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 that is applied in large number of electricity markets worldwide. 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 henge 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 restore efficiency?

Using a two-period stochastic entry game with two firms, we show that the socially optimal investment level depends on an option value of waiting for potentially more efficient future technologies. Nodal pricing, unable to capture this option value, leads to over-investments. Moreover, nodal pricing with financial transmission rights leads to even more over-investments. 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 first mover firm.

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

JEL-codes: L94, L13, C72, D43.

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 constraint 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 (even for risk neutral firms), 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 we address the questions: Does nodal pricing, with and without financial transmission rights, lead to efficient outcome? If not, is there any other regulatory scheme that restore 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 or not in period 2. The entrant is assumed more efficient (in terms of marginal cost of production) than the incumbent. The fixed cost of the entrant firm is stochastic and it is revealed at the end of period 1/beginning of period 2. 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, firms do not internalize this option value, and will enter too often. Hence, there is no hold-up problem, but rather the one 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 of abuses 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 right affect 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 in our model.

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 stage two, when the fixed cost of entrant is revealed. The uncertainty over the future rewards in the first period justify 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.

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 (and allows 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 future cash flows from the project 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 of 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 (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 problem, whether by counterparties or government entities, can lead to underinvestment, 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 more efficient technology which exhibits constant returns to scale and reduces firm's production cost, but that, once installed, has a resale value less than its original cost (there is a sunk cost). Hence, the original cost can only be recovered if the price behavior of the firm results sufficient 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:

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

It is obvious that, the intervention of the regulator (after the investment by the firm is made) by pushing down the market price level lead to the reduction of 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 (for example if it is obliged to adopt marginal cost pricing behavior) so, it has no incentives for investment.

On the contrary, during 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 The Model

Consider an electricity market with one small export constrained area N and one large import constrained S that are connected with a transmission line that has capacity of $K = 1$ (see Figure 1). The import constrained area has a marginal cost of production $C_S = 1$ which is larger than the marginal cost C_N of the export constrained area.

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 location N of the market.

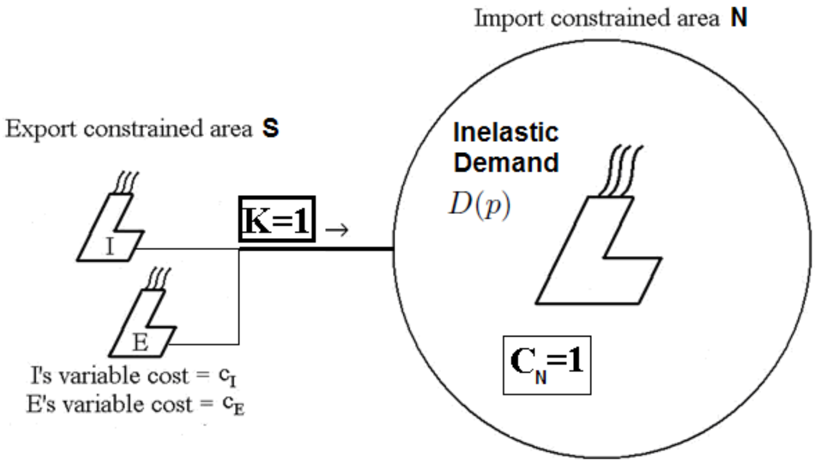

Figure 1: The electricity market

Both firms can produce only 1 unit of electricity and only the most efficient firm can use the transmission line at the each moment[1].

The entrant and the incumbent have marginal costs $c_E, c_I \in [0,1]$ and fixed costs $F_E, F_I \in [0,1]$ respectively. We assume that $c_I > c_E$, $C_N - c_E - F_E > 0$ and $C_N - c_I - F_I > 0$ in order to focus on the strategic effects between the two firms. In absence of such interactions firms will have entered 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.

The fixed cost of the entrant F_E is treated as a discrete stochastic variable which takes a low value F_E^L or a high value F_E^H following the distribution:

[1] So that welfare is maximized

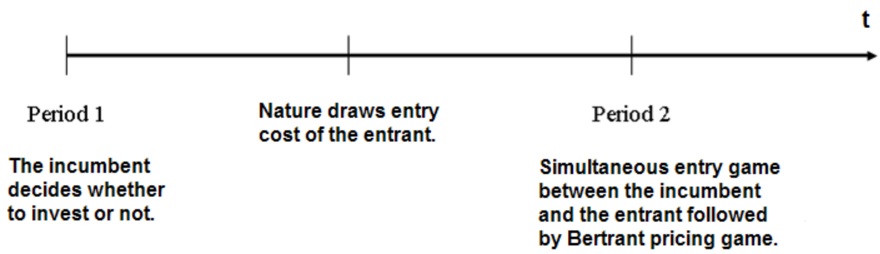

Figure 2: Time line of the entry game

$$F_E = \begin{cases} F_E^L & \text{with probability 1-p} \\ F_E^H & \text{with probability p} \end{cases} \quad (1)$$

where $F_E^L < F_E^H$. The distribution of F_E is of common knowledge.

Moreover, if T_1 and $T_2 = 1$ are the durations of the two periods then the profit of incumbent if it invests at the first period will be $a = \frac{T_1}{T_1+T_2}(C_N - c_I)$. Notice that we consider in the analysis below that $T_1 < 1$[2].

3.1 Timing of the Game

The timing of the game is as follows (see Figure 2):

- Period 1: The incumbent chooses whether to enter the market by paying a fixed cost F_I or to wait. In the case it enters the market, its first period's payoff is $a - F_I$.

[2]This consideration is necessary because one of our assumptions as we will see later is that the first mover cannot recover all its cost from the first period only:$a < F_I$

- Between the first and the second period, nature draws the fixed cost F_E of the entrant.
- Period 2: The entrant and the incumbent (in the case that it did not enter the market at 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 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 F_E which determines the efficiency of the entrant and consequently its competitiveness in the resulting Bertrand game (considering that $c_I > c_E$).

3.2 Further Assumptions

We assume that the most efficient entrant has a lower total cost than the marginal cost of the incumbent, $F_E^L + c_E < c_I$ while the least efficient entrant has a higher cost, $c_I < F_E^H + c_E$.

In addition, we assume that the incumbent cannot profitably enter the market unless it is active during the second period (at least in some states of the world). Hence, $a - F_I < 0$[3]. Considering that both firms adopt the same discount factor δ for their future profits, we further assume that the profit of the incumbent in period 1 outweighs the capital costs incurred in period 1 (i.e. interest payments on capital invested during that period), so:

[3]This can be justified by the consideration that the length of the first period is smaller than that of the period 2.

$$a > (1 - \delta)F_I \tag{2}$$

which defines as a threshold condition for the share of F_I that should be paid in the second period. In other words, this condition implies that incumbent recovers some part of its fixed cost (a) at the first period and the remainder in the second period ($\frac{F_I - a}{\delta}$).

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:

- 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 property rights that 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 for both periods) unconditional on its decision to enter or not 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 (depending on the equilibrium outcome).

- Physical Transmission Rights After Entry (hereafter: PTR after entry): The incumbent is allowed to buy the transmission rights only after it entered the market in period 1.

Analytically, 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, 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 insures 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_N for their electricity independently on 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 does not receive any compensation for not producing in period 2 while under counter trading it receives..

4 Analysis

This section investigates the effect of access regulation on the incumbent and entrant investment's strategies and compare it with the socially optimal outcome. For this reason we develop initially as benchmark case the social planner's investment policy and then we study private incentives for investment for each of the different scenarios described above. We begin our analysis with a deterministic description of social planner's policies before we proceed to the introduction of uncertainty on investment strategies.

4.1 Social Optimal investment under Certainty

Investment in the first period is socially optimal when 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 given demand, the optimal social outcome corresponds to the minimum total production cost.

To begin with, if the social planner knows that the cost of entrant is in the domain $F_E < c_I - c_E$, the total cost of entrant (in the second period) is less than the marginal cost of the incumbent. Then, investment at 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 a to outweigh the investment cost F_I. Thus, the total cost is minimized when the incumbent does not invest in period 1. Analytically, if B_1 and B_2 are the social benefits from investing and waiting in the period 1 respectively, we have:

$$
\begin{aligned}
B_1 &= a - F_I + \delta(1 - c_E - F_E) \\
B_2 &= \delta(1 - c_E - F_E)
\end{aligned}
$$

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

If the fixed cost of the entrant, F_E is in the domain $c_I < F_E + c_E < c_I + F_I$ then, the social benefits B_1 and B_2 will be:

$$\begin{aligned} B_1 &= a - F_I + \delta(1 - c_I) \\ B_2 &= \delta(1 - c_E - F_E) \end{aligned}$$

from which we conclude that the critical condition socially optimal investment in the first period is:

$$c_E + F_E > c_I + \frac{F_I - a}{\delta} \tag{3}$$

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

As for the domain $c_I + F_I < F_E + c_E$ firm I is always more efficient than firm E (regardless whether it will invest in the first period or not). Thus, social planner's benefits under each of the two cases will be:

$$\begin{aligned} B_1 &= a - F_I + \delta(1 - c_I) \\ B_2 &= \delta(1 - c_I - F_I) \end{aligned}$$

Thus, taking into account condition (2) we conclude that investment is socially optimal in this domain.

To sum up (see Figure 3), condition (3) separates the F_E domain into two regions: The

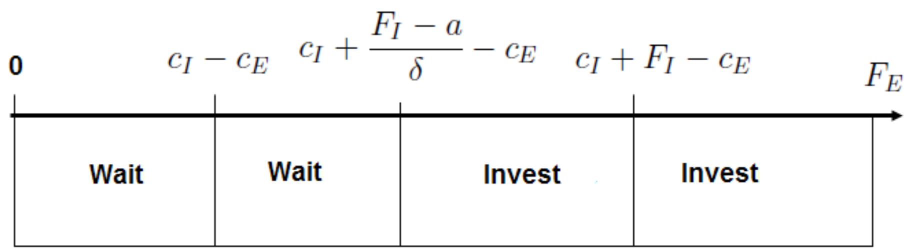

Figure 3: Socially optimal investment regions for different domains of fixed cost of the entrant.

region $c_E + F_E < c_I + \frac{F_I - a}{\delta}$ where investment in the first period is not socially optimal and the region $c_E + F_E > c_I + \frac{F_I - a}{\delta}$ where the option value of waiting is lower and investment in the first period is socially optimal.

4.2 Socially Optimal Investment Under Uncertainty

We proceed by allowing the cost F_E to be a discrete stochastic variable given by (1). We restrict F_E^L in the domain $[0, c_I - c_E]$ in order to capture the value of the real option of the incumbent to wait and we allow the high cost F_E^H to lie in two different domains, the domains A: $[c_I + F_I - c_E, 1]$ and the domain B: $(c_I - c_E, c_I + F_I - c_E]$.

In the case that F_E^H lies in the domain A, the payoff of the social planner from investment in the first period, B_1 and from no investment in period 1, B_2^A will be:

$$\begin{aligned} B_1 &= a - F_I + \delta[(1-p)(1 - c_E - F_E^L) + p(1 - c_I)] \\ B_2^A &= \delta[(1-p)(1 - c_E - F_E^L) + p(1 - c_I - F_I)] \end{aligned} \tag{4}$$

Thus, investment in the first period is socially optimal under the condition:

$$F_I > \frac{F_I - a}{p\delta} \tag{5}$$

As we showed above, when F_E^L is realized, investment in period 1 is not optimal ex post. When the cost F_E^H is realized, the opposite holds. Thus, whether investment in the first period is socially optimal depends on the probability p that the entrant is a high cost firm. Notice that the condition (5) is more restrictive than condition (2). When the probability p is low, it is highly probable that the entrant is more efficient than the incumbent. Thus, condition (5) is satisfied only when a large part of F_I is covered in the first period of investment. When the probability p increases, condition (5) becomes less restrictive due to the fact that the entrant is likely to be less efficient than the incumbent. By rewriting condition (5), investment in the first period is optimal as long as F_I is smaller than the cut off value F_I^A[4].:

$$F_I < F_I^A \equiv \frac{a}{1 - p\delta} \tag{6}$$

Notice that F_I^A is an increasing function of p. This reflects the fact that as the probability for having a high cost entrant increases, investment in the first period is socially optimal for larger range of F_I. In the rest of the analysis we restrict our attention to values $F_I^A \geq 0 \Rightarrow p\delta \leq 1$.

When the high cost entrant is relatively efficient (F_E^H lies within the domain B), the payoff of the social planner for the case of investment in the first period remains the same (B_1) while

[4]Recall that F_E^H lies in the domain A. This implies that $F_I < F_E^H + c_E - c_I$ and therefore that if $F_I^A > F_E^H + c_E - c_I$ investment is optimal in all the domain A.

in the "no investment" case it becomes:

$$B_2^B = \delta[(1-p)(1-c_E-F_E^L)+p(1-c_E-F_E^H)] \tag{7}$$

which does not depend on the incumbent's costs c_I and F_I.

In this case, investment is socially optimal only if:

$$F_E^H + c_E - c_I > \frac{F_I - a}{p\delta} \tag{8}$$

which is more restrictive than condition (5) as the range of F_I values for which investment in the first period is optimal is lower than that in the domain A. This can be attributed to the fact that the high cost entrant is more efficient than in the previous case, so, the incumbent invest only when the probability p is sufficiently large.

If inequality (8) is not satisfied, then there is again a critical value F_I^B below which investment in the first period is socially optimal.

$$F_I < F_I^B = a + \delta p(c_E + F_E^H - c_I) \tag{9}$$

which implies that if $F_E^H + c_E - c_I < F_I^B < 1$, investment is not optimal in all the domain.

We can summarize the social planner's investment strategy as F_I increases from 0 to 1. Figure 4, Figure 5 and Figure 6 represent the three different investment policies of social planner (in the 'y-axis' B_i denotes the the benefit of the social planner, where $i = 1$ refers to the investment case and $i = 2$ in the 'no investment' case. In the 'x-axis' values of F_I are presented. For values $F_I \in (0, F_I^A)$ investment in the first period is socially optimal).

To begin with, consider firstly the case in which $F_I \in [0, c_E + F_E^H - c_I]$. For small values

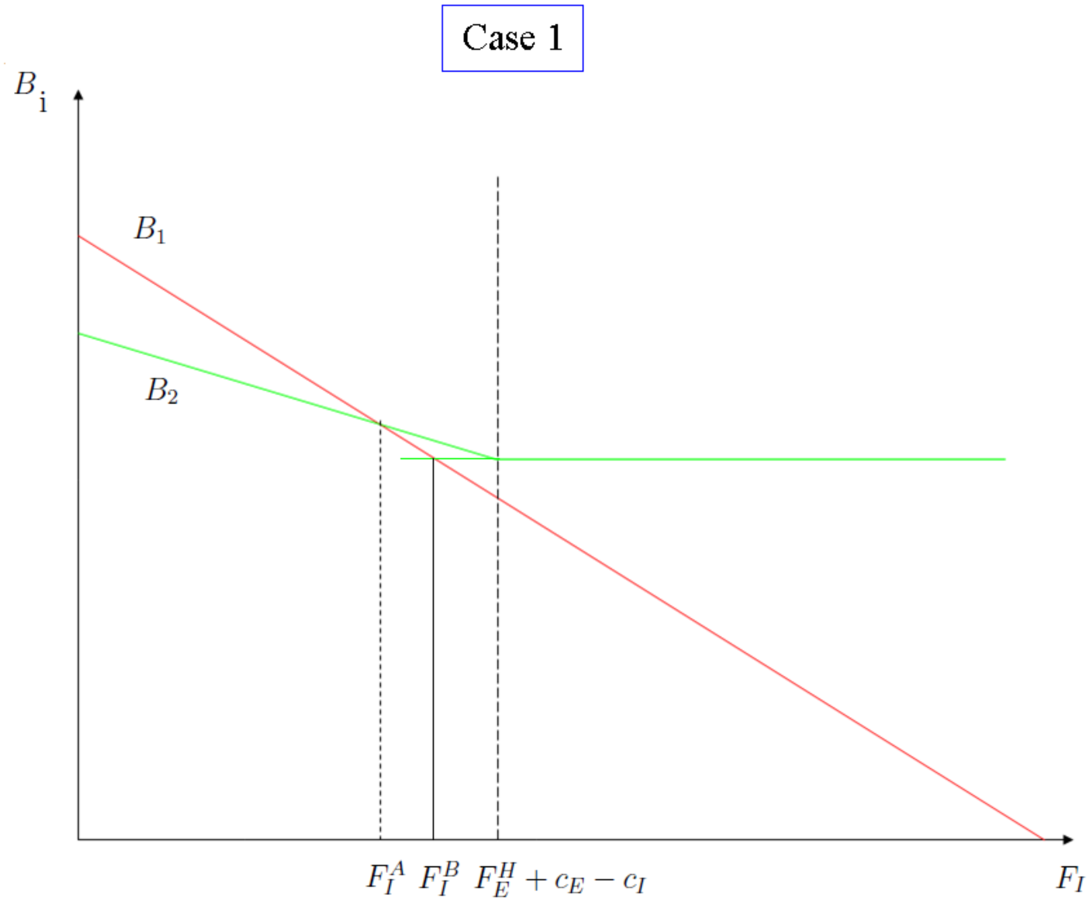

Figure 4: The social benefits for the 'investment' and the 'no investment' case when condition $F_I < F_I^A$ is not satisfied for all $F_I \in [0, c_E + F_E^H - c_I]$, or, in other words, when $F_I^A < c_E + F_E^H - c_I$.

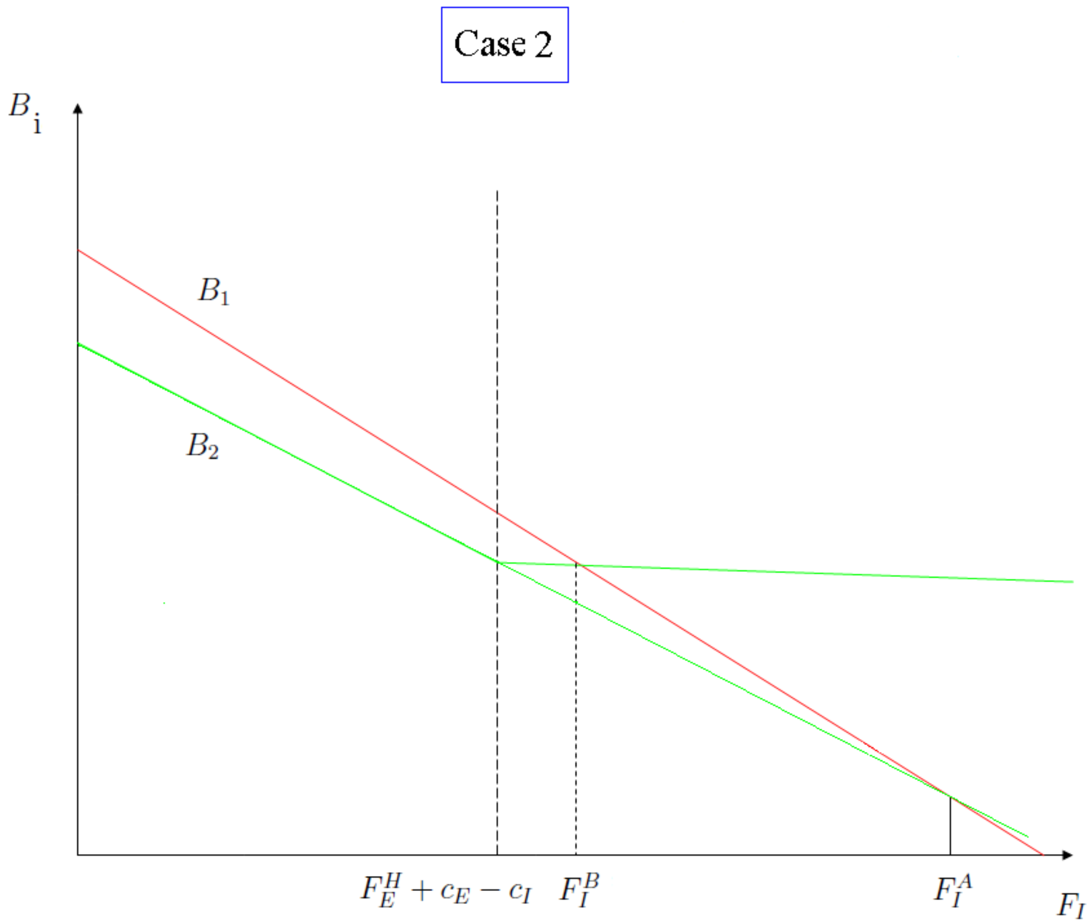

Figure 5: The social benefits for the 'investment' and the 'no investment' case when $F_I^A > c_E + F_E^H - c_I$ but, $c_E + F_E^H - c_I < F_I^B < 1$. The two axis are the same as in Figure 4. For values $F_I \in (0, F_I^B)$ investment in the first period is socially optimal.

Case 3

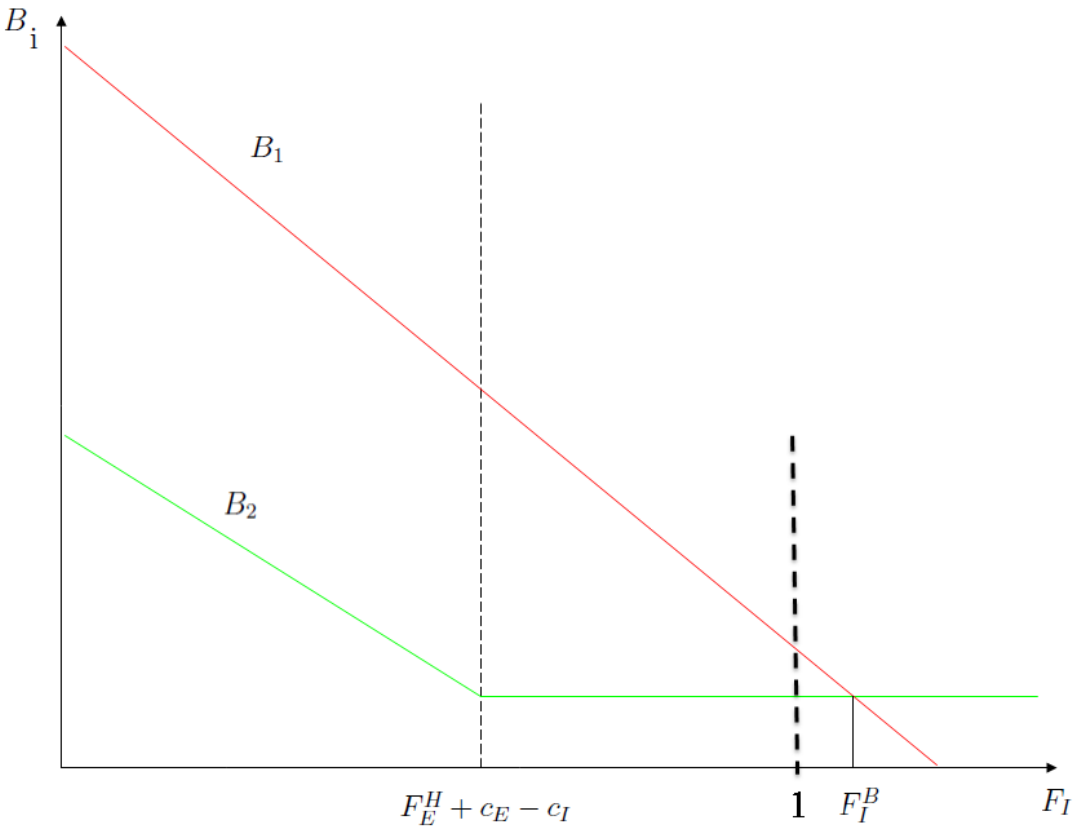

Figure 6: The social benefits for the 'investment' and the 'no investment' case when when $F_I^A > c_E + F_E^H - c_I$ and $F_I^B > 1$. The two axis are the same as in Figure 4. Investment in the first period is socially optimal for all possible values of F_I.

of F_I investment is always optimal[5]. As the F_I increases, the payoff of the social planner in both "investment" and "no investment" case declines monotonously. The discount factor δ and the probability p determine the negative effect of the increasing incumbent's fixed cost to the payoff B_2^A while the slope of B_1 curve with respect to F_I is constant (-1). Thus, if condition (5) is satisfied for all the values of $F_I \in [0, c_E + F_E^H - c_I]$, there is not intersection between the two curves and $F_I^A > c_E + F_E^H - c_I$[6]. In the case that condition (5) is violated, there is a critical value $F_I = F_I^A < c_E + F_E^H - c_I$ above which investment is not optimal.

For values $F_I \in [c_E + F_E^H - c_I, 1]$, the payoff of "no investment" case becomes independent from F_I. This corresponds to a B_2^B curve with constant slope equal to zero. The slope of B_1 curve remains the same. In this case, intersection inside this domain occurs only when the condition $c_E + F_E^H - c_I < F_I^B < 1$ is satisfied.

Therefore, there are three different cases for the determination of the socially optimal investment regions:

- Case 1: We have $0 < F_I^A < c_E + F_E^H - c_I$. Then the curves intersect once in the domain $F_I \in [0, c_E + F_E^H - c_I]$ at the point F_I^A signaling the initiation of the waiting region (see Figure 4).

- Case 2: Condition $F_I < F_I^A$ is satisfied for all $F_I \in [0, c_E + F_E^H - c_I]$ ($F_I^A > c_E + F_E^H - c_I$) while $c_E + F_E^H - c_I < F_I^B < 1$. In this case, a region in which investment is not optimal is defined within the domain $F_I \in [c_E + F_E^H - c_I, 1]$ (see Figure 5).

- Case 3: Condition $F_I < F_I^A$ is satisfied for all $F_I \in [0, c_E + F_E^H - c_I]$ and condition $F_I < F_I^B$ is satisfied for all values of $F_I \in [c_E + F_E^H - c_I, 1]$ ($F_I^B > 1$). Then, investment

[5]Notice that expression (4) implies that for $F_I = 0$ we have $B_1(F_I = 0) > B_2^A(F_I = 0)$.

[6]Note that the intersection point defines the initiation of the region in which investment in the first period is not optimal. Therefore, if there is no intersection point, investment is optimal in all the specified domain.

is optimal and there is not any meeting point of the curves B_1 and B_2^A or B_2^B in the domain $F_I \in (0,1)$ (see Figure 6).

4.3 Nodal Pricing

In this section we study the private incentives for investment in the case that transmission rights are short term. 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 enters the market.

If F_E^H lies in the domain A then the incentives for investment for social planner and the incumbent coincides. This is because the entrant and the TSO have the same payoff regardless the decision of the incumbent to invest or to wait. Thus, the payoff of the incumbent is not only the basic determinant of its investment decisions but also the determinant of social planner's investment policy. The payoff of the incumbent in the investment and the 'no investment' case will be:

$$\begin{aligned} \Pi_1 &= a - F_I + \delta p(1 - c_I) \\ \Pi_2^A &= \delta p(1 - c_I - F_I) \end{aligned} \tag{10}$$

Notice that $\Pi_1 < B_1$ and $\Pi_2^A < B_2^A$, but $\Pi_1 - \Pi_2^A = B_1 - B_2^A$ and $\frac{\vartheta \Pi_i}{\vartheta F_I} = \frac{\vartheta B_i}{\vartheta F_I}$ for i=1,2. Hence, under condition $F_I^A > c_E + F_E^H - c_I$ the incumbent finds optimal to invest for all values of $F_I \in [0, c_E + F_E^H - c_I]$, while, if $F_I^A < c_E + F_E^H - c_I$, there is a regions of values of F_I in which the incumbent prefers to wait and not to invest.

The situation is not the same if F_E^H lies in the domain B. In this case due to the fact that incumbent is unable to capture the negative externality effect he exerts to the entrant's entry decision (through its first period investment decision), its incentives to invest are higher than in the social optimum.

The incumbent's payoffs for "investment" and "no investment" case are:

$$\begin{aligned} \Pi_1 &= a - F_I + \delta p(1 - c_I) \\ \Pi_2^B &= 0 \end{aligned} \tag{11}$$

Thus, incumbent finds optimal to invest in the first period for every value of $F_I \in [c_E + F_E^H - c_I, 1]$ when the following condition is satisfied:

$$1 - c_I > \frac{F_I - a}{p\delta} \tag{12}$$

where $1 - c_I > F_I$.

We observe that condition (12) is less restrictive than conditions (5) and (8) and it can satisfied even when (5) and (8) are violated (notice that in the case condition (5) or (8) is satisfied, so does condition (12)). Under condition (12), incumbent finds optimal to invest for all the possible values of F_I and deviates from the social optimal behavior. This implies that the incumbent is more willing to undertake risky investments than the social planner. This can be attributed to the fact that social planner takes into account the lost value of the entrant through the investment of the incumbent in period 1 while incumbent ignores this externality effect and focus 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 there is no any hold up problem.

Condition (12) can be rewritten as $F_I < F_I^{cr}$ where:

$$F_I^{cr} = a + \delta p(1 - c_I) \tag{13}$$

is the critical value of fixed cost of the incumbent above which investment is not optimal. Thus, for $F_I^{cr} > 1$, investment is optimal in all the domain.

Obviously, $F_I^{cr} > F_I^B$ which shows that the incumbent deviates from the social optimum and overinvests (when $F_I > F_I^B$) due to its substantial first mover advantage[7].

In order to correct the incentives of the incumbent and induce him to behave according to the social optimum it is necessary to impose a tax T on it or equivalently to subsidize the entrant[8]. Both of those measures will affect the cost asymmetry between the firms.

The optimal size of tax can be calculated by solving the equation $\Pi_1 - \Pi_2^B - T = B_1 - B_2^B$ which gives that the size of the tax equals the negative externality on the entrant:

$$T^{opt} = \delta p(1 - c_E - F_E^H) \tag{14}$$

To sum up, the three different cases for private investment decisions are presented in Figures 7-9. To make the comparison between social and private incentives easier, we include

[7]Recall that we consider $C_S - c_E - F_E > 0$ for every realization of F_E and with $C_S < 1$.

[8]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.

the social benefit curves (in the 'y-axis' Π_i and B_i denote the the benefit of the incumbent and the social planner respectively, where $i = 1$ refers to the investment case and $i = 2$ in the 'no investment' case. The 'x-axis' presents values of F_I).

- Case $F_I^A < c_E + F_E^H - c_I$: From (6) we can write:

$$\begin{aligned} \frac{a}{1-p\delta} &< c_E + F_E^H - c_I \\ \Rightarrow a - p\delta c_I &< (c_E + F_E^H)(1-p\delta) - c_I < 1 - p\delta \\ \Rightarrow a + p\delta(1-c_I) &< 1 \end{aligned}$$

from where we conclude that $F_I^{cr} < 1$.

Hence, we can distinguish two cases that are presented in Figure 7 and Figure 8. In Figure 7 depicts the case that $\Pi_1(F_I = c_E + F_E^H - c_I) > 0$ (which implies that $c_E + F_E^H - c_I < F_I^{cr} < 1$) while Figure 8 refers to the case $\Pi_1(F_I = c_E + F_E^H - c_I) < 0$ (or equivalently $\delta p < \frac{c_E + F_E^H - c_I - a}{1-c_I}$ or $F_I^{cr} < c_E + F_E^H - c_I$). Social planner's investment behavior in both cases is the same. Investment is optimal for values $F_I \in [0, F_I^A]$ while for higher values investment in the first period is not optimal. As for the incumbent, in the case that $\Pi_1(F_I = c_E + F_E^H - c_I) > 0$ there are two different domains of F_I for which investment is optimal. The first one coincides with that of the social planner ($F_I \in [0, F_I^A]$). In the domain $F_I \in [F_I^A, c_E + F_E^H - c_I]$, the incumbent prefers to wait instead of investing. The second domain in which investment is optimal is $F_I \in [c_E + F_E^H - c_I], F_I^{cr}$ while for higher values of F_I the incumbent prefers not to invest. This second investment region of the incumbent's optimal strategy reveals its tendency to invest too much, more than the social optimum. In the case that $\Pi_1(F_I = c_E + F_E^H - c_I) < 0$ private and social incentives for investment coincide (investment is optimal only in the domain $F_I \in [0, F_I^A]$).

- Case $F_I^A > c_E + F_E^H - c_I$ and $F_I^B < 1$: The incumbent invests too much deviating from the socially optimal outcome. The critical value F_I^{cr} can either satisfy $F_I^B < F_I^{cr} < 1$ or $F_I^B < 1 < F_I^{cr}$. In both cases, the social planner finds optimal to invest only when F_I lies in the domain $F_I \in [0, F_I^B]$ which is smaller than the investment region of the incumbent ($F_I \in [0, F_I^{cr}]$ or $F_I \in [0, 1]$ respectively)

- Case $F_I^A > c_E + F_E^H - c_I$ and $F_I^B > 1$: Private and social incentives for investment coincides. The incumbent and the social planner invest for every possible value of F_I.

We can conclude that in the case that the incumbent is more efficient than the high cost entrant regardless its entry decision in period 1 (this is the case when the fixed cost F_E^H lies in the domain A), 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_E^H lies in the domain B), the first mover has more incentives to invest than in the social optimum.

4.4 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 cases 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).

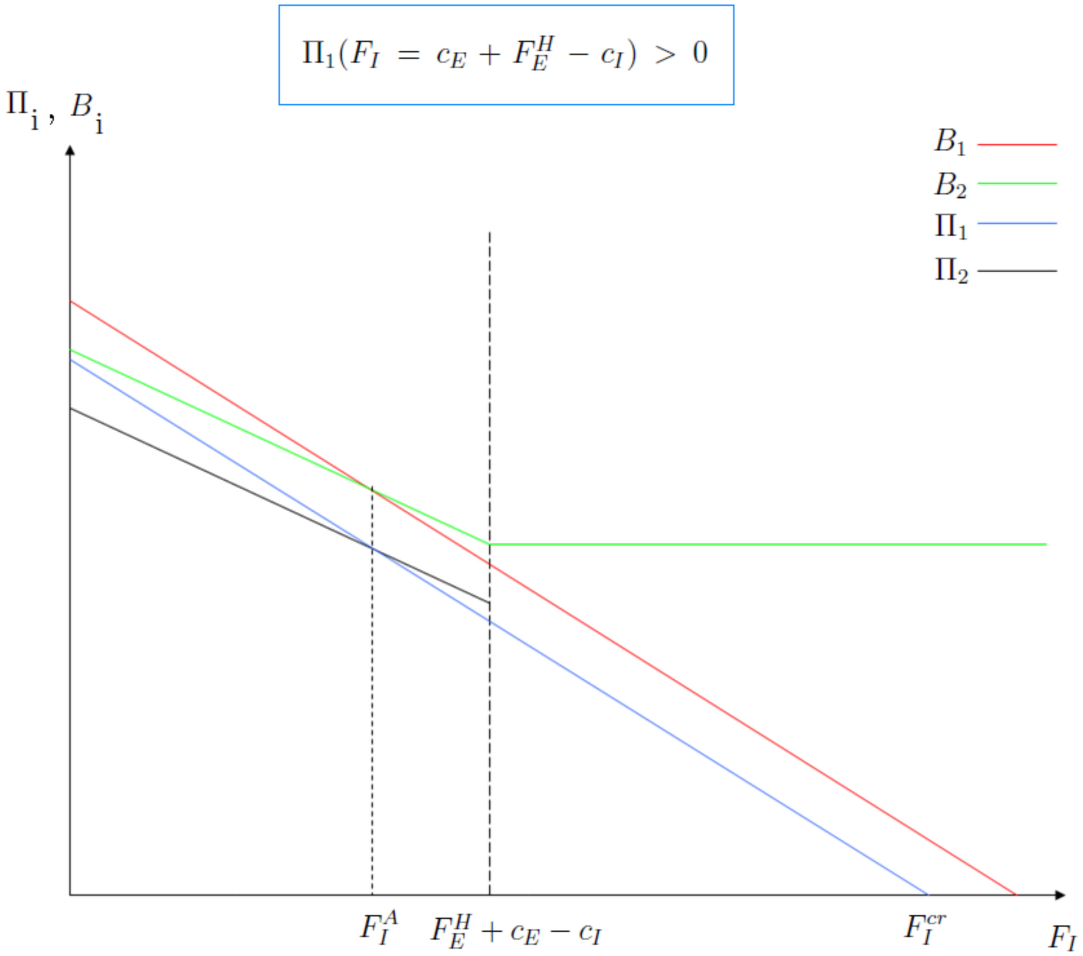

Figure 7: The private and social benefits for the 'investment' and the 'no investment' case when $F_I^A < c_E + F_E^H - c_I$ with $\Pi_1(F_I = c_E + F_E^H - c_I) > 0$.

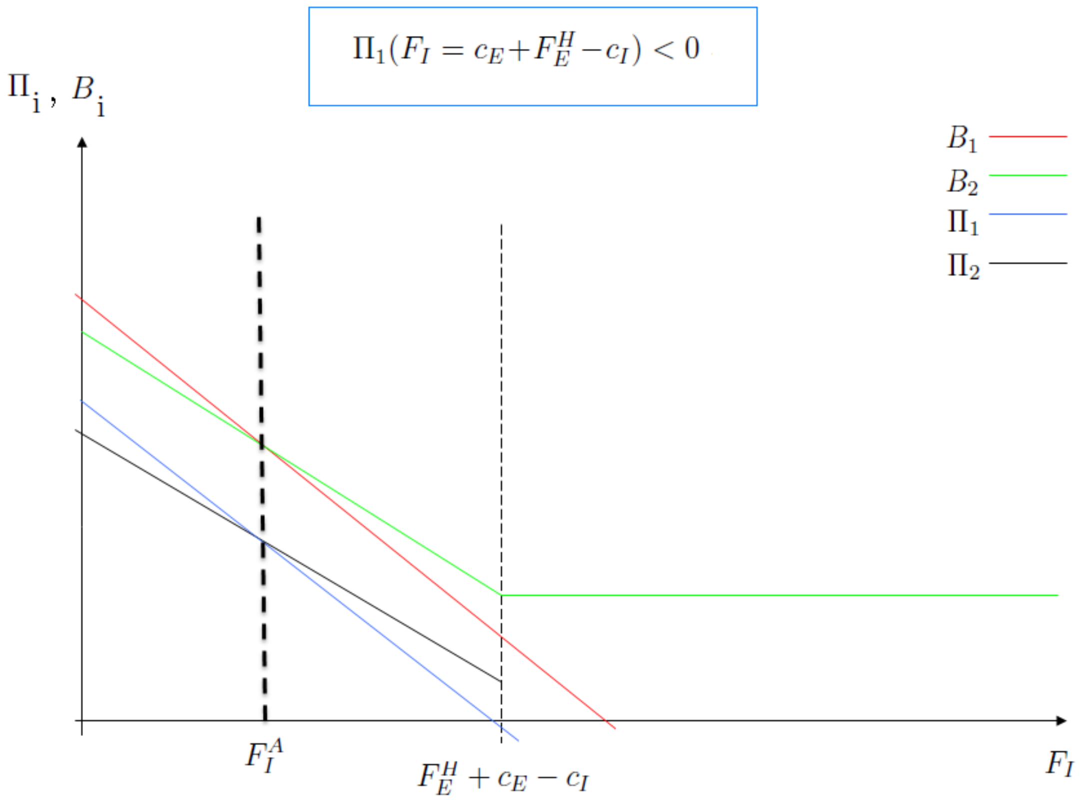

Figure 8: The private and social benefits for the 'investment' and the 'no investment' case when $F_I^A < c_E + F_E^H - c_I$ with $\Pi_1(F_I = c_E + F_E^H - c_I) < 0$.

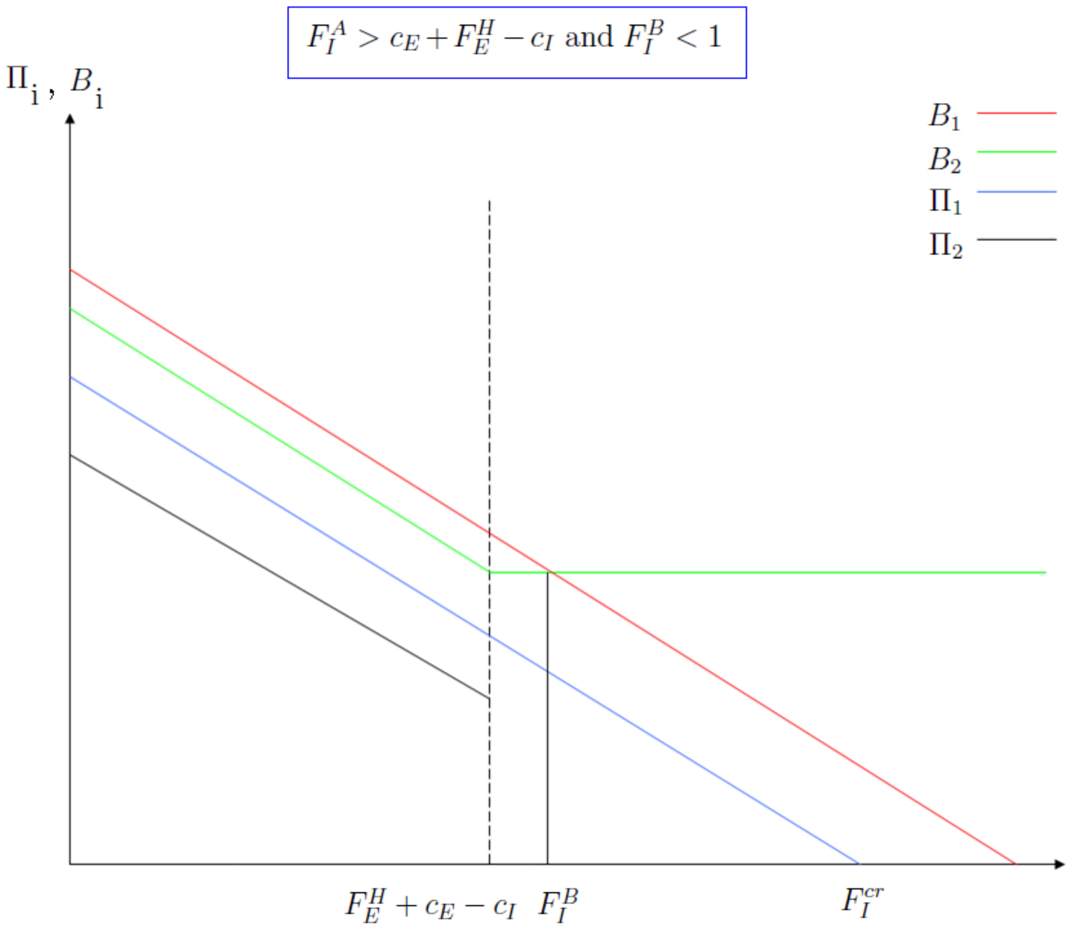

Figure 9: The private and social benefits for the 'investment' and the 'no investment' case when $F_I^A > c_E + F_E^H - c_I$ and $F_I^B < 1$.

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. 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:

S. pl.	$F_E < c_I - c_E$	$c_I - c_E < F_E < c_I + F_I - c_E$	$c_I + F_I - c_E < F_E$
Inv.	$a - F_I + \delta(1 - c_E - F_E)$	$a - F_I + \delta(1 - c_I)$	$a - F_I + \delta(1 - c_I)$
No inv.	$\delta(1 - c_E - F_E)$	$\delta(1 - c_E - F_E)$	$\delta(1 - c_I - F_I)$
I			
Inv.	$a - F_I + \delta(1 - c_E - F_E) - P$	$a - F_I + \delta(1 - c_I) - P$	$a - F_I + \delta(1 - c_I) - P$
No inv.	$\delta(1 - c_E - F_E) - P$	$\delta(1 - c_E - F_E) - P$	$\delta(1 - c_I - F_I) - P$
E+ TSO			
Inv.	P	P	P
No inv.	P	P	P

Table 1: The payoffs for the case of physical property rights before entry.

Notice that the incentives of the incumbent for investment coincides with those of the social planner. For the domain $F_E < c_I - c_E$ investment is not optimal while for $c_I + F_I - c_E < F_E$ it is. In the case of the domain $c_I - c_E < F_E < c_I + F_I - c_E$ investment is optimal only when $c_E + F_E - c_I > \frac{F_I - a}{\delta}$.

Thus, there is not need for further investigation of the investment policies of incumbent and social planner for the domains of realizations of F_E. 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 F_E 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 at the first period (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 at 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:

I	$F_E < c_I - c_E$	$c_I - c_E < F_E < c_I + F_I - c_E$	$c_I + F_I - c_E < F_E$
Inv.	$a - F_I + \delta(1 - c_E - F_E) - P$	$a - F_I + \delta(1 - c_I) - P$	$a - F_I + \delta(1 - c_I) - P$
No inv.	0	0	$\delta(1 - c_I - F_I) - P'$
E+ TSO			
Inv.	P	P	P
No inv.	$\delta(1 - c_E - F_E)$	$\delta(1 - c_E - F_E)$	P'

Table 2: The payoffs for the case of property rights after entry.

Notice that the prices P and P' do not affect the social incentives for investment while they can be proven basic determinants of incumbent's investment strategy. For $P = P' = 0$ incumbent invests too much, in all the possible domains of realization of F_E. 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 F_E^H lies in the domain B. Then, the only determinant policy parameter of incumbent's strategy is price P. The payoffs Π_1 and Π_2^B of the incumbent becomes:

$$\begin{aligned}
\Pi_1 &= a - F_I + \delta[(1-p)(1-c_E-F_E^L)+p(1-c_I)] - P \\
\Pi_2^B &= 0
\end{aligned} \tag{15}$$

So, the optimal price P is determined by solving the equation $\Pi_1 = B_1 - B_2^B$ which gives:

$$P^{opt} = \delta[1 - c_E - (1-p)F_E^L - pF_E^H] \tag{16}$$

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

$$\begin{aligned}
\Pi_1 &= a - F_I + \delta[(1-p)(1-c_E-F_E^L)+p(1-c_I)] - P \\
\Pi_2^A &= \delta p(1 - c_I - F_I - P')
\end{aligned} \tag{17}$$

Thus the optimal combination (P, P') is estimated by the solution of the equation $\Pi_1 - \Pi_2^A = B_1 - B_2^A$:

$$P^{opt} - \delta p P'^{opt} = \delta(1-p)(1-c_E-F_E^L)$$

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 entrant's incentives further. Thus, the optimal price of the transmission property rights, P^{opt} becomes:

$$P^{opt} = \delta(1-p)(1-c_E-F_E^L) \tag{18}$$

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

4.5 Financial Property Rights

In the case that 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:

I	$F_E < c_I - c_E$	$c_I - c_E < F_E < c_I + F_I - c_E$	$c_I + F_I - c_E < F_E$
Inv.	$a - F_I + \delta(1 - c_I) - P$	$a - F_I + \delta(1 - c_I) - P$	$a - F_I + \delta(1 - c_I) - P$
No inv.	$\delta(1 - c_I - F_I) - P$	$\delta(1 - c_I - F_I) - P$	$\delta(1 - c_I - F_I) - P$
E			
Inv.	$\delta(1 - c_E - F_E)$	0	0
No inv.	$\delta(1 - c_E - F_E)$	$\delta(1 - c_E - F_E)$	0
TSO			
Inv.	$P - \delta(1 - c_I)$	P	P
No inv.	$P - \delta(1 - c_I - F_I)$	$P - \delta(1 - c_I - F_I)$	P

Table 3: The payoffs for the financial property rights case.

From Table 3, it becomes clear that, due to condition (2), the incumbent has incentives to invest for every possible realization of F_E. The price P does not affect its incentives, so, it deviates from the social optimum by overinvesting. Moreover, notice that the private incentives for investment do not depend on the probability p 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 F_E^H lies in the domain B the imposition of appropriate tax T to the incumbent 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:

$$\begin{aligned}\Pi_1 &= a - F_I + \delta(1 - c_I) - P - T \\ \Pi_2^B &= \delta(1 - c_I - F_I) - P \end{aligned} \tag{19}$$

By solving the equation $\Pi_1 - \Pi_2^A = B_1 - B_2^B$ we find the optimal tax T^{opt} that corrects private incentives for investment:

$$T_{opt}^B = \delta[(1-p)F_I + p(c_I + F_I - c_E - F_E^H)] \tag{20}$$

In the same way when F_E^H lies in the domain, the optimal tax policy is:

$$T_{opt}^A = \delta(1-p)F_I < T_{opt}^B \tag{21}$$

Notice that the less efficient the high cost entrant is, the lower the tax levied on the incumbent will be. As it can be observed from the comparison of expressions and (20) the optimal tax under financial rights depends on the degree of asymmetry between the two firms while in the standard nodal pricing model it depends only of the total cost of the entrant.

4.6 Counter-trading

In the case of counter-trading both firms enter the market in the second period and compensation is given to the less efficient firm for not producing[9]. 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:

[9]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.

I	$F_E < c_I - c_E$	$c_I - c_E < F_E < c_I + F_I - c_E$	$c_I + F_I - c_E < F_E$
Inv.	$a - F_I + \delta(1 - c_I)$	$a - F_I + \delta(1 - c_I)$	$a - F_I + \delta(1 - c_I)$
No inv.	$\delta(1 - c_I - F_I)$	$\delta(1 - c_I - F_I)$	$\delta(1 - c_I - F_I)$
E			
Inv.	$\delta(1 - c_E - F_E)$	$\delta(1 - c_E - F_E)$	$\delta(1 - c_E - F_E)$
No inv.	$\delta(1 - c_E - F_E)$	$\delta(1 - c_E - F_E)$	$\delta(1 - c_E - F_E)$
TSO			
Inv.	$-\delta(1 - c_I)$	$-\delta(1 - c_E - F_E)$	$-\delta(1 - c_E - F_E)$
No inv.	$-\delta(1 - c_I - F_I)$	$-\delta(1 - c_I - F_I)$	$-\delta(1 - c_E - F_E)$

Table 4: The payoffs for the counter-trading method.

From Table 4, 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_I. 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 negative due to the compensation is provides the 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 p that the entrant is 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 domain.

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. Adding financial transmission rights to the market design reduces the investment risk, but does not solve the problem of over-investment. On the contrary 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 programme. 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 first mover 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. For example, in the nodal pricing case, 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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