Generation Investment and Access Regulation in the Electricity Market: a Real Option Approach*

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Abstract

Nodal pricing complemented with financial transmission rights is considered as the state of art system to organize electricity markets. Nodal spot prices reflect physical constraints of electricity systems, guaranteeing the efficient use of networks and minimizing production cost. Financial transmission rights can be used as a hedge against transportation risks without giving incumbent firms the opportunity to foreclose the market by withholding capacity. This paper studies how this regulatory framework affects investment decisions in generation: Does nodal pricing, with or without financial transmission rights, lead to efficient investment levels? If not, is there any other regulatory scheme that restores efficiency?

Using a two-period stochastic entry game with two firms, we show that the socially optimal investment level depends on the option value of waiting for potentially more efficient production technologies. Under nodal pricing, firms are unable to internalize this option value, which leads to over-investments. Moreover, nodal pricing complemented with financial transmission rights leads to even more over-investment. The adoption of physical property rights can restore efficiency but it raises market power concerns. Alternatively, the regulator can counteract private investment incentives by imposing an appropriate tax on the incumbent firm.

Keywords: Congestion management, access regulation, counter-trading, real option theory, electricity markets.
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Contents

1 Introduction

With nodal spot pricing, electricity prices reflect physical constraints, i.e. the capacity limits of the transmission lines and Kirchoff's laws, and hence, scarcity of the transmission network. In the short run, nodal spot prices therefore ensure optimal usage of the transmission network. However, in the long run, nodal spot prices alone may not lead to optimal investment decisions by generators due to hold-up problems (e.g. sufficient real option value of waiting) and substantial externality effects (e.g. first mover advantage). For instance, a generation firm might not invest in new capacity in an export constrained area if it fears that a future, more efficient entrant will build generation capacity at the same location and outbid him for obtaining access to the network, or it may invest too much if investment makes the incumbent much more efficient than the possible entrants. A possible market failure is the lack of well-defined long term transmission rights: if historical access rights are not recognized by the regulator, this can lead to a hold-up problem in generation investment, and hence, socially inefficient investment levels by forward looking firms.

This paper examines whether this hold-up problem exists and investigates under which conditions private incentives for investment coincide with the social ones. We study how investment decisions in regulation are affected by different regulatory frameworks, and address the following questions: Does nodal pricing, with and without financial transmission rights, lead to an efficient outcome? If not, is there any other regulatory scheme that restores efficiency?

We develop a two-stage entry game with two firms: a first-mover (the incumbent) and a second mover (the entrant). In period 1, the first-mover firm decides whether to invest immediately or to delay its investment until period 2. The entrant firm only decides on investing in period 2. The entrant is assumed to be more efficient (in terms of its marginal cost of production) than the incumbent. The fixed cost of the entrant firm is stochastic and is revealed at the end of period 1. We derive the social optimal investment levels and compare the efficiency of the nodal pricing method under four different transmission rights schemes.

We find that in the social optimum firms should take into account the real option value of waiting, as future entrants might have lower investment cost levels. Under the standard nodal spot pricing model which only recognizes short term transmission rights, firms do not internalize this option value, and will enter too often. Hence, there is no hold-up problem, but rather a problem of over-investment. Adding financial transmission rights to the market design reduces the investment risk, but does not solve the problem of over-investment. Physical transmission rights can be used to solve the over-investment problem, but they lead to obvious concerns on the abuse of market power.

The remainder of this paper is organized as follows. Section 2 offers some background on nodal spot pricing, long-term transmission rights, real option theory, and hold-up problems. Section 3 presents the framework of our model while section 4 investigates the efficiency of nodal spot pricing, counter-trading and tradable financial and physical transmission rights. We explore whether using nodal spot prices may lead to suboptimal investment decisions by generators, and how the introduction of financial and physical property rights affects the incentives for investment. Section 5 concludes.

2 Literature Review

This section reviews on the concepts of nodal spot pricing, long-term transmission rights, real option theory, and hold-up. The former two are discussed in subsection 2.1, and the latter two in subsection 2.2.

2.1 Nodal Spot Pricing and Long-term Transmission Rights

The concept of nodal spot pricing on electricity markets originates from the work of Schweppe et al. (1988). In the short run, nodal spot pricing ensures that regional prices reflect physical constraints (i.e. congestion on the transmission lines), and hence, scarcity on the transmission network. Hogan (1992) argues that nodal spot pricing must be integrated with a policy for long-term access and contracts for firm transmission service. In theory, a series of efficient short-term markets for transmission capacity and energy can lead to the long-term optimal outcome, but this would only be possible in an ideal world, without lumpy investments and with constant returns to scale in transmission and generation capacity. Investors in long-lived, fixed facilities of the type and scale of major electric power plants will be reluctant to make commitments with no more than a promise of being allowed to participate in a short-term spot market for transmission services. Hence, practical development of long-term deals with the associated capacity and energy payments must include some form of firm right to power transmission. Ideally, these rights will be combined with a usage pricing mechanism that reinforces the incentives for open access, and efficient secondary markets for long-term transmission rights (Hogan, 1992). Such rights can take the form of point-to-point transmission rights (Hogan, 2003).

Lapuerta and Harris (2004) stress that locational signals using transmission tariffs should reflect no more and no less than the cost to the transmission network of a siting decision. Furthermore, the authors state that a UK study (Oxera, 2003) estimates that around 80% of the benefits of locational signals result from the long-term effect of plant siting. Hence, only 20% comes from the short-term optimization of existing plants. They argue that since siting a power plant is a long-term decision, locational signals need to be predictable and credible in the long-run. According to the authors, these locational signals can take the form of long-term transmission contracts or connection charges. Rious et al. (2009) perform a theoretical study on the efficiency of a two-part tariff to coordinate the location of power plants with lumpy transmission investments. They show that, in the case of nodal spot pricing and no network tariff ("one-part tariff" case), the differences in nodal prices are insufficient to incentivize the power plants to locate efficiently. This occurs because the lumpiness in transmission investment greatly decreases the differences in nodal prices that should signal congestion. When including the network tariff to give long-run locational incentives to the generators, however, the social optimal is reached.

Joskow and Tirole (2000) show that financial transmission rights allow firms to hedge risks without giving generation firms the opportunity to "foreclose" the market by withholding transmission rights. Such financial transmission rights in effect ensure an efficient secondary market for transmission access. Physical transmission rights, on the other hand, could give incumbent firms an opportunity to block entry in certain energy markets, and are therefore less efficient.

In our paper, we will not only look at the effects of congestion management and financial transmission rights on the efficient short term operation of the electricity market, but also on the long term investment decisions of generators. Our method is comparable to that of Rious et al. (2009), with the exception that we focus on investments in the generation market and assume transmission investments to be fixed. We add to this paper by introducing entry and uncertainty to the generation market, and allowing transmission rights to be traded.

2.2 Real Option Theory and Hold-up

The two-stage setup of our model allows the first-mover firm to decide on investing or delaying its investment decision until period 2 (when the fixed cost of the entrant is already revealed). The uncertainty over the future rewards in the first period explains the real option value of waiting which determines the investment decision of the first mover. Furthermore, the entry of a possibly more efficient entrant might create a hold-up problem for the first-mover as the latter might fear that the entrant could outbid him for obtaining access to the network. The following serves as a short review on real option theory and hold-up.

In general, investment can be defined as the act of incurring an immediate cost in the expectation of future rewards (Dixit and Pindyck, 1996). Considering that most investments are (at least partly) irreversible, strategic interactions are very important determinants of investment decisions. Real option theory states that the opportunity to invest in a project is analogous to a call option on the investment opportunity (Grenadier, 2000). When there exists only one firm in the market, the only important determinant for its investment decision is the level of uncertainty (over the return of investment) and the information that is provided (which allows for the partial prediction of the return of investment). If a project's future revenues are quite uncertain, the firm will decide to wait for further information that specifies clearer the project's future cash flows while taking into account the growth rate and discount rate of the investment decision.

This situation changes when more firms enter the market. In this case, each firm should take into account the strategies of its rivals. For example, if the investment decisions of firms are related to entrance in a new market, even if the uncertainty is high, a firm may decide to invest immediately in order to avoid being pre-empted by its rivals. Such strategic interactions among firms make them deviate from the standard model of real option theory: as competition increases, the real option value decreases. Cournot competition is often related to strategic substitutes: If one firm decides to produces a larger quantity, this results in a lower equilibrium quantity for its competitors. Bertrand competition is typically related to strategic complements: A reduction in price by one firm will be matched by a profit-maximizing price cut by the competitor. As we move from Cournot to Bertrand competition the real option value of waiting decreases (Smit and Trigeorgis, 2004).

According to Leahy (1993), Kogan (2001), and Grenadier (2002), competition erodes option values and pushes firms back to the standard maximization of net present value as the possibility to delay investments decreases. Conversely, Novy-Marx (2007) states that competition does not necessarily lead to the failure of real option theory. He shows that in industries in which opportunity costs (the cost of waiting) and heterogeneity (not only in demand, i.e. heterogeneous products, but also in supply, i.e. cost differences) are important, real option values are significant, and therefore, investments are delayed.

The use of short term contracts in long term relationships can give rise to problems. A major problem that has been widely discussed in the literature (see for example the seminal contribution of Williamson, 1979) is known as the hold-up problem. The hold-up problem can be described as a situation in which the network operator may not be allowed to sell long-term access rights to the incumbent. It is widely recognized that hold-up problems, whether by counterparties or government entities, can lead to under-investment, and that credible long-term contracts (or vertical integration) are efficient responses to these problems (see for example Joskow, 1987, Hart, 1995). The hold-up effect can be illustrated as follows: Consider a market with demand function $D(p)$ (monotonously decreasing in price p), and suppose that a firm produces homogeneous product A and makes an investment on a new and more efficient technology which exhibits constant returns to scale and reduces the firm's production cost, but that, once installed, it has a resale value less than its original cost (there is a sunk cost, say, F). Hence, the original cost can only be recovered if the price behavior of the firm results in a sufficiently high price-cost margin. If $\hat{p}$ is the price of product A set by the firm, and c the marginal production cost, then the sufficient condition for the investment is:

$$(\hat{p} - c)D(p) - F \geq 0 \tag{1}$$

It is obvious that, the intervention of a regulator (after the investment is made), f.e. pushing down the market price level, will lead to the reduction of the firm's incentives for investment in the new technology. Depending on how restrictive the regulator's pricing policy is, the firm may not be able to recover its original cost (f.e. if it is obliged to adopt marginal cost pricing behavior) and will not have any incentive to invest. On the contrary, under a long-term contract agreement, the regulator and the firm can agree and commit on a price-cap scheme which makes the investment on the new technology viable.

3 Model

Consider an electricity market with one small low cost area in the North (N) and one large high cost area in the South (S) that are connected with a transmission line that has a capacity of $K = 1$ (see Figure 1). The high cost area has a marginal cost of production, which is normalized to 1, ($C_S = 1$) while for the marginal cost in the North: $C_N < 1$.

We develop a two stage stochastic investment model in which two firms, the incumbent (I) and the entrant (E) consider the possibility to invest in the Northern location N. Both firms can produce exactly 1 unit of electricity and only one firm can use the transmission line at each moment[1].

The incumbent and the entrant have marginal costs $c, d \in [0, 1]$, and fixed costs $F, G \in [0, 1]$, respectively. We assume that the entrant has a lower marginal cost than the incumbent ($c > d$). For instance, the entrant might be a wind producer with marginal cost equal to zero. The fixed cost of the entrant G is treated as a discrete stochastic variable which takes a low value G^L or a high value G^H following the distribution:

[1]So that welfare is maximized.

$$G = \begin{cases} G^L & \text{with probability } 1\text{-}\lambda \\ G^H & \text{with probability } \lambda \end{cases} \tag{2}$$

where $G^L < G^H$. The distribution of G is of common knowledge. The fixed cost of the incumbent is deterministic. We further assume that the total cost of the entrant and the incumbent is lower than the marginal production cost in the South, in order to focus on the strategic effects between the two firms. In the absence of transmission constraints, both firms would enter the market. Strategic interactions between the firms imply that the investment strategy of the one firm affects the profit of the other and therefore its investment decision.

3.1 Timing of the Game

We develop a two period game. The timing is as follows (see Figure 2):

- Period 1: The incumbent chooses whether to enter the market by paying a fixed cost F or to wait.
- Between the first and the second period, nature draws the fixed cost G of the entrant.
- Period 2: The entrant and the incumbent (in the case that it did not enter the market in the first period) simultaneously decide whether they will enter the market. Note that when the incumbent enters in period 1, it remains in the market for the second period of the game without having the option to exit, so, in this case, in the second period, there is only one entry decision (to be made by the entrant). Once the entry decisions are taken, firms choose their pricing behavior in the resulting Bertrand game, and the most efficient firm (in terms of total cost of investment) ends up using the transmission line.

Thus, the stochastic variable of interest is the entrance cost G which determines the efficiency of the entrant and consequently its competitiveness in the resulting Bertrand game . Period 1 and 2 have a duration of D_1 and D_2. The second period is normalized to ($D_2 = 1$), and the first period is shorter than the second period. Both firms discount profits with the discount factor $\delta < 1$.

3.2 Further Assumptions

We assume that the most efficient entrant has a lower total cost than the marginal cost of the incumbent, $G^L + d < c$, while the least efficient entrant has a higher cost, $c < G^H + d$, (i.e. we restrict our attention to the non-trivial cases of the model). In addition, we assume that the incumbent cannot profitably enter the market unless it is active during the second period . Hence, its first period profit, ($\mu \equiv D_1(C_S - c)$ is smaller than its investment cost F, ($\mu < F$)[2]. However, the incumbent's first period profit outweighs the extra capital costs of investing in period 1 (F) instead of delaying the investments until period 2 (δF). Summarizing:

$$F > \mu > (1 - \delta)F \tag{3}$$

[2]Which is true for small D_1.

3.3 Different Scenarios

In what follows, we examine five scenarios. The scenarios differ in whether we consider long-term or short term-transmission rights and whether these rights are physical or financial.

Under nodal pricing, the differences in locational prices and congestion charges can vary widely over time. This variation in price creates a demand by risk-averse agents for instruments to hedge against price fluctuations. One of these instruments is called financial transmission rights. These rights give the holders a claim on the congestion rents created when the network is constrained, and in effect allows them to hedge against variations in the difference between nodal prices and the associated congestion charges. Another instrument to hedge against price fluctuations is a physical transmission right. Under this approach, congestion pricing is decentralized and only the holders of physical transmission rights are allowed to use congested transmission lines. Once a firm has such a physical right, there is no additional charge for using the congested line. In this case, the markets for physical transmission rights determine the market-clearing prices for congestion (Joskow and Tirole, 2000).

- Nodal Pricing: There are no long-term transmission rights. Each period firms compete for network access. In the second period, the incumbent competes *á* la Bertrand with the entrant, and in the equilibrium the most efficient firm uses the transmission line.

- Physical Transmission Rights Before Entry (hereafter: PTR before entry): The long-term physical property rights give the incumbent the right to withhold access to transmission property even when it decides not to enter the market. The property rights of the transmission line are sold to the incumbent before period 1 and are valid for both periods unconditional on the incumbent's decision to enter the market in the first period. In the second period, the incumbent has the opportunity to resell the property rights to the entrant or to block its entry .

- Physical Transmission Rights After Entry (hereafter: PTR after entry): In this scenario the incumbent is allowed to buy the transmission rights only after it entered the market in period 1. Furthermore, if it invests in period 1, it resells the property rights to the entrant only in the case that the latter enters in period 2. If the incumbent does not enter in period 1, no rights are allocated in period 1, and the property rights are bought by the most efficient player in period 2.

- Financial Transmission Rights (FTR): Before period 1, the incumbent obtains FTR. FTR insure the incumbent against price changes in the transmission rights market. In the case that the incumbent is less efficient than the entrant in the period 2, it is compensated for not producing.

- Counter-trading: Both firms receive the right to obtain a price C_S for their electricity regardless of the amount of congestion. Hence, in period 2, the most efficient firm uses the transmission line, while the other firm is fully compensated for not using the transmission line in period 2.

Note that the scenarios of financial transmission rights and counter-trading are quite similar (compensation to the incumbent for not producing) and the basic distinction between them comes from the fact that in the former, if the entrant is the least efficient firm, it does not receive any compensation for not producing in period 2 while under counter-trading it does receive compensation.

4 Analysis

This section investigates the effects of access regulation on both the incumbent's and the entrant's investment strategies and compare them with the socially optimal outcome. For this reason, we first develop the social planner's investment policy to serve as a benchmark case. Subsequently, westudy the private incentives for investment for each of the different scenarios described above. We begin our analysis with a deterministic description of the social planner's policiy before we proceed with the introduction investment under uncertainty.

4.1 Socially Optimal Investment

4.1.1 Socially Optimal Investment under Certainty

Investment in the first period is socially optimal if the social benefit from investing is larger than the benefit from waiting. The social planner's payoff equals the sum of the incumbent and the entrant's profits and the benefit received by the Transmission System Operator (TSO). For a given demand, the optimal social outcome corresponds to the minimum total production cost.

Firstly, if the social planner knows that the fixed cost of entrant is very low ($G < c - d$), then the total cost of the entrant (in the second period) is less than the marginal cost of the incumbent. Hence, in this case, investment by the incumbent in the first period is not socially optimal. This is because, irrespective of the investment strategy of the incumbent in the first period, the entrant always invests in the second period. If the incumbent decided to produce in period 1, it would generate insufficient benefit μ to outweigh the investment cost F. Thus, the total cost is minimized when the incumbent does not invest in period 1. Analytically, if B_I and B_W are the social benefits from investing and waiting in period 1, respectively, we have:

$$B_I = \mu - F + \delta(1 - d - G) \quad (4)$$
$$B_W = \delta(1 - d - G) \quad (5)$$

so, considering that $\mu - F < 0$, we can conclude that the social benefit is higher when the incumbent does not invest in the first period.

Secondly, if the fixed cost of the entrant, G, is intermediate,such that $c - d < G < c + F - d$, the entrant will only enter the market to reduce the total production costs if the incumbent has not yet entered. In this case, the social benefits B_I and B_W are given by:

$$B_I = \mu - F + \delta(1 - c) \ / \quad (6)$$
$$B_W = \delta(1 - d - G) \quad (7)$$

from which we conclude that it is only socially optimal to invest in the first period when the

	$G < c - d$	$c - d < G < c + F - d$	$c + F - d < G$
B_I	$\mu - F + \delta(1 - d - G)$	$\mu - F + \delta(1 - c)$	$\mu - F + \delta(1 - c)$
B_W	$\delta(1 - d - G)$	$\delta(1 - d - G)$	$\delta(1 - c - F)$
Decision	Never invest	Invest as long as $F < \mu + \delta(d + G^H - c)$	Always invest

Table 1: Social Planner under Certainty

following holds:

$$d + G > c + \frac{F - \mu}{\delta} \tag{8}$$

Namely, only if the total cost of the entrant is larger than the cost of the incumbent in period 2 – its production cost c plus the share of its fixed cost F that is not covered by the first period's investment, $(\frac{F-\mu}{\delta})$ – investment in the first period is optimal.

Finally, if the fixed cost of the entrant is high, $(c + F < G + d)$, then the incumbent is always more efficient than the entrant (regardless whether it will invest in the first period or not). Hence, the social planner's benefits will be either:

$$B_I = \mu - F + \delta(1 - c) \ / \tag{9}$$
$$B_W = \delta(1 - c - F) \tag{10}$$

Taking into account condition (8) we conclude that investment, in the first period, is socially optimal in this case.

Summarizing, if the entrant has a sufficiently low investment cost $(G < c + \frac{F-\mu}{\delta} - d)$, then investment in the first period is not socially optimal. Otherwise, investment in the first period is socially optimal.

4.1.2 Socially Optimal Investment under Uncertainty

We proceed by allowing the entrant's investment cost, G, to be a discrete stochastic variable given by 2. We assume that G^L is sufficiently low, in order to capture the value of the real option of the incumbent to wait ($G^L < c - d$). Furthermore, we assume that for the high realization the fixed cost, $G^H > c - d$.

The optimal action of the incumbent depends on the total costs of the incumbent and the entrant. We consider two different cases, A,B. In case A, the incumbent is more efficient than the high cost entrant, even in total cost terms, or $F < G^H + d - c$. In case B, $F > G^H + d - c$, the high cost entrant is more efficient than the incumbent in total cost terms, but once the investment cost of the incumbent is sunk, investment by the high cost entrant does not lower total production costs. Finally, we define $F^{AB} \equiv G^H + d - c$ as the investment cost which makes the total cost of the incumbent equal to the total cost of the high cost entrant.

In case A, the payoff of the social planner from investment in the first period, B_I, and from no investment in period 1, B_W^A, are:

	$F < F^{AB}$	$F > F^{AB}$
When to invest?	$F < F^{A}_{SP}$	$F < F^{B}_{SP}$

Note that $F^{A}_{SP} = \frac{\mu}{1-\lambda\delta}$, $F^{AB} = G^H + d - c$ and $F^{B}_{SP} = (1-\lambda\delta)F^{A}_{SP} + \lambda\delta F^{AB}$.

Table 2: Social Planner under Uncertainty

Case A:

$$B_I = \mu - F + \delta[(1-\lambda)(1-d-G^L) + \lambda(1-c)] \; / \tag{11}$$

$$B^A_W = \delta[(1-\lambda)(1-d-G^L) + \lambda(1-c-F)] \tag{12}$$

Comparing both equations, investment in the first period will only be optimal if the investment costs of the incumbent are not too high, or:

$$F < F^A_{SP} \equiv \frac{\mu}{1-\lambda\delta} \tag{13}$$

Notice that F^A_{SP} is a positive number as $\lambda \leq 1$ and $\delta \leq 1$, and an increasing function of λ. This reflects the fact that as the probability of having a high cost entrant increases, investment in the first period is socially optimal for a larger range of F.

In case B, $F + c > G^H + d$, the incumbent is less efficient than the high cost entrant in total cost terms. The payoff of the social planner for the case of investment in the first period (B_I) remains the same . The payoff from no investment in period 1 is now given by:

$$B^B_W = \delta[(1-\lambda)(1-d-G^L) + \lambda(1-d-G^H)] \tag{14}$$

which does not depend on the incumbent's costs c and F.

In this case, investment is socially optimal only if:

$$F < F^B_{SP} \equiv \mu + \delta\lambda(d + G^H - c) \tag{15}$$

Again the critical investment cost for the incumbent is increasing in λ. Hence, as it becomes more likely that the entrant is a high cost firm, it is more likely to be socially optimal for the incumbent to enter in the first stage.

The social planner's investment strategy can be summarized as follows: "invest in period 1 if $F < F^A_{SP}$, and $F < G^H + d - c$, or if $F < F^B_{SP}$ and $F_I > F + c_E - c_I$. Note that $F^B_{SP} = (1-\lambda\delta)F^A_{SP} + \lambda\delta F^{AB}$, hence F^B_{SP} is always closer to F^{AB} than to F^A_{SP}. Thus, two type of outcomes can be considered:

- Situation 1: $0 < F^A_{SP} < F^{AB}$: The incumbent should invest as long as $F < F^A_{SP}$.
- Situation 2: $F^{AB} < F^A$: The incumbent should invest as long as $F < F^B_{SP}$.

	$F < F^{AB}$	$F > F^{AB}$
When to invest?	$F < F^{A}_{SP}$	$F < F^{B}_{NP}$
Note that $F^{B}_{NP} = F^{B}_{SP} + \delta\lambda(1 - G^{H} - d)$.		

Table 3: Nodal Pricing: Uncertainty

4.2 Nodal Pricing

In this section, we study the private incentives for investment in the case that the market is characterized by short-term transmission rights (nodal pricing). In period 1, the rights to use the transmission line are given to the incumbent if he decides to enter, and in period 2 they are awarded to the most efficient firm that is present in the market.

In case A $(F < F^{AB})$, the investment incentives for the social planner and the incumbent coincide. This is because the investment decision of the incumbent does not affect the pay-off of either the entrant or the network operator. Hence, the investment decision does not create an externality. In other words, the payoff of the incumbent determines its investment decision, but is also the determinant of the social planner's investment policy. Hence, the payoff of the incumbent from investing and waiting in period 1 are given by:

$$\begin{aligned} \Pi_I &= \mu - F + \delta\lambda(1 - c) \\ \Pi^{A}_{W} &= \delta\lambda(1 - c - F) \end{aligned} \tag{16}$$

Notice that $\Pi_I < B_I$ and $\Pi_W < B_W$ in case A, but that $\Pi_I - \Pi^{A}_{W} = B_I - B^{A}_{W}$ and $\frac{\vartheta \Pi_i}{\vartheta F} = \frac{\vartheta B_i}{\vartheta F}$ for $i = I, W$. Note that the ctitical value of the incumbent's fixed cost which separates investment from waiting region equals F^{A}_{SP}. Hence, under condition $F^{A}_{SP} > F^{AB}$ the incumbent finds optimal to invest for all values of $F < F^{AB}$, while, if $F^{A}_{SP} < F^{AB}$, there is a region of values of F for which the incumbent prefers to wait and not to invest $(F \in [F^{A}_{SP}, F^{AB}])$.

In case B, $(F > F^{AB})$ the situation is different. In this case, investments will create a negative externality for the entrant. Therefore, the incumbent's incentives to invest are higher than in the social optimum. The incumbent's payoffs from investing and waiting in period 1 are given by:

Case B:

$$\begin{aligned} \Pi_I &= \mu - F + \delta\lambda(1 - c) \\ \Pi^{B}_{W} &= 0 \end{aligned} \tag{17}$$

Thus, the incumbent finds it optimal to invest in the first period when $F < F^{B}_{NP}$ where:

$$F^{B}_{NP} = \mu + \delta\lambda(1 - c) \tag{18}$$

Obviously, $F^{B}_{NP} > F^{B}_{SP}$ which shows that the incumbent deviates from the social optimum and over-invests (when $F > F^{B}_{NP}$) due to its substantial first mover advantage. This implies that the incumbent is more willing to undertake risky investments than the social planner. This behavior can be attributed to the fact that the social planner takes into account the lost value of the entrant caused by the investment of the incumbent in period 1, while the incumbent ignores this externality effect and focuses only on the maximization of its own profit. In other words, the first mover advantage of the incumbent dominates the real option value of waiting (and hence, there is no hold-up problem) .

To correct the incentives of the incumbent and induce him to behave according to the social optimum, it is necessary to impose an entry tax t on the incumbent, or to subsidize the entrant[3]. Both measures will affect (in the same way) the cost asymmetry between the firms.

The optimal size of tax can be calculated by solving the equation for case B: $\Pi_I - \Pi_W^B - t = B_I - B_W^B$ which determines that the size of the tax equals the negative externality on the entrant:

$$t = \delta\lambda(1 - d - G^H) \tag{19}$$

Summarizing, four cases for private and social investment decisions can be distinguished:

1. Case $F_{SP}^A < F^{AB}$ and $F^{AB} < F_{NP}^B$[4]. Investment in the first period is socially optimal for values $F \in [0, F_{SP}^A]$, while for higher values it is not. Under nodal pricing the incumbent will invest for all values $F \in [0, F_{SP}^A] \cup [F^{AB}, F_{NP}^B]$. Hence, there are two domains of F for which investment is optimal. This second investment region of the incumbent's optimal strategy reveals its tendency to invest too much. Investments for those values of F increase total production cost for society, and increase the profit of the incumbent at the expense of a lower profit for the entrant and the network owner.

2. Case $F_{SP}^A < F_{NP}^B < F^{AB}$. The social optimal investment decisions, and the private investment levels under nodal pricing are identical. The private and social incentives for investment coincide (investment is optimal only in the domain $F \in [0, F_{SP}^A]$).

3. Case $F_{SP}^A > F^{AB}$ and $F_{SP}^B < 1$. It is socially optimal to invest as long as the investment costs are sufficiently small: $F \in [0, F_{SP}^B]$. For the incumbent under nodal pricing, investments are optimal as long as $F \in [0, \min\{F_{NP}^B, 1\}]$. Hence under nodal pricing there is over-investment.

4. Case $F_{SP}^B > 1$. It is socially and privately optimal to always invest in the first stage. Private and social incentives for investment coincides. The incumbent and the social planner invest for all values of $F \in [0, 1]$.

We can conclude that in the case that the incumbent is more efficient than the high cost entrant regardless of its entry decision in period 1 (this is the case where $F < F^{AB}$), it invests according to social planner's investment behavior. On the other hand, when the incumbent finds that investment in the first period is necessary in order to be more efficient than the high cost entrant in the second period ($F > F^{AB}$), it has more incentives to invest than is socially optimal.

[3]The sale of the short term transmission rights at a particular positive price cannot be considered as an effective policy measure due to the fact that it will result the reduction of the entrant's incentives to enter the market in period 2.

[4]It can be shown that if $F_{SP}^A < F^{AB}$, it immediately follows that $F_{NP}^B < 1$.

	$G < c - d$	$c - d < G < c + F - d$	$c + F - d < G$
Π_I Π_W	$\mu - F + \delta(1 - d - G) - P$ $\delta(1 - d - G) - P$	$\mu - F + \delta(1 - c) - P$ $\delta(1 - d - \mathrm{G}) - P$	$\mu - F + \delta(1 - c) - P$ $\delta(1 - c - F) - P$
Decision	Never Invest	Invest as long as $F < \mu + \delta(d + G^H - c)$	Always invest
O_I O_W	P P	P P	P P

Table 4: Physical property rights before entry: Incumbent and outsider's profit: Certainty

4.3 Nodal Pricing with Physical Property Rights

In the case that long term transmission rights are given to the incumbent, it has the opportunity to resale them to the entrant in the case that the entrant decides to enter the market. We distinct two different cases. In the first one, property rights are given to the incumbent conditional on its entry in the first period (PTR after entry case) while in the second they are given beforehand (PTR before entry case).

In the PTR before entry case we denote by P the price that the incumbent pays in order to buy the property rights for both periods of the game. According to our framework, in the second period, the property rights are held by the most efficient firm. Hence, in the case that the most efficient firm in the second period is the entrant, it buys the property rights from the incumbent at a price that equals its expected profit from the second period investment. In other words the incumbent is in the advantageous position to extract all the entrant's profit from its second period investment. In overall, the entrant has zero profit either it enters or not while incumbent captures all the profit of entrant additionally to the profit it earns from its own production. The transmission system operator (TSO) has always as a payoff the benefit from selling the property rights to the incumbent before the first period. The payoffs of the participating players are presented in Table 1 (where by $O_I$and $O_W$we denote the payoffs of the entrant and the TSO for the cases that the incumbent invest and waits in the first period): Notice that the incentives of the incumbent for investment coincides with those of the social planner. For the domain $G < c - d$ investment is not optimal while for $c + F - d < G$ it is. In the case of the domain $c - d < G < c + F - d$ investment is optimal only when $d + G - c > \frac{F - \mu}{\delta}$.

Thus, there is not need for further investigation of the investment policies of incumbent and social planner for the domains of realizations of G. Incumbent invests always optimally. Moreover, notice that the incentives for private investment do not depend on the price of the transmission rights set by the TSO. This implies that the TSO can maximize its benefit by increasing the selling price of the property rights provided that the accumulated profit of the incumbent for all the possible realizations of G remains non-negative (which is the necessary condition so that its incentives for investment are not distorted). Despite the fact that PRT before entry certify the socially optimal behavior of the incumbent, they may be hard to be implemented due to market power concerns. For instance, the incumbent has the opportunity to withhold the property rights without investing at the first period and then sell them to the entrant.

In the case that the incumbent buys the property rights only if it enters in the first period

	$G < c - d$	$c - d < G < c + F - d$	$c + F - d < G$
Π_1	$\mu - F + \delta(1 - \mathrm{d} - G) - P$	$\mu - F + \delta(1 - c) - P$	$\mu - F + \delta(1 - c) - P$
Π_2	0	0	$\delta(1 - c - F) - P'$
Decision	Never Invest	Invest as long as $F < \mu + \delta(d + G^H - c)$	Always invest
O_1	P	P	P
O_2	$\delta(1 - d - G)$	$\delta(1 - d - G)$	P'

Table 5: Physical property rights after entry: Incumbent and outsider's profit: Certainty

(PRT after entry) we observe deviations of incumbent's policy from social optimum. Again, the most efficient player in the second period use the transmission line. Let P be the price that the property rights are sold in the first period to the incumbent if it decides to enter the market. In the case that the incumbent enters in the first period, it will resell the property rights in the second period to the entrant extracting all its profit only if the entrant is more efficient. If the incumbent chooses not to invest in the first period, then the most efficient firm buys the property rights in the second period at price P'. The payoffs of the players is presented in Table 2:

Notice that the prices P and P' do not affect the social incentives for investment while they can be proven basic determinants of the incumbent's investment strategy. For $P = P' = 0$ the incumbent invests too much, in all the possible domains of realization of G. Property rights give to the incumbent an extra motivation to invest due to the fact that it can extract all the profit of the entrant in the case that the entrant is more efficient. Therefore, uncertainty does not affect its incentives to invest and the first mover advantage dominates the real option of waiting.

An important question that is raised is: what are the optimal prices P, P' of the transmission rights in order to induce the incumbent to invest according to the social optimal outcome?

We consider firstly that G^H lies in the domain B. Then, the only determinant policy parameter of incumbent's strategy is price P. The payoffs Π_{I} and Π_{W} of the incumbent becomes:

$$\begin{aligned} \Pi_I &= a - F_I + \delta[(1-p)(1 - c_E - F_E^L) + p(1 - c_I)] - P \\ \Pi_W^B &= 0 \end{aligned} \tag{20}$$

So, the optimal price P is determined by solving the equation $\Pi_I = B_I - B_W^B$ which gives:

$$P^{opt} = \delta[1 - d - (1-p)G^L - pG^H] \tag{21}$$

which corresponds to the expected profit that the entrant would have gained if it had free access to the transmission line. Thus, the optimal price extracts from the incumbent's payoff the amount corresponds to the expected reselling revenue. Notice that P^{opt} is decreasing function of probability p. As the probability of a high cost entrant increases, the optimal price P^{opt} decreases as the incumbent is more probable to be the most efficient firm in the second period.

As for the case when F_E^H lies in the domain A, then the optimal response of the regulator can be derived not only by estimating the optimal value for P but by finding the optimal combination (P, P') of the prices that the incumbent should pay in the first and in the second period (in the

	$G < c - d$	$c - d < G < c + F - d$	$c + F - d < G$
Π_I	$\mu - F + \delta(1-c) - P$	$\mu - F + \delta(1-c) - P$	$\mu - F + \delta(1-c) - P$
Π_W	$\delta(1-c-F) - P$	$\delta(1-c-F) - P$	$\delta(1-c-F) - P$
Decision	Never Invest	Invest as long as $F < \mu + \delta(d + G^H - c)$	Always invest
O_I	$P - \delta(d + G - c_I)$	P	P
O_W	$P - \delta(d + G - c - F)$	$P - \delta(d + G - c - F)$	P

Table 6: Financial property rights: Incumbent and outsider's profit: Certainty

case it does not enter at the first period). The payoffs of the incumbent in both cases will be:

$$\begin{aligned} \Pi_I &= \mu - F + \delta[(1-p)(1-d-G^L) + p(1-c)] - P \\ \Pi_W^A &= \delta p(1-c-F-P') \end{aligned} \tag{22}$$

Thus the optimal combination (P, P') is estimated by the solution of the equation $\Pi_I - \Pi_W^A = B_I - B_W^A$:

$$P^{opt} - \delta p P'^{opt} = \delta(1-p)(1-d-G^L) \tag{23}$$

Due to the fact the negative externality that is exerted to the entrant resulting the reduction of its incentives for investment, it is reasonable to set the policy variable $P' = 0$ in order not to distort further entrant's incentives. Thus, the optimal price of the transmission property rights, P^{opt} becomes:

$$P^{opt} = \delta(1-p)(1-d-G^L) \tag{24}$$

which equals to expected reselling price of the property rights from the incumbent to the entrant in the case that the second mover is a low cost firm.

4.4 Nodal Pricing with Financial Property Rights

When the incumbent holds financial transmission rights, it is not in the position to block the investment of the entrant in the second period but in the cases that the entrant is more efficient and enters, it receives a compensation that equals the profit it forgoes (due to the investment of the entrant). If P is the sale price of the financial transmission rights, the payoffs of the incumbent, the entrant and the TSO are presented in Table 3:

From Table 3, it becomes clear that the incumbent has incentives to invest for every possible realization of G. The price P does not affect its incentives, so, it deviates from the social optimum by over-investing. Moreover, notice that the private incentives for investment do not depend on the probability λ that the entrant is a high cost firm. In other words, financial property rights move incumbent's investment strategy far way from the efficient outcome. On the other hand, the entrant under-invests in the second period having less incentives from investment than in the optimum due to the negative externality effect exerted on it by the incumbent.

In the case that G^H lies in the domain B the imposition of appropriate tax T to the incumbent

	$G < c - d$	$c - d < G < c + F - d$	$c + F - d < G$
Π_I	$\mu - F + \delta(1 - c)$	$\mu - F + \delta(1 - c)$	$\mu - F + \delta(1 - c)$
Π_W	$\delta(1 - c - F)$	$\delta(1 - c - F)$	$\delta(1 - c - F)$
Decision	Never Invest	Invest as long as $F < a + \delta(d + G^H - c)$	Always invest
O_1	$-\delta(d + G - c)$	0	0
O_2	$-\delta(d + G - c - F)$	$-\delta(d + G - c - F)$	0

Table 7: Pay-off Counter trading: Incumbent and outsider's profit: Certainty

conditional on its entry in period 1, can restore the social optimum. The incumbent's payoffs for both the cases it invests in the first period (and being taxed) and it does not (no tax) are:

$$\begin{aligned} \Pi_I &= \mu - F + \delta(1 - c) - P - T \\ \Pi_W^B &= \delta(1 - c - F) - P \end{aligned} \tag{25}$$

By solving the equation $\Pi_I - \Pi_W^B = B_I - B_W^B$ we find the optimal tax T^{opt} that corrects private incentives for investment:

$$T_{opt}^B = \delta[(1 - p)F + p(c + F - d - G^H)] \tag{26}$$

In the same way when F_E^H lies in the domain A (note that$\Pi_W^A = \Pi_W^B$), the optimal tax policy is:

$$T_{opt}^A = \delta(1 - p)F < T_{opt}^B \tag{27}$$

Notice that in the domain B the less efficient the high cost entrant is, the lower the tax levied on the incumbent will be. In other words, the optimal tax under financial rights depends on the degree of asymmetry between the two firms. In contrast, in the domain A, the optimal tax does not depend on the expected investment cost of the entrant.

4.5 Counter-trading

In the case of counter-trading both firms enter the market (the incumbent in the first period and the entrant in the second period) and compensation is given to the less efficient firm for not producing during the second period[5]. In each case, the compensations equals to profit that the less efficient firm forgoes for being inactive in the market. The payoffs of the incumbent and the entrant are presented in Table 4:

From 7, it can be concluded that the incumbent's incentives for investment are above the social optimum (for the incumbent counter-trading system and financial transmission rights corresponds to the same investment behavior). The incumbent invests in the first period for every value of F. Notice that the entrant has also increased incentives (in comparison to the cases above) to invest in the second period. In fact, the incumbent's behavior does not exert any externality to the entrant's investment strategy. As for the TSO's payoff, it is in every case

[5] Namely, compensation is not given only to the incumbent when it does not produce as in the case of financial transmission rights but also to the entrant in the case that it is less efficient.

negative due to the compensation it provides to the least efficient firm in the second period.

5 Conclusions

In conclusion, in almost all the institutional settings we examined, real option value of waiting does not counterbalances the first mover advantage resulting the over-investment of the first mover. The probability λ that the entrant is a high cost firm, the level of the discount factor δ and the realization of the entrant's fixed cost are the parameters that define and separate investment and no investment regions.

As we showed, in the social optimum the first mover firm should take into account the real option value of waiting, as the future entrant might have lower investment cost levels. Under the standard nodal spot pricing model, the first mover does not internalize this option value, and will enter too often deviating from the social optimum. Making transmission rights financial, indeed reduces the incentives of firms to foreclose the market (short-term efficiency), but leads to over-entry (long-term inefficiency). The first mover's incentives for investment increase even further away from the efficient outcome. The application of the counter-trading method does not seem to improve efficiency but it eliminates the strategic effects between the firms as both of them enter the market. The introduction of physical property rights that are given to the first mover before its entry decision is the only way for the restoration of the efficiency, without any additional policy measure taken by the regulator, as both firms invest according to social planner's investment program. However, such a scheme raises concerns about the increased market power of the first mover. Notice that if the physical property rights are given to the incumbent under the condition that it enters the market, the first mover advantage become large and the incumbent over-invests.

The above results reveal the important role of the regulator in restoring the social optimum. In the case of standard nodal pricing method, the regulator has two options: Either it can tax the entry of the first mover or before the first mover builds a new power plant, it can commit to subsidize the second mover. The optimal level of tax that can induce incumbent to invest according to the social optimal outcome is equal to the expected payoff of the high cost entrant. Notice that in the case of physical property rights given after the entry, the incumbent can be taxed implicitly by increasing the price that it pays to obtain the transmission rights. In this case, the social optimum can be reached if the regulator taxes the incumbent only in the case that it enters the market. On the contrary under financial transmission rights scheme or the counter-trading method, the price of the rights cannot be used as a policy instrument as it does not affect the incentives of incumbent for investment. The incentives for over-investment in the financial transmission rights case can be corrected by imposing a tax on the incumbent that depends on its fixed cost and the cost asymmetry between the two firms.

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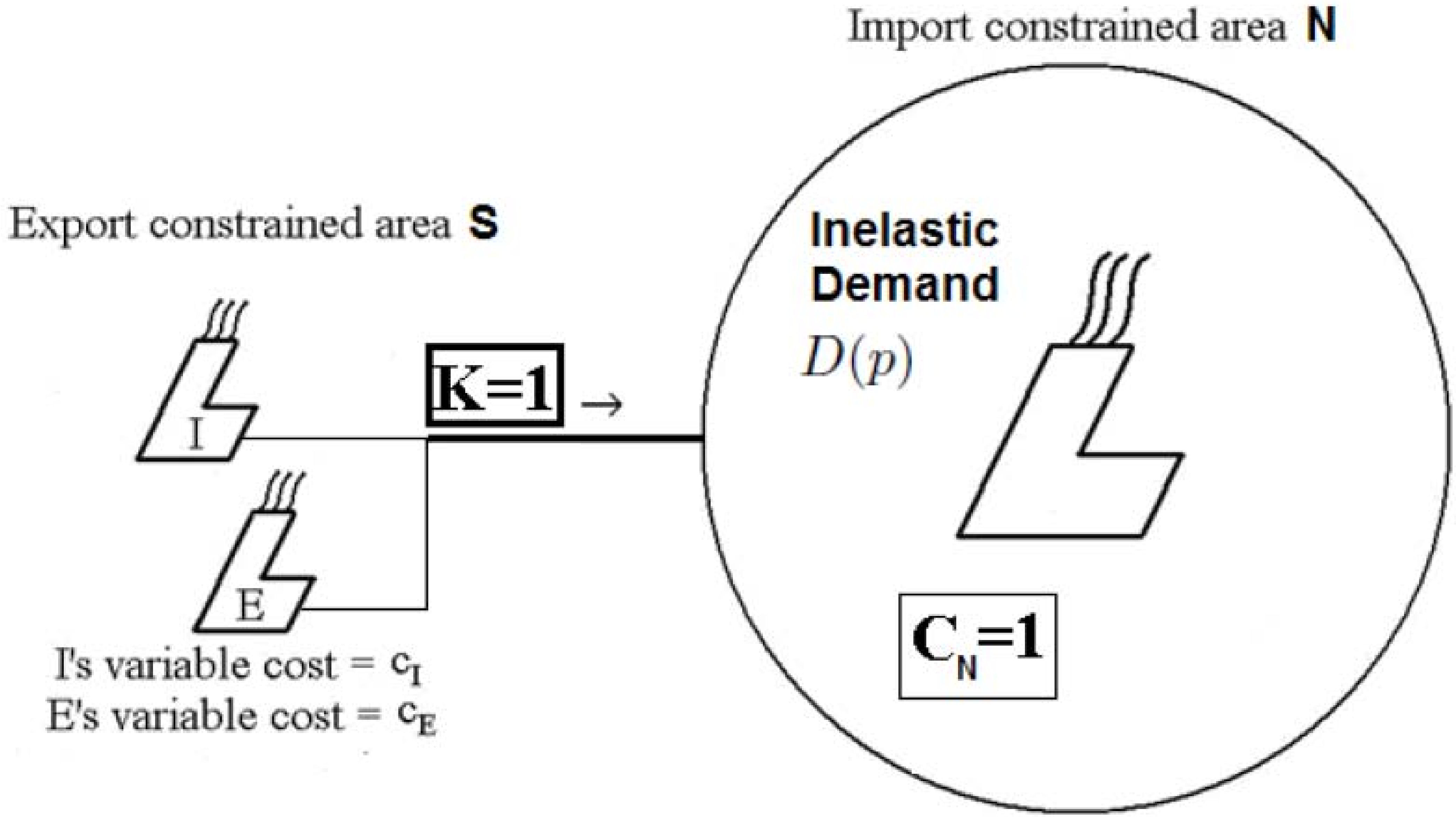

Figure 1: The electricity market

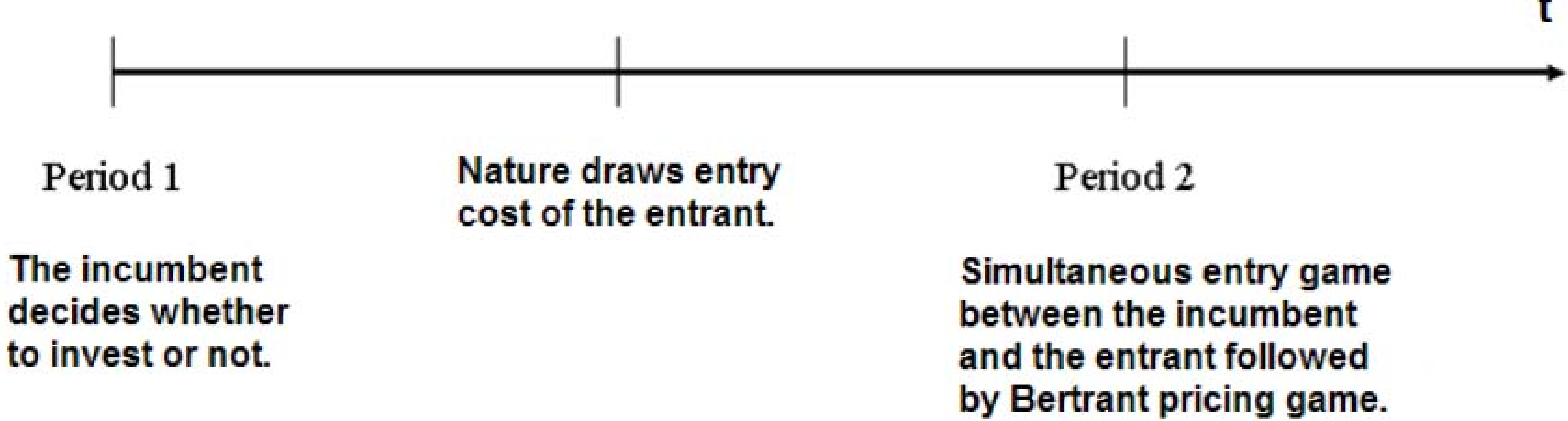

Figure 2: Time line of the entry game