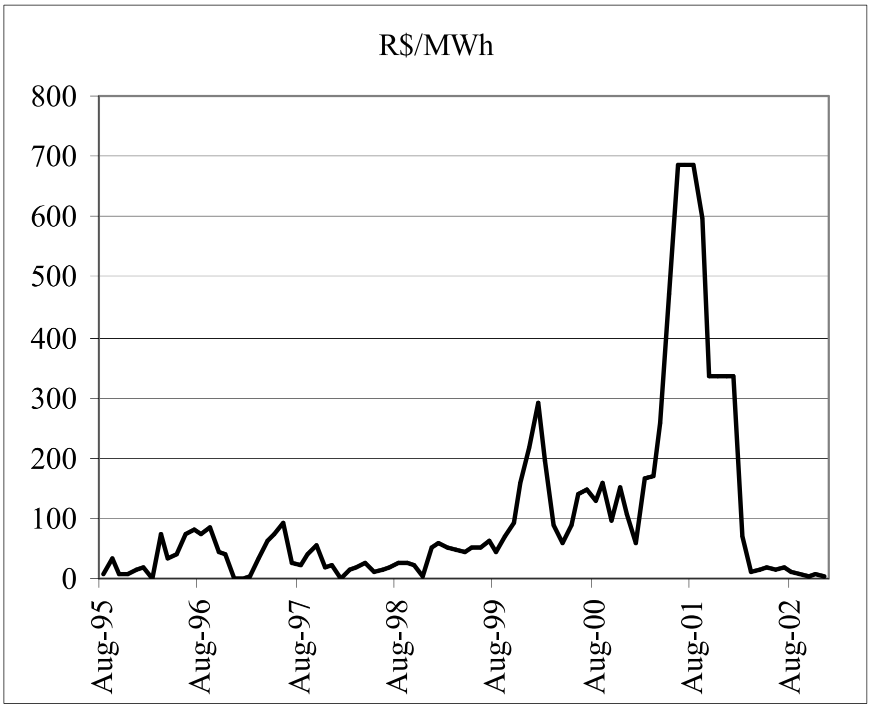

Figure 4: Spot Price and Year Effects

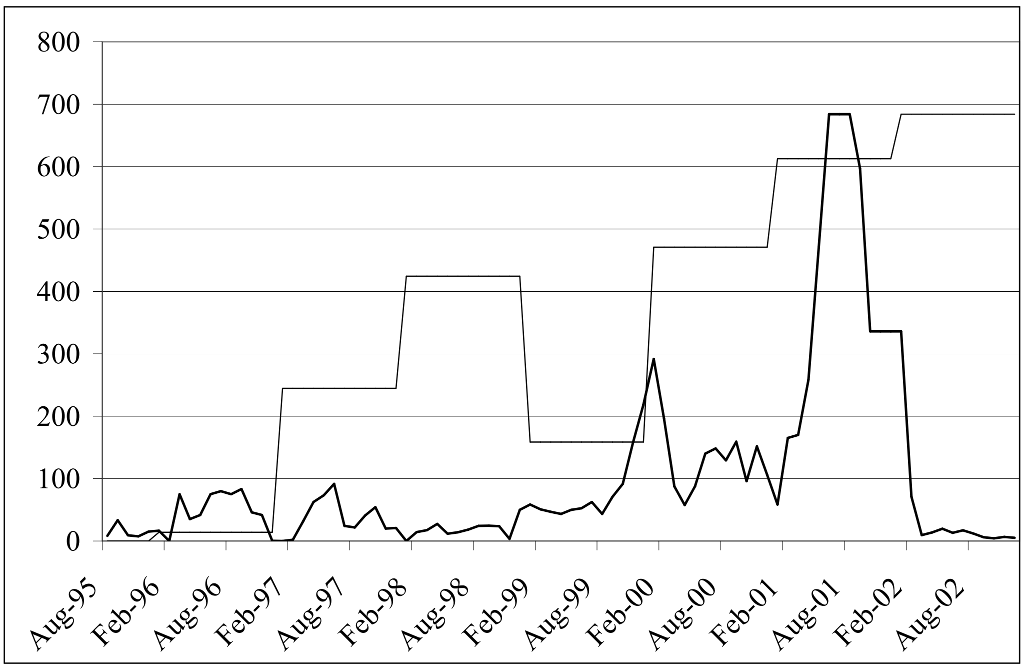

Figure 5: Uruguay Basin