

Price Regulation and Investment: A Real Options Approach

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JEL Classification: L51

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1. Introduction

The role of monopoly price regulation has experienced a significant shift in many countries. At its inception, following a wave of corporatisation and privatisation of government owned enterprises, price regulation was designed to promote static efficiency through the establishment of cost reduction mechanisms in an environment where capacity constraints were lax in many industries. Despite the development of several distinct regulatory methodologies, prices have by and large been set in order to secure a zero net present value (NPV) for regulated firms.¹

However, sustained economic growth over the past decade as well as substantial technological change in industries such as telecommunications have created an environment where significant amounts of investment are necessary to provide new services or update existing ones. Consequently, a second wave of regulatory reform across the world has shifted the focus of price regulation from promoting static efficiency towards supporting dynamic efficiency and, consequently, providing appropriate investment incentives.

The tension between price regulation and investment incentives is highlighted, for example, in the current debate on the deployment of fibre-optic infrastructure and so-called Next Generation Networks (NGNs). This debate is characterised by firms requiring regulatory certainty before they invest in order to avoid circumstances in which they would be required to provide access to the new infrastructure at prices that would yield a zero net present value if the new service is successful, but access seekers would not share the losses if the new service fails. It is also anticipated that the relationship between price regulation and investment incentives will be increasingly important in a low carbon emissions world where substantial amounts of renewable and gas-fired micro generation will be introduced into the electricity system. The achievement of such change will necessitate significant new investment to adapt and expand existing electricity networks, mainly because renewable energy involves site-specific power plants.²

Although it is not the responsibility of regulators to provide firms with incentives to make particular investments (for example in NGNs), it is important that the incentives for efficient investment are not distorted. This requires a regulatory framework that correctly accounts for the risks faced by firms when investing in a new network facility. These risks are related to the combination of two underlying characteristics: (demand) uncertainty and irreversibility.

¹ For instance, the revenue cap regulation applied to electricity transmission in Australia states that regulated firms have a maximum revenue allowance that covers the operating expenses and the return on investment, that is, maximum revenue is set to remunerate the cost of capital yielding a zero NPV.

Future cash flows in almost all network industries depend significantly on uncertain events such as the evolution of technology, tastes, general economic conditions and natural events as well as competition from newly developed close substitutes. While most, if not all, firms in a competitive economy arguably face such uncertainty, the combination of demand uncertainty and large irreversible investments are important characteristics of network industries. If the investments were reversible in the case of insufficient cash flows to cover the capital costs, an investor would be able to recover any losses through the resale of its assets. Similarly, the irreversibility concept would be of less concern in the absence of uncertainty.

Investments in network industries are irreversible for two main reasons. Firstly, for some types of investment, recovery through resale is simply not possible. For example, in telecommunications it is not economically viable to remove and resell copper or fibre-optic cable that has been placed underground. Secondly, even if certain equipment can be uninstalled and resold, it is likely to be industry-specific and thus its value dependent on the economic conditions of the industry. Even if a firm wanted to resell an asset, it is unlikely that other firms would be willing to buy the equipment, particularly at a price that recovered the investment made.³

The combination of uncertainty, irreversibility and investment timing flexibility provides the building blocks of the option to delay theory. Although the option to delay's concept has been extensively studied in competitive markets,⁴ its implications on regulated prices and investment incentives are less well understood. Indeed, there has been much debate on this subject recently.

For instance, in the context of telecommunications, the New Zealand Commerce Commission stated that "the obligation to provide interconnection services removes the option for access providers to delay investment in their fixed Public Switched Telephone Networks."⁵ If this option has a value, the costs of foregoing the option are a cost that should be reflected in interconnection prices" (Commerce Commission 2002). In its latest cost of capital consultation, the telecommunications regulator in the United Kingdom proposed that "Ofcom should begin to develop a framework by which regulatory policy might reflect the value of these options (real options)" and "a key area identified by Ofcom as being one in which the value of wait and see options might be significant was that of next generation access networks" (Ofcom 2005).

Under real options theory, a firm will invest in a project today if its NPV is higher or equal than the NPV of investing at anytime in the future. Therefore, as a result of such options to delay, profit-

² A site-specific power plant is an electric generating facility that can be only built in one specific location due to natural conditions. For example, a hydro power plant or wind farm.

³ See, for example, Pindyck (2004).

⁴ See, for example, Dixit and Pindyck (1994) and Trigeorgis (1996).

⁵ A Public Switched Telephone Network (PSTN) is the traditional phone system. Also referred to as the 'landline' network, it uses a copper wire network to carry voice and data.

maximising firms might choose not to undertake an investment even though its NPV is positive. In these cases, it follows that a regulator who sets the price so that to ensure that the NPV is equal to zero will distort the firm's investment decision. As a result, traditional regulation, which focuses on setting the price at some notion of long run average cost so that the NPV of the investment is zero, might not provide the correct investment incentives as it fails to take into account the cost of uncertainty that the firm has to bear if it were to invest early.

In this paper we examine a simple three-period model of an investment decision in a network industry characterized by demand uncertainty, economies of scale and sunk costs. In this model a firm may invest in the first period or wait until the second period to decide whether to invest in the network. Uncertainty does not resolve itself until the last period.

In the absence of regulation we identify the market conditions (i.e., the nature of demand) under which an unregulated monopolist decides to invest early as well as the underlying overall welfare output. The unregulated monopoly outcome is then set as the benchmark that the regulator will try to improve upon.

We first consider a monopolist firm facing no downstream competition but subject to a price cap on the downstream retail (final good) market. Our focus is on regulatory interventions where the regulator commits ex-ante to a set of prices that are not contingent on demand.⁶ Thus, our 'regulatory game' is such that the regulator makes a one-off offer and the firm then decides whether to invest early or not. We rule out the regulator's ability to commit to demand contingent prices. Such commitment might not be possible as a result of political pressures that emerge when the realised state of demand calls for high prices in order to be consistent with full capital maintenance. This is the well-known regulatory expropriation problem.

In this ex-ante regulated environment, we identify the welfare-maximising regulated prices. In particular, we show that there are three possible optimal scenarios: regulated prices that provide a zero payoff to the firm, regulated prices that include an option to delay value and provide a positive payoff to the firm and no regulation. From a policy perspective, this indicates that regulated prices that exclude an option to delay and that are designed to yield zero economic profits might not be optimal.

We also consider a vertically integrated network provider that is required to provide access to downstream competitors. We show that when the regulator has only one instrument, namely the access price, an option-to-delay pricing rule generates (weakly) higher welfare than the Efficient Component Pricing Rule (ECPR), except under very specific circumstances.

⁶ Another possible type of ex-ante regulation for new network services is the notion of a 'regulatory holiday'. See Hausman (1999).

The basic idea is that access prices under the option-to-delay pricing rule are (weakly) lower than those following the ECPR. The main reason is that under an option-to-delay pricing rule, even an inefficient entrant can constraint the monopoly rents that the incumbent can extract, whereas an ECPR price embeds full monopoly rents.

As we discuss in the next section, this paper differs from earlier literature in at least three significant aspects. First, it explicitly considers the process by which a regulator sets regulated prices. Second, it shows that the design of welfare-maximising price regulation depends on market conditions. Third, it investigates optimal access pricing and unlike Pindyck (2004) who advocates an ECPR-type methodology, we find that except under very specific conditions, an access price that accounts for the option to delay value is welfare-superior to the ECPR.

This paper is organized as follows. Section 2 surveys the recent literature on regulation and the option to delay. Section 3 sets out the investment decision model in an unregulated industry. In Section 4 we compute the NPV and the option to delay value associated with the unregulated monopolist investment decision. Section 5 investigates the effect of retail price regulation in the incentives to invest. In Section 6 we examine the effects of access price regulation on the firm's investment decision under downstream competition and compare two types of regulation, namely those based on the ECPR and those based on an option to delay rule. Section 7 concludes the paper.

2. Literature Review

One of the earliest set of papers related to this topic was Teisberg (1993 and 1994). Both articles focus on a firm's decision to delay investment, choose shorter-lead-time technologies (even if they are more expensive) and abandon partially completed projects when this firm is faced with uncertain and asymmetric profit and loss restrictions due to regulation.

The value to the firm of the investment project is a function of the uncertain value of a completed project in the future and the direct costs of completing construction. The value to the firm of a completed project depends on exogenous regulatory treatments of cost allowances, financing costs and abandoned projects.

The analysis uses a stylized representation of exogenous cost allowance policy. The value of an already completed project is assumed to be known. However, the value of a project that is not yet complete is uncertain. The expected change on the project's value is the expected rate of return on an operating project less a regulatory term representing expected changes in cost allowances.

Future uncertainty about the value of a completed project is due to future regulatory outcomes as well as future market conditions.

The modelling framework used in both papers also assumes that the financing cost policy is such that the investment generates no positive cash flows until it is completed. Finally, a stylised abandonment policy is considered, in which the firm recovers an exogenously specified fraction of previously sunk costs when the project is abandoned.

Teisberg (1993) shows that when the firm faces uncertain and asymmetric profit and loss restrictions it invests in smaller, shorter-lead-time plants, or simply delay investment. Firms choose smaller projects to reduce the expected size of regulatory penalties and shorter-lead-time projects to reduce the chance that the realised usefulness of the plant due to regulatory uncertainty will be very different from the original expectations. Decisions to delay investment also result from asymmetric profit and loss restrictions.

Teisberg (1994) provides a numerical analysis of optimal construction strategies based on the model developed in Teisberg (1993). The analysis presents four results: the value of flexibility to delay or abandon construction, the effects of uncertainty on the project value and on the decision threshold for investment, the value of a shorter construction lead time (shorter lead time technology), and the effects of abandonment policy. It shows, for instance, that the value of the options to delay and abandon construction may be very substantial. Also, it shows that the value of the investment project under regulation is lower than in an unregulated case and the more uncertainty there is, the more regulation reduces the investment project's value.

It follows from Teisberg (1993, 1994) that the project's value under regulation is lower than in its absence. As a result, regulation might lead a firm to delay its investment. As in Teisberg, we develop a model that compares the investment decision of an unregulated monopolist and a firm that is subject to price regulation. However, we explicitly consider the process by which the regulator sets regulated prices and characterise the socially optimal price regulation.

Other important references include those by Hausman (1999) and Hausman and Myers (2002). While Teisberg investigates the impact of regulatory uncertainty on firm's investment decisions, these authors focus on access pricing methodologies and asymmetric rights between incumbent and entrants in the telecommunications and railroad industries. Moreover, they argue that regulated prices in these industries should reflect the importance of sunk costs and the irreversibility of investments.

In particular, Hausman (1999) argues that the U.S. Telecommunications Act of 1996 in the form of its access pricing methodology (TSLRIC)⁷ can lead to serious negative effects on innovation and new investment in the local telephone network because it does not account for the interaction of uncertainty with sunk and irreversible costs of investment. The author concludes that a mark up factor must be applied to the investment cost component of TSLRIC. Hausman points out that this mark up is the value of the free option that regulators force incumbent providers to grant to new entrants, where an option is the right but not the obligation to purchase the use of the unbundled elements of the incumbent's network.

Hausman and Myers (2002) make the same point as Hausman (1999) but their focus is on the railroad industry. The authors estimate the size of the differences between the returns calculated using the regulator's pricing methodology and an alternative method that includes the interaction of uncertainty with sunk and irreversible costs of investment by applying a real options approach (using Monte Carlo Simulation). They find that the required return calculated from a regulator's model ignoring these factors is lower than the optimal amount; the size of the error vis-à-vis the optimal amount lies between 30% and 84.4%.

As in Hausman (1999) and Hausman and Myers (2002) we investigate access pricing in the context of infrastructure investment. However, we explicitly determine an access pricing policy that accounts for the option to delay value. Moreover, we show that the format that the welfare-maximising price regulation will take depends on market condition.

Finally, Pindyck (2004) address the impact of the network sharing arrangements mandated by the U.S. Telecommunications Act of 1996 on investment incentives, with a focus on the implications of irreversible investment. As in Hausman (1999), Pindyck argues that because the entrant does not bear the sunk costs, this leads to an asymmetric allocation of risk and return that is not properly accounted for in the pricing of the network services. Pindyck argues that such asymmetric allocation of risk and return creates a significant investment disincentive.

In contrast with Hausman (1999), Pindyck (2004) investigates the relationship between regulation and uncertainty by using discrete modelling frameworks. More specifically, Pindyck (2004) considers two distinct frameworks to analyse the link between the option to delay and regulated prices.

The first framework consists of a single firm assessing a network investment that will generate cash flows in perpetuity. The firm can invest in the first period or wait until the second period to

⁷ TSLRIC (Total Service Long-Run Incremental Cost) is a cost-based pricing methodology reflecting "forward-looking costs" of an efficient operator, comprising direct costs, the cost of capital, and a share of common costs.

decide whether to invest in the network. The cash flow in the first period is known, but the cash flow in the second period can either increase or decrease. This uncertainty is resolved in the second period and from there onwards the same cash flow (high or low) will eventuate each year. The required investment amount is unchanged from the first to the second period – that is, the real cost of investment decreases over time. Thus, the combination of uncertain cash flows and a declining investment requirement in real terms creates an incentive for the firm to delay. The cost of waiting is the first period cash flow, which is foregone when the firm delays its investment. This framework is used to explain the basic concept of option value. Additionally, in order to illustrate the problem of ex post access regulation, Pindyck uses a numerical example of irrational behaviour by a firm; that is, it is optimal to wait but the firm invests early nonetheless. Pindyck then uses this example to show that under a low demand scenario the incumbent firm has a negative payoff while the entrant avoids any losses by not taking up access to the network. Pindyck suggests that access prices should incorporate an option to delay value to compensate the incumbent for this asymmetric risk.

Pindyck also examines a hypothetical example where an incumbent installs a telecommunications switch that can be utilized by an entrant. As in the previous example, it is optimal for the incumbent to wait until uncertainty is resolved but the firm invests anyway. In this example, the author suggests that this would be the case where the investment is mandatory and the firm has a duty to serve. Pindyck shows that when there is entry, the entrant's expected gain is precisely the incumbent's expected loss. In order to correct access prices to account for the option to delay value, Pindyck suggests that the entrant's expected cash flow should be set equal to zero and consequently the incumbent would be indifferent between providing access to entrants and providing the retail service itself (an ECPR-type methodology).

As in Pindyck (2004) we use a three period model to investigate access pricing in the context of infrastructure investment. However, our modelling framework differs from Pindyck's in several ways. First, in our model the cash flow in the first period is uncertain whereas this amount is known in Pindyck's model. Second, in our framework uncertainty does not resolve itself until the last period while in Pindyck (2004) uncertainty is resolved in the second period. Finally, in order to isolate the effect of demand uncertainty on the option to delay value we consider that the investment outlay is financially neutral over time. In Pindyck (2004) the real cost of investment decreases over time.

Importantly, while Pindyck advocates in favour of an ECPR-type methodology to account for the interaction between irreversibility and demand uncertainty, we find that, except under very specific conditions, an access price that accounts for the option to delay value generates at least the same welfare than an ECPR-based price.

3. The Investment Decision Model

This Section develops a simple three-period model framework to investigate the role of the option to delay on investment decisions in network industries. Our framework encompasses four common characteristics of network industries: timing flexibility when making the investment decision, demand uncertainty, investment irreversibility and natural monopoly.

We consider a firm's decision regarding whether to build a network in order to provide a new service. It takes one period to build the network. The firm can build the network at $t = 0$ or at $t = 1$, with services starting at $t = 1$ or $t = 2$, respectively. If the firm does not invest at $t = 0$, it has the right but not the obligation to invest at $t = 1$. If the firm invests at $t = 0$, it will have the cash flows from periods $t = 1$ and $t = 2$. On the other hand, if the firm invests at $t = 1$ it will only get the cash flow from period $t = 2$. Thus, there is a cost of waiting when the firm delays its investment (the first period cash flow). Also, we assume that when indifferent as to investing, the firm invests and when indifferent between investing at $t = 0$ or at $t = 1$, the firm invests at $t = 0$.

The investment outlay to build the network at $t = 0$ is equal to I , whereas the outlay to build it at $t = 1$ is equal to $(1+k)I$, where k is the project's cost of capital. Thus, the investment expenditure is financially neutral over time. Moreover, the investment is sunk and there are no maintenance or operational costs to run the network.

At $t = 1$ the inverse demand function is characterized by a choke price equal to $\bar{P}_1$. At any price below or equal to $\bar{P}_1$ the demand, denoted by q_1 , will be either equal to uQ (where $u > 1$) or equal to dQ (where $0 < d < 1$) with probabilities θ and $(1-\theta)$, respectively, where Q is the expected demand at $t = 0$. The demand at a price above $\bar{P}_1$ is always equal to zero.

At $t = 2$ the inverse demand function is characterized by a choke price equal to $\bar{P}_2$. At any price below or equal to $\bar{P}_2$ the demand, denoted by q_2 , will be either equal to u^2Q , udQ or d^2Q with probabilities θ^2 , $2\theta(1-\theta)$ and $(1-\theta)^2$, respectively. The demand at a price above $\bar{P}_2$ is always equal to zero.

Under these conditions, the gross value of future cash inflows will fluctuate in line with the random fluctuations in demand (Figure 1). Note that demand uncertainty creates an incentive for the firm to delay its investment decision until $t = 1$. Note also that this uncertainty does not resolve itself until the last period.

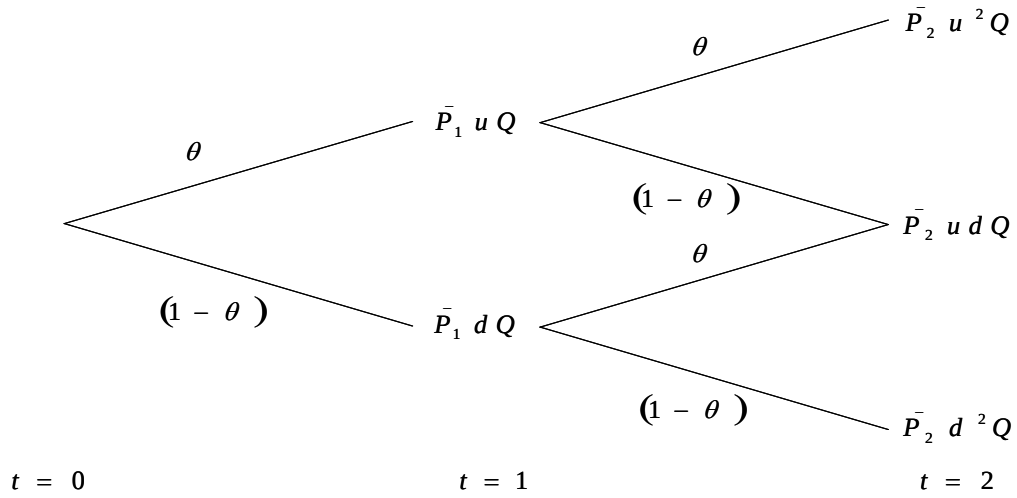


Figure 1

The network is used to provide services to final consumers. The technology is such that the production of the final good requires one unit of the network service and one unit of a generic input with unit prices c_1 at $t = 1$ and c_2 at $t = 2$. Therefore, at $t = 0$ the firm's cost function to provide the downstream service is given by:

$$\begin{cases} C_0(q_1, q_2) = I + \frac{c_1 q_1}{(1+k)} + \frac{c_2 q_2}{(1+k)^2} \\ C_1(q_2) = I + \frac{c_2 q_2}{(1+k)^2} \end{cases} \quad (1)$$

where C_0 and C_1 are the cost functions when investing at $t = 0$ and at $t = 1$, respectively, evaluated at time $t = 0$. It is clear from (1) that the provision of network services constitutes a natural monopoly.

In the next section we analyse the investment decision of an unregulated monopolist who does not anticipate that its prices will be regulated.

4. Pricing the NPV and the Option to Delay in the Absence of Regulation

An unregulated monopolist is considering whether to invest in a network facility to provide a new service. When making its investment decision, this firm knows the choke prices consumers would pay for its new service as well as the expected demand under the alternative states of the world. At this stage, the monopolist does not anticipate that its prices will be regulated.

First, we calculate this investment decision as a standard NPV. Note that if the firm invests at $t = 0$ the project has an expected net value at $t = 1$ equal to

$$\begin{aligned}
 NV(\theta) = & \theta \left[\left(\bar{P}_1 - c_1 \right) uQ + \frac{\theta \left(\bar{P}_2 - c_2 \right) u^2 Q + (1 - \theta) \left(\bar{P}_2 - c_2 \right) udQ}{(1 + k)} \right] + \\
 & + (1 - \theta) \left[\left(\bar{P}_1 - c_1 \right) dQ + \frac{\theta \left(\bar{P}_2 - c_2 \right) udQ + (1 - \theta) \left(\bar{P}_2 - c_2 \right) d^2 Q}{(1 + k)} \right] - (1 + k)I
 \end{aligned}$$

Financial theory suggests that the cost of capital of a project is determined by its cash flows' risk profile. Remember that the future cash inflows will fluctuate in line with the random fluctuations in demand. In particular, recall that demand at each period equals the demand from the previous period multiplied by u or d with probabilities θ and $(1 - \theta)$. It follows then that $\theta u + (1 - \theta)d = (1 + k)$.

Thus, discounting the $NV(\theta)$ at the opportunity cost of capital k we obtain a NPV equal to

$\left[\left(\bar{P}_1 - c_1 \right) + \left(\bar{P}_2 - c_2 \right) \right] Q - I$. The same NPV can be calculated using a risk-neutral valuation. In

a risk-neutral world, all assets would earn the risk-free return r , and so expected cash flows (weighted by the risk-neutral probabilities, p and $(1-p)$) could be appropriately discounted at the risk-free rate. The risk-neutral probability is stated in Lemma 1 below. The proof of the Lemma is in the Appendix.

Lemma 1: The risk-neutral probability is given by $p = \frac{(1+r)-d}{u-d}$.

Thus, the NPV of this investment decision, denoted by $\overline{NPV}$, is equal to

$$\overline{NPV} = \left[\left(\bar{P}_1 - c_1 \right) + \left(\bar{P}_2 - c_2 \right) \right] Q - I = \frac{NV(\theta)}{(1+k)} = \frac{NV(p)}{(1+r)} \quad (2)$$

where

$$NV(p) = p \left[\left(\bar{P}_1 - c_1 \right) uQ + \frac{p \left(\bar{P}_2 - c_2 \right) u^2 Q + (1-p) \left(\bar{P}_2 - c_2 \right) udQ}{(1+r)} \right] + \\ + (1-p) \left[\left(\bar{P}_1 - c_1 \right) dQ + \frac{p \left(\bar{P}_2 - c_2 \right) udQ + (1-p) \left(\bar{P}_2 - c_2 \right) d^2 Q}{(1+r)} \right] - (1+r)I$$

Given the values of the parameters, the NPV is fixed at $\overline{NPV}$. In the next section we will calculate the changes in the NPV as prices are set by the regulator rather than the firm.

The risk-neutral methodology will now be used to calculate this investment decision as a call option, that is, if the firm does not invest at $t = 0$ it has the right but not the obligation to invest at $t = 1$. The rationale for using the risk-neutral methodology can be explained as follows. As the cash flows risk profile of the deferral option is different from the standard NPV, these cash flows cannot be discounted using the same cost of capital k as in the NPV case. Thus, instead of

calculating the correct risk-adjusted discount rate applied to the expected cash flows from the project (given deferral), we simply calculate the risk-neutral probabilities and then discount the cash flows using the risk free rate.⁸

Note from Figure 2 below that (i) the benefit of waiting is that the firm avoids negative payoffs and (ii) the cost of waiting is the first period cash flow, which is foregone when the firm delays its investment decision.

$$\begin{array}{c}
 \overline{OD} \begin{array}{l} \nearrow^p \\ \searrow_{(1-p)} \end{array} \begin{array}{l} OD^+ = \text{Max} \left[\frac{p(\bar{P}_2 - c_2)u^2Q + (1-p)(\bar{P}_2 - c_2)udQ}{(1+r)} - (1+r)I; 0 \right] \\ OD^- = \text{Max} \left[\frac{p(\bar{P}_2 - c_2)udQ + (1-p)(\bar{P}_2 - c_2)d^2Q}{(1+r)} - (1+r)I; 0 \right] \end{array}
 \end{array}$$

Figure 2

The expected return on the option, denoted by $\overline{OD}$, must also equal the risk-free rate in a risk-neutral world, that is,

$$\overline{OD} = \frac{pOD^+ + (1-p)OD^-}{1+r}$$

or

$$\overline{OD} = \frac{p \text{Max} \left[\left(\bar{P}_2 - c_2 \right) uQ - (1+r)I; 0 \right] + (1-p) \text{Max} \left[\left(\bar{P}_2 - c_2 \right) dQ - (1+r)I; 0 \right]}{1+r} \quad (3)$$

It is easy to see from (3) that the option to delay only has value when $\bar{P}_2 > c_2$. Since our goal is to investigate the relation between the option to delay and regulation we assume throughout the paper that this inequality holds. Note also from (3) that when considering the option to delay (OD) as a function of demand, there are three ranges that play an important role in our analysis. In the first range, both states of demand, high and low, yield negative payoffs. In this case the option to delay is equal to zero. In the second range only the high demand scenario yields a positive payoff

⁸ A more formal rationale is provided by Teisberg (1994) who points out that in an option pricing model the value of the investment opportunity is derived from the market value of the project. This implies that the riskless rate, rather than the cost of capital, should be used in the valuation of the investment as the risk of the project is incorporated in the market valuation of the project. It follows then that the cost of capital is exogenous and any changes in its value are captured by the market value of the project.

and the slope of the function is $\frac{pu}{1+r}(\bar{P}_2 - c_2)$. In the third range, both scenarios yield positive payoffs and the slope of the function is $(\bar{P}_2 - c_2)$. As with the NPV, given parameter values,

$\overline{OD}$ has a fixed value. In the next section we investigate how regulation affects the value of OD.

In order to decide whether, and when, to invest in the network facility the firm must compare the values of $\overline{NPV}$ and $\overline{OD}$ which are given by (2) and (3), respectively.⁹ Recall that the benefit of waiting is that the firm avoids negative payoffs while the cost of waiting is the first period cash flow, which is foregone when the firm delays its investment. Thus, it is clear that the comparison between the market value of the $\overline{NPV}$ and the $\overline{OD}$ at $t = 0$ depends on $(\bar{P}_1 - c_1)$, the term that drives the first period net revenue. There are four different possibilities depending on the magnitude of this term, which are listed in Lemma 2. Its proof and figures covering the various cases are in the Appendix.

Lemma 2: *Table 1 below summarizes the unregulated monopolist investment decision outputs given $(\bar{P}_1 - c_1)$.*

Condition	The firm never invests if	The firm invests at $t = 1$ when $q_1 = uQ$ if	The firm always invests at $t = 1$ if	The firm invests at $t = 0$ if
$(\bar{P}_1 - c_1) < 0$ (Fig 3)	$\overline{OD} = 0$	$OD^+ > 0$ and $OD^- = 0$	$OD^+ > 0$ and $OD^- > 0$	-
$(\bar{P}_1 - c_1) = 0$ (Fig 4)	$\overline{OD} = 0$	$OD^+ > 0$ and $OD^- = 0$	-	$OD^+ > 0$ and $OD^- > 0$
$(\bar{P}_1 - c_1) > 0$ (Fig 5)	$\overline{OD} = 0$	$OD^+ > 0$, $OD^- = 0$ and $\overline{NPV} < \overline{OD}$	-	$OD^+ > 0$, $OD^- \geq 0$ and $\overline{NPV} \geq \overline{OD}$
$(\bar{P}_1 - c_1) > 0$ (Fig 6 and 7)	$\overline{OD} = 0$ and $\overline{NPV} < \overline{OD}$	-	-	$\overline{NPV} \geq \overline{OD} \geq 0$

Table 1

⁹ Clearly, NPV is the net present value of investing at $t = 0$ and OD is the net present value of investing at $t = 1$.

Lemma 2 shows how market conditions (choke prices and expected demand) affect the firm's investment decision. It remains for us to compute the total welfare associated with each decision.

First, if the firm invests at $t = 0$ ($\overline{NPV} \geq \overline{OD}$) the total welfare at $t = 0$ is given by:

$$W_M^0 = \alpha \overline{NPV} \quad (4)$$

where $\alpha < 1$ denotes the weight assigned to firm's profits. Second, if the firm invests at $t = 1$ independently of the demand scenario ($\overline{NPV} < \overline{OD}$, $OD^+ > 0$ and $OD^- > 0$) the total welfare at $t = 0$ is given by:

$$W_M^{H,L} = \alpha \left\{ \left(\bar{P}_2 - c_2 \right) Q - I \right\} \quad (5)$$

Finally, if the firm invests at $t = 1$ only in case demands turns out to be high ($\overline{NPV} < \overline{OD}$, $OD^+ > 0$ and $OD^- = 0$) the total welfare at $t = 0$ is given by:

$$W_M^H = \alpha p \pi_{t=1}^H \quad (6)$$

Where $\pi_{t=1}^H = \left[\frac{\left(\bar{P}_2 - c_2 \right) u Q}{(1+r)} - I \right]$ denotes the present value of profits when the firm invests at

$t = 1$ if demand is high. Of course, the total welfare associated with no investment is equal to zero.

5. Retail Price Regulation

This section investigates the effect of retail price regulation on the incentives to invest. More specifically, we consider a monopolist firm that faces no downstream competition and is subject to a price cap on the downstream retail (final good) market. The regulator and the firm both observe the choke prices ($\bar{P}_1$ and $\bar{P}_2$) and are fully informed about the nature of demand

uncertainty and the cost function. The regulator sets regulated prices P_1^R and P_2^R that will prevail at $t = 1$ and at $t = 2$, respectively, in order to maximize total welfare:

$$\text{Max } W_R = CS + \alpha\pi \quad (7)$$

where CS denotes consumer surplus, π is the firm's profit and $\alpha < 1$ denotes the weight given to firm profits.¹⁰

This paper departs from most of the modern literature on regulation (Laffont and Tirole 1993) by abstracting from the existence of asymmetric information between the regulated firm and regulator. Our focus is instead on a situation where the costs of the project (I) can be determined with certainty. Perhaps our model can be seen as a reduced form approach where the regulated firm puts in a claim regarding the cost of the project and the regulator decides accurately the amount that it will allow the firm to recover through regulated prices.¹¹ Moreover, our focus is on a specific investment to provide a new service, for instance, a new technology in the telecom industry. In such cases the investment is subject to scrutiny by audit firms hired by the regulator, by society at large and also by potential competitors. This additional scrutiny may mitigate the existence of asymmetric information vis-à-vis the more standard case where a regulated monopolist undertakes a marginal investment, which is only subject to the scrutiny of the regulator.

Our focus is on *ex ante* regulation. That is, we assume that the regulator sets P_1^R and P_2^R at $t = 0$ before the resolution of demand uncertainty. Although it is true that a regulator could extract the entire surplus by offering an *ex post* demand contingent price contract, we assume that a regulator cannot commit to such contract. This assumption is consistent with regulatory practice around the world. Moreover, it suffices there to be a small probability that, *ex post*, the regulator will renege on the promise of a high retail price (e.g., if demand turns out to be low) for the firm not to invest at $t = 0$.

Thus, we focus on a 'regulatory game' where the regulator makes a one-off offer which consists of *ex ante* non-demand contingent maximum prices P_1^R and P_2^R that the firm will be allowed to

¹⁰ In our set up the horizontal demand implies that when $\alpha = 1$ any reduction in the firm's profit (through lower prices) would be equal to an equivalent increase in the consumer surplus. Thus, when $\alpha = 1$ in our model, a regulator cannot improve upon the outcome of the unregulated market.

¹¹ For an empirical analysis of the difference between firms' claims and regulatory cost allowances in Australia see Breunig, Hornby, Menezes and Stacey (2006).

charge at $t = 1$ and at $t = 2$, respectively. The firm then decides whether to invest at $t = 0$ or at $t = 1$ (if demand turns out to be high).

As we shall demonstrate below, the optimal regulation depends on the impact of the regulated prices on the comparison between the Net Present Value and the Option to Delay value. There are three cases to consider, where each case corresponds to one of the three different ranges of the Option to Delay function in an unregulated market. The next three propositions characterise the optimal set of regulated prices for each of these cases. Their proofs and figures covering the various cases are in the Appendix. Below we will use the following terminology, $C = \frac{I}{Q}$ denotes

the average fixed cost of investing at $t = 0$ for expected demand Q , $C_H = \frac{(1+r)I}{uQ}$ is the

average fixed cost of investing at $t = 1$ under high demand, and $C_L = \frac{(1+r)I}{dQ}$ is the average

fixed cost of investing at $t = 1$ under low demand.

Proposition 1: Suppose $\overline{NPV} \geq \overline{OD} = 0$. If $\overline{NPV} = \overline{OD} = 0$, the unregulated outcome is optimal. If $\overline{NPV} > \overline{OD} = 0$, the optimal ex ante demand non-contingent price contract is $P_1^R = C + (c_1 + c_2) - \bar{P}_2$ and $P_2^R = \bar{P}_2$. In both cases the firm will invest at $t = 0$.

Proposition 1 characterises the optimal regulated prices when the option to delay value in an unregulated market is equal to zero. It is easy to see that when $\overline{NPV} = \overline{OD} = 0$ the best the regulator can do is to replicate the choke prices $\bar{P}_1$ and $\bar{P}_2$. When $\overline{NPV} > \overline{OD} = 0$, however, the regulator is able to set $P_1^R < \bar{P}_1$ and $P_2^R = \bar{P}_2$ so that the net present value under regulation becomes zero. Since the option to delay value remains unchanged, we have $NPV = \overline{OD} = 0$ and the firm still invests at $t = 0$. In this case the regulator can extract the entire surplus from the firm – by transferring it to the consumer – without distorting the decision of investing at $t = 0$. This is socially optimal since the overall welfare function puts a greater weight to the consumer's surplus than the firm's profit as $\alpha < 1$.

Note that the sum of P_1^R and P_2^R is equal to $C + (c_1 + c_2)$. That is, when $\overline{NPV} > \overline{OD} = 0$, regulated prices that are equal to the average cost but do not include an option to delay value

provide the socially optimal investment incentives. This is the type of regulation that has been applied throughout the world over the last decades. Proposition 1 makes the useful but obvious point that standard regulation is optimal when the option to delay has no value.

The next proposition determines the optimal price regulation when the payoff of investing in an unregulated market at $t = 1$ under high demand is positive while the payoff in the low demand scenario is negative. That is, we look at the case where $OD^+ > 0$ and $OD^- = 0$.

As we will see below (Proposition 2b), under some circumstances it might not be possible for the regulator to extract all the surplus from the firm without distorting the decision of investing at $t = 0$. In such cases, the minimum prices that induce the firm to invest early provide an option to delay value, which can be lower than or equal to the option to delay value in an unregulated market.

In such cases, it is also convenient to define a constant $M > 0$, which is determined implicitly by regulation, as the value above the average total cost of investing at $t = 1$ (if demand is high) such

that we have $NPV = OD < \overline{OD}$. This is the price regulation that provides the minimum option to delay value to the firm such that it invests early. The price that satisfies this condition is

$$P_2^R = \bar{P}_2 - \frac{(\overline{NPV} - OD)}{Q}. \text{ Since we are referring to the second range of the option to delay}$$

function this price also satisfies the following condition $C_H + c_2 < P_2^R < C_L + c_2$. Then, there is a value $M > 0$ such that $P_2^R = C_H + c_2 + M$.

Proposition 2a: Suppose there is an expected demand level $\tilde{Q}$ such that $NPV(\bar{P}_1, \bar{P}_2, \tilde{Q}) = OD(\bar{P}_1, \bar{P}_2, \tilde{Q}) = 0$ and that the actual expected demand is such that $\overline{NPV} > \overline{OD}$, $OD^+ > 0$ and $OD^- = 0$ (see Figure 7). The optimal ex ante demand non-contingent price contract is $P_1^R = \bar{P}_1$ and $P_2^R = C + (c_1 + c_2) - \bar{P}_1$ (the firm invests at $t = 0$).

Proposition 2b: Suppose there is an expected demand level $\tilde{Q}$ such that $NPV(\bar{P}_1, \bar{P}_2, \tilde{Q}) = OD(\bar{P}_1, \bar{P}_2, \tilde{Q})$, $OD^+ > 0$ and $OD^- = 0$ (see Figure 5). When the actual expected demand $Q = \tilde{Q}$ is such that $\overline{NPV} = \overline{OD}$, $OD^+ > 0$ and $OD^- = 0$, the optimal ex

ante demand non-contingent price contract is $P_1^R = \bar{P}_1$ and $P_2^R = C_H + c_2$ if $p > \alpha \frac{\overline{NPV}}{\pi_{t=1}^H}$ (the

firm invests at $t = 1$ only if demand is high) or $P_1^R = \bar{P}_1$ and $P_2^R = \bar{P}_2$ if $p \leq \alpha \frac{\overline{NPV}}{\pi_{t=1}^H}$ (the firm

invests at $t = 0$). When the actual expected demand Q is such that $\overline{NPV} > \overline{OD}$, $OD^+ > 0$

and $OD^- = 0$, the optimal ex ante demand non-contingent price contract is $P_1^R = \bar{P}_1$ and

$P_2^R = C_H + c_2$ if $p > p^*$ (the firm invests at $t = 1$ only if demand turns out to be high) or

$P_1^R = \bar{P}_1$ and $P_2^R = C_H + c_2 + M$ if $p \leq p^*$ (the firm invests at $t = 0$), where

$$p^* = \frac{\left(\bar{P}_2 - (C_H + c_2 + M) \right) Q + \alpha \left\{ \left[\left(\bar{P}_1 - c_1 \right) + (C_H + M) \right] Q - I \right\}}{\pi_{t=1}^H}.$$

Proposition 2a characterises the conditions under which the regulator is able to extract the entire profit from the firm without changing its decision of investing at $t = 0$. When there is an expected demand such that the net present value and the option to delay value are equal to zero in an unregulated market, the regulator can set prices equal to the average total costs ($P_1^R = \bar{P}_1$ and $P_2^R = C + (c_1 + c_2) - \bar{P}_1$) and the firm invests at $t = 0$. In this case, regulated prices that are equal to the average costs but do not include an option to delay value provide the socially optimal investment incentives.

Proposition 2b characterises the conditions under which the regulator cannot set prices below a certain level without changing the firm's decision of investing at $t = 0$. For instance, to induce the firm to invest at $t = 0$ when $\overline{NPV} = \overline{OD}$ the regulator must provide to the firm an option to delay value that is equal to the option to delay value in an unregulated market. However, doing so might not be socially optimal as the total welfare when the firm invests at $t = 1$ might be higher than the total welfare when the firm invests at $t = 0$. The reason is that the prices that the regulator needs to set to induce the firm to invest at $t = 1$ are lower than the prices that induce the firm to invest at $t = 0$.

In particular, the minimum prices that induce the firm to invest at $t = 1$ when demand is high are equal to $P_1^R = \bar{P}_1$ and $P_2^R = C_H + c_2$. Under these prices, total regulated revenue is equal to the

average total costs of investing at $t = 1$ and the entire profit is transferred to consumers. However, the firm will only invest at $t = 1$ if demand is high. Proposition 2b shows that this alternative is optimal when $p > \alpha \frac{\overline{NPV}}{\pi_{t=1}^H}$, where $\alpha \overline{NPV}$ is the firm's profit when the firm invests early -- this is the welfare that is lost when the firm invests at $t = 1$ -- while $p\pi_{t=1}^H$ represents the expected consumer surplus and welfare when the firm delays its investment.

The same rationale can be applied to the case where $\overline{NPV} > \overline{OD}$. In this case optimal regulation will be one of the following: (i) $P_1^R = \bar{P}_1$ and $P_2^R = C_H + c_2 + M$, or (ii) $P_1^R = \bar{P}_1$ and $P_2^R = C_H + c_2$. Under (i) the firm invests at $t = 0$ (at these prices $NPV = OD < \overline{OD}$). Under (ii) the firm invests at $t = 1$ if demand is high. Which case is optimal depends on the probability of the high demand state. For a sufficiently high probability ($p > p^*$) (ii) is optimal. Note that the numerator of p^* is the sum of the consumer surplus generated by prices below market levels and α multiplied by the firm's profit, which is equal to the minimum option to delay value such that the firm invests early ($OD < \overline{OD}$). Note that this is the amount that is lost when there is an investment delay. However, an investment at $t = 1$ causes an increase in the consumer surplus such that the expected welfare at this period is equal to $p\pi_{t=1}^H$.

The next propositions characterise the optimal price regulation when the payoff of investing in an unregulated market at $t = 1$ under low demand is positive (i.e., $OD^- > 0$). We will see below that the optimal regulatory policy in the third range of the option to delay function has the same characteristics as seen in the second range of this function.

Proposition 3a: Suppose there is an expected demand $\tilde{Q}$ such that $NPV(\bar{P}_1, \bar{P}_2, \tilde{Q}) = OD(\bar{P}_1, \bar{P}_2, \tilde{Q}) = 0$ and that the actual expected demand is such that $\overline{NPV} > \overline{OD}$, $OD^+ > 0$ and $OD^- > 0$ (see Figure 7). The optimal ex ante demand non-contingent price contract is $P_1^R = \bar{P}_1$ and $P_2^R = C + (c_1 + c_2) - \bar{P}_1$ (the firm invests at $t = 0$).

Proposition 3b: Suppose there is an expected demand $\tilde{Q}$ such that $NPV(\bar{P}_1, \bar{P}_2, \tilde{Q}) = OD(\bar{P}_1, \bar{P}_2, \tilde{Q})$, $OD^+ > 0$ and $OD^- = 0$ and the actual expected demand Q is such that $\overline{NPV} > \overline{OD}$, $OD^+ > 0$ and $OD^- > 0$ (see Figure 5). The optimal ex ante demand non-contingent price contract is $P_1^R = \bar{P}_1$ and $P_2^R = C_H + c_2$ if $p > p^*$ (the firm invests at $t = 1$ only if demand turns out to be high) or $P_1^R = \bar{P}_1$ and $P_2^R = C_H + c_2 + M$ if $p \leq p^*$ (the firm invests at $t = 0$).

Proposition 3c: Suppose that $\overline{NPV} = \overline{OD}$, $OD^+ > 0$ and $OD^- > 0$ (see Figure 4). The optimal ex ante demand non-contingent price contract is $P_1^R = \bar{P}_1$ and $P_2^R = C_H + c_2$ if $p > p^{**}$, (the firm invests at $t = 1$ only if demand is high) or $P_1^R = \bar{P}_1$ and $P_2^R = C_L + c_2$ if $p \leq p^{**}$ (the firm invests at $t = 0$), where

$$p^{**} = \frac{\left[\left(\bar{P}_2 - (C_L + c_2) \right) Q + \alpha \left\{ \left[\left(\bar{P}_1 - c_1 \right) + C_L \right] Q - I \right\} \right]}{\pi_{t=1}^H}.$$

Preposition 3a is similar to Proposition 2a. That is, when there is an expected demand such that the net present value and the option to delay value are equivalent to zero in an unregulated market, the regulator can set prices equal to the average total costs ($P_1^R = \bar{P}_1$ and $P_2^R = C + (c_1 + c_2) - \bar{P}_1$) and the firm invests at $t = 0$. In this case, regulated prices that are equal to the average costs but do not include an option to delay provide the socially optimal investment incentives. Proposition 3b is equivalent to Proposition 2b. That is, when there is an expected demand such that the net present value is equal to the option to delay value in the second range of the OD function and the actual expected demand is such that the net present value is higher than the option to delay value ($\overline{NPV} > \overline{OD}$), both conditions holding in an unregulated market, the optimal regulation will be one of the following two possibilities: (i) $P_1^R = \bar{P}_1$ and $P_2^R = C_H + c_2 + M$ or (ii) $P_1^R = \bar{P}_1$ and $P_2^R = C_H + c_2$. The determination of which regulation is optimal depends on the probability of the high demand state. As above, approach (ii) is optimal when $p > p^*$.

Proposition 3c yields a new result. When the choke price in the first period is equal to the marginal cost of producing the service at the same period ($\bar{P}_1 = c_1$) we have $\overline{NPV} = \overline{OD}$ in the third range of the option to delay function (see Figure 4). Then, the minimum prices that induce the firm to invest at $t = 0$ are $P_1^R = \bar{P}_1$ and $P_2^R = C_L + c_2$. These prices include an option to delay value for the firm. Once more, to determine the optimal regulated prices, one must compare these prices with those that induce the firm to invest at $t = 1$ under high demand (i.e., $P_1^R = \bar{P}_1$ and $P_2^R = C_H + c_2$). In a similar manner to Proposition 3b above, the latter is optimal when the probability of the high demand state is sufficiently high (i.e., $p > p^{**}$). Note that the numerator of p^{**} is the sum of the consumer surplus generated by prices below market levels and α multiplied by the firm's profit, which is equal to the minimum option to delay value such that the firm invests early ($OD < \overline{OD}$); this amount is lost when there is an investment delay. However, an investment at $t = 1$ causes an increase in the consumer surplus such that the expected welfare at this period is equal to $p\pi_{t=1}^H$.

Note that $p^* > p^{**}$. This follows as the welfare generated by an early investment is higher under $P_1^R = \bar{P}_1$ and $P_2^R = C_H + c_2 + M$ than under $P_1^R = \bar{P}_1$ and $P_2^R = C_L + c_2$. The reason is that in the first regulation the minimum option to delay value that is necessary to induce the firm to invest early is lower than in the second case, that is, $C_H + c_2 + M < C_L + c_2$. Under the first price setting the regulator is able to extract more profit from the firm without changing its decision of investing early.

6. Access Regulation

This Section studies the effect of access price regulation on the firm's investment decision and total welfare. Our benchmark is an unregulated, vertically integrated firm who does not have to provide access to its network. This firm invests at $t = 0$, charges consumers prices for the new service that are equal to $\bar{P}_1$ at $t = 1$ and $\bar{P}_2$ at $t = 2$, and serve the entire demand at these prices. Under the benchmark the incumbent has no incentive to allow access to its network by downstream competitors.

To consider the effects of access price regulation, we assume that the regulator requires the incumbent to provide access to its network and sets the access prices. There are infinitely many potential entrants with the same technology as the incumbent and retail unit costs equal to c_{1E} at $t = 1$ and c_{2E} at $t = 2$. Firms compete à la Bertrand and consumers prefer to buy from the incumbent when prices are identical. We focus on two distinct access pricing methodologies: The Efficient Component Pricing Rule (ECPR) and the Option to Delay Pricing Rule (ODPR).

The important conceptual distinction between the analysis of retail price and access price regulation lies on the assumption of an infinite number of potential downstream competitors under the latter. When competitors are more efficient retailers than the incumbent, then access price regulation can always improve over the outcome of an unregulated monopolist who does not need to provide access to its network.

The more interesting and novel result is that even when the incumbent is more efficient than entrants, the threat of entry can be used to change the option value of the incumbent under an ODPR-based access price, whereas an ECPR-based access price preserves any monopoly rents. This means that under some market circumstances and when the probability of the high demand state is sufficiently high, we show below that a welfare-maximising regulator might be able to reduce the access price to a point where the firm will invest at $t = 1$ to earn a zero expected payoff.

6.1. The Efficient Component Pricing Rule - ECPR

The ECPR is a regulatory pricing rule that links retail and wholesale prices. It reflects the incumbent's true opportunity cost of selling one unit of access to an entrant and so comprises the resource costs of providing access as well as the revenue loss from selling one less unit in the retail market. At the ECPR, the incumbent is indifferent between providing access to entrants or providing the retail service itself.¹²

Thus, we can define the access price contract following the ECPR as:

$$A_1^{ECPR} = \bar{P}_1 - c_1 \text{ and } A_2^{ECPR} = \bar{P}_2 - c_2$$

¹² See, for example, Willig (1979) and Baumol (1983).

At this access prices the incumbent firm would be indifferent between providing access to the entrant and receiving A_1^{ECPR} and A_2^{ECPR} or providing the retail service itself and receiving $\bar{P}_1 - c_1$ and $\bar{P}_2 - c_2$. Under the ECPR any entrant with retail marginal costs c_{1E} and c_{2E} such that $(c_{1E} + c_{2E}) < (c_1 + c_2)$ can enter the market, provide the retail service and fulfil the entire demand at prices P_1^{ECPR} and P_2^{ECPR} such that the sum of the entrant's net revenue in both periods is equal to zero and the incumbent's decision of investing at $t = 0$ is not distorted. This is summarised as follows.

Proposition 4: When $(c_{1E} + c_{2E}) < (c_1 + c_2)$ the ECPR yields higher overall welfare and the same investment at $t = 0$ as an unregulated industry that is not required to provide access.

Note that when the potential entrant is less efficient than the incumbent (i.e., $(c_{1E} + c_{2E}) \geq (c_1 + c_2)$) an ECPR-based access price yields the same outcome as an unregulated monopolist as entry does not take place.

6.2 The Option to Delay Pricing Rule - ODPR

We define the access price contract following the Option to Delay Pricing Rule (ODPR) as:

$$A_1^{ODPR} = P_1^R - c_1 \text{ and } A_2^{ODPR} = P_2^R - c_2$$

That is, the access price under ODPR is equal to the difference between the maximizing-welfare retail price and the incumbent's marginal cost at each period. Table 6 in the Appendix shows all possible access prices under the ODPR.¹³ It follows that access prices under ODPR are lower or equal than prices under the ECPR. Thus, we can define a variable $Z \geq 0$ that satisfies $(A_1^{ECPR} + A_2^{ECPR}) - (A_1^{ODPR} + A_2^{ODPR}) = Z$. That is,

$$\left(\bar{P}_1 + \bar{P}_2 \right) - \left(P_1^R + P_2^R \right) = Z \quad (8)$$

Below we show how the outcome under Bertrand competition downstream depends on Z and on the incumbent's and entrant's marginal costs.

Proposition 5a characterises the market conditions where access prices under the ODPR and ECPR are identical while Propositions 5b and 5c characterise the market conditions where access prices under ODPR are lower than under the ECPR. In Proposition 5b access prices under ODPR are the minimum prices such that the incumbent firm invests early while in Proposition 5c access prices under ODPR are the minimum prices such that the incumbent firm invests at $t = 1$ when demand is high. The proofs of Propositions 5a to 5c are in the Appendix.

Proposition 5a: *When the unregulated market is characterised by one of the following*

conditions: (i) $\overline{NPV} = \overline{OD} = 0$ and (ii) $\overline{NPV} = \overline{OD}$, $OD^+ > 0$, $OD^- = 0$ and $p \leq \frac{\alpha \overline{NPV}}{\pi_{t=1}^H}$,

the ODPR generates the same overall welfare than the ECPR.

Proposition 5b: *Suppose the unregulated market is characterised by one of the following*

conditions: (i) $\overline{NPV} > \overline{OD} = 0$, (ii) there is an expected demand level $\tilde{Q}$ such that

$NPV(\bar{P}_1, \bar{P}_2, \tilde{Q}) = OD(\bar{P}_1, \bar{P}_2, \tilde{Q})$, $OD^+ > 0$ and $OD^- = 0$, and the actual expected demand

Q is such that $\overline{NPV} > \overline{OD}$, $OD^+ > 0$, $OD^- \geq 0$ and $p \leq p^$, (iii) there is an expected*

demand $\tilde{Q}$ such that $NPV(\bar{P}_1, \bar{P}_2, \tilde{Q}) = OD(\bar{P}_1, \bar{P}_2, \tilde{Q}) = 0$, and the actual expected demand is

such that $\overline{NPV} > \overline{OD}$, $OD^+ > 0$ and $OD^- \geq 0$ and (iv) $\overline{NPV} = \overline{OD}$, $OD^+ > 0$,

*$OD^- > 0$ and $p \leq p^{**}$. When the potential entrant is less efficient than the incumbent and*

$(c_{1E} + c_{2E}) \geq (c_1 + c_2) + Z$, the ODPR generates the same overall welfare as an unregulated

industry that is not required to provide access. When the potential entrant is less efficient than the

incumbent and $(c_1 + c_2) \leq (c_{1E} + c_{2E}) < (c_1 + c_2) + Z$, the ODPR generates higher overall

welfare than an unregulated industry that is not required to provide access. When the potential

entrant is more efficient than the incumbent (i.e., $(c_{1E} + c_{2E}) < (c_1 + c_2)$) the ODPR generates

higher overall welfare than the ECPR. In addition, the ODPR-based access price is lower than the

ECPR-based access price.

¹³ In order to avoid exclusionary conduct, this methodology must be applied in combination with an imputation test which assures that the incumbent firm will charge retail consumers a price greater than or equal to the cost of providing the service.

Proposition 5c: Suppose the unregulated market is characterised by one of the following

conditions: (i) $\overline{NPV} = \overline{OD}$, $OD^+ > 0$, $OD^- = 0$ and $p > \frac{\alpha \overline{NPV}}{\pi_{t=1}^H}$, (ii) there is an expected

demand level $\tilde{Q}$ such that $NPV(\bar{P}_1, \bar{P}_2, \tilde{Q}) = OD(\bar{P}_1, \bar{P}_2, \tilde{Q})$, $OD^+ > 0$ and $OD^- = 0$, and

the actual expected demand Q is such that $\overline{NPV} > \overline{OD}$, $OD^+ > 0$, $OD^- \geq 0$ and $p > p^*$

and (iii) $\overline{NPV} = \overline{OD}$, $OD^+ > 0$, $OD^- > 0$ and $p > p^{**}$. When the potential entrant is less efficient than the incumbent and $c_{2E} \geq c_2 + Z$, the ODPR generates a lower or equal overall welfare than an unregulated industry that is not required to provide access. When the potential entrant is less efficient than the incumbent and $c_2 \leq c_{2E} < c_2 + Z$, the ODPR generates higher overall welfare than an unregulated industry that is not required to provide access if

$p > p^{***}$ where $p^{***} = \frac{\alpha \overline{NPV}}{\left[\frac{(\bar{P}_2 - c_{2E})uQ}{(1+r)} - I \right] + \alpha \left[\frac{(c_{2E} - c_2)uQ}{(1+r)} \right]}$. When the potential entrant is

more efficient than the incumbent (i.e., $c_{2E} < c_2$) the ODPR generates higher overall welfare

than the ECPR if $p > p^{****}$ where $p^{****} = \frac{\left[(c_1 + c_2 - c_{1E} - c_{2E}) + \alpha \overline{NPV} \right]}{\left[\frac{(\bar{P}_2 - c_{2E})uQ}{(1+r)} - I \right]}$. In addition, the

ODPR-based access price is lower than the ECPR-based access price.

Proposition 5a characterises the market conditions where access prices under the ODPR and ECPR are identical. Under such conditions the ODPR generates the same welfare as the ECPR. Proposition 5b characterises the market conditions where access prices under ODPR are the minimum prices such that the incumbent firm still invests early. In this case, there are three possible outcomes under Bertrand competition between the incumbent and (infinitely many) potential entrants.

First, when the entrant is less efficient than the incumbent and $(c_{1E} + c_{2E}) \geq (c_1 + c_2) + Z$, the entrant can only offer retail prices above the choke prices. As a consequence, the incumbent

serves the market at the choke prices. Welfare under the ODPR is equivalent to an unregulated market and also to the ECPR. Second, when the entrant is less efficient than the incumbent and $(c_1 + c_2) \leq (c_{1E} + c_{2E}) < (c_1 + c_2) + Z$ the threat of entry leads the incumbent to reduce its prices such that $P_1^E + P_2^E = (A_1^{ODPR} + c_{1E}) + (A_2^{ODPR} + c_{2E})$ and $P_1^E + P_2^E < \bar{P}_1 + \bar{P}_2$. Under this condition the incumbent still serves the entire market under the ODPR. However, since the retail prices under ODPR are lower than the choke prices and the incumbent firm still invests early, this access regulation generates a higher welfare than the unregulated market and also the ECPR. In fact, under the ECPR potential entry only impacts prices when the entrant is more efficient than the incumbent. Third, when the potential entrant is more efficient than the incumbent, that is, $(c_{1E} + c_{2E}) < (c_1 + c_2)$ the incumbent cannot offer the same price conditions as the entrant's and consequently the entrant serves the market. Since access prices under the ODPR are lower than under the ECPR, retail prices under the former regulation are lower than those under the latter regulation as well. In fact, when the entrant serves the market retail prices are equal to the sum of access prices and marginal costs. Also, the firm invests at $t = 0$ under both access regulations. Thus, ODPR generates higher welfare than the ECPR.

Proposition 5c characterises the market conditions where access prices under ODPR are the minimum prices such that the incumbent firm invests at $t = 1$ when demand is high – recall that under the ECPR the incumbent firm always invest at $t = 0$. There are also three possible cases. First, when the entrant is less efficient than the incumbent and $c_{2E} \geq c_2 + Z$ the entrant can only offer a retail price above the choke price $\bar{P}_2$. As a consequence, the incumbent serve the market at the choke price. Note that in this case the welfare under the ODPR is equal to $\alpha \overline{OD}$. We know that in an unregulated market welfare is given by $\alpha \overline{NPV}$. Also, our benchmark is a monopolist firm that invests at $t = 0$, that is, $\overline{NPV} \geq \overline{OD}$. Thus, if $\overline{NPV} = \overline{OD}$, the ODPR generates the same welfare than an unregulated industry and when $\overline{NPV} > \overline{OD}$, the ODPR generates less welfare than an unregulated industry.

Second, when the potential entrant is less efficient than the incumbent and $c_2 \leq c_{2E} < c_2 + Z$, the threat of entry leads the incumbent to reduce its price such that $P_2^E = c_{2E} + C_H$ and $P_2^E < \bar{P}_2$. Note that the incumbent still serves the market but this access regulation extracts part of the firm's profit, transferring it to the consumer surplus. In this case we will have an optimality rule that will depend on α and p . Under the ODPR consumer surplus is positive while in an

unregulated market it is zero. However, the incumbent firm invests at $t = 0$ in an unregulated market and at $t = 1$ in case demand turns out to be high under the ODPR. Then, the ODPR will be optimal only if the probability of the high demand state is larger than p^{***} . Note that the denominator of p^{***} is the sum of the consumer surplus and the incumbent's profit under the ODPR. This surplus (weighted by the probability of the high demand state p) must be larger than the firm's profit in an unregulated market weighted by α -- the amount that is lost when the firm delays its investment -- to be socially optimal to have investment at $t = 1$ as induced by an ODPR-based access price.

Third, when the potential entrant is more efficient than the incumbent (i.e., $c_{2E} < c_2$), both the incumbent's and entrant's profits are equal to zero. In this case, the entire profit is transferred to the consumer surplus. However, as in the previous case under the ECPR the incumbent firm invests at $t = 0$ and under the ODPR at $t = 1$ in case demand turns out to be high. Once more, the ODPR will be optimal only if the probability of the high demand state is larger than p^{****} . Note that the denominator of p^{****} is the consumer surplus under the ODPR. This surplus (weighted by the probability of the high demand state p) must be larger than the sum of the consumer surplus generated by lower retail prices and the firm's profit weighted by α under the ECPR -- the amount that is lost when the firm delays its investment -- for an ODPR-based access price to be optimal.

Thus, we have shown that the ODPR generates (weakly) higher welfare than the ECPR, except under very specific circumstances. The main reason is that under an option-to-delay pricing rule, even an inefficient entrant can constraint the monopoly rents that the incumbent can extract, whereas an ECPR price embeds full monopoly rents.

7. Conclusion

In this paper we examine a simple three-period investment model in a network industry characterized by demand uncertainty, economies of scale and sunk costs. In this model a firm may invest in the first period or wait until the second period to decide whether to invest in the network.

This paper differs from the earlier literature in that it explicitly determines the optimal price regulation when investments are sunk and irreversible. In general, whether optimal regulated prices should incorporate an option to delay value will depend on demand conditions.

In particular, in the absence of retail competition, there are three possible optimal scenarios: regulated prices that provide a zero payoff to the firm, regulated prices that include an option to delay value and provide a positive payoff to the firm and no regulation. From a policy perspective, this indicates that regulated prices that exclude an option to delay and that are designed to yield zero economic profits might not be optimal.

When retail competition is possible, we show that an access price that incorporates an option to delay value (ODPR) often yields higher welfare than the ECPR. This contrasts with Pindyck (2004) who found that when there is entry the entrant's expected gain is identical to the incumbent's expected loss. Pindyck suggests that in order to account for the option to delay value the access price should be set according to an ECPR-based methodology; the price at which the incumbent would be indifferent between providing access to entrants or providing the retail service itself. At this price, the entrant's expected cash flow would be set equal to zero. In contrast, when entry is possible in our model, the entrant's expected gain in equilibrium is equal to zero - this follows from the assumption of a perfectly elastic supply of entrants - and the incumbent's expected loss equals the expected increase in consumer surplus. In this environment and under most circumstances, the ODPR-based access price, which is lower or equal than the ECPR is sufficient to provide the appropriate investment incentives and generates at least the same welfare. It is also important to note that in contrast with the ECPR methodology, under ODPR-based access price the potential entrant constrains the monopoly power of the vertically integrated firm even when the entrant is less efficient than the incumbent. In this case, the incumbent is required to charge a lower retail price to block entry by an inefficient entrant.

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Appendix

Proof of Lemma 1: In a risk-neutral world, all assets would earn the risk-free return r , and so expected cash flows (weighted by the risk-neutral probabilities, p and $(1-p)$) could be appropriately discounted at the risk-free rate. Note that in this case the investment outlay to build the network at $t = 1$ is equal to $(1+r)I$.

Likewise, it is easy to see that in a risk-neutral world the expected return on the investment must equal the risk-free rate, that is,

$$pR^+ + (1-p)R^- = r.$$

The risk-neutral probability p can be obtained from the equation above where

$$R^+ = \frac{\left(\bar{P}_1 - c_1\right)uQ + \frac{p\left(\bar{P}_2 - c_2\right)u^2Q + (1-p)\left(\bar{P}_2 - c_2\right)udQ}{(1+r)} - (1+r)I}{\left[\left(\bar{P}_1 - c_1\right) + \left(\bar{P}_2 - c_2\right)\right]Q - I} - 1 \text{ is the return under}$$

the high demand, and

$$R^- = \frac{\left(\bar{P}_1 - c_1\right)dQ + \frac{p\left(\bar{P}_2 - c_2\right)udQ + (1-p)\left(\bar{P}_2 - c_2\right)d^2Q}{(1+r)} - (1+r)I}{\left[\left(\bar{P}_1 - c_1\right) + \left(\bar{P}_2 - c_2\right)\right]Q - I} - 1 \text{ is the return if the}$$

demand is low. Solving for p yields

$$p = \frac{(1+r) - d}{u - d} \quad \square$$

Proof of Lemma 2: The graphs below (Figures 3 to 7) show payoff associated with investment decisions where $\overline{OD}$ and $\overline{NPV}$ are functions of Q . These figures were constructed using the same values of $\bar{P}_2$, c_1 , c_2 , I , r , u and d . However, each figure is draw with a different value for $\bar{P}_1$. The monopolist learns the expected demand Q and then decides whether to invest in the network facility.

Figure 3 below shows that if $\left(\bar{P}_1 - c_1\right) < 0$ then $\overline{NPV} < \overline{OD}$ for all values of expected demand Q . The reason is that there is no advantage of investing at $t = 0$ because the first period cash flow is negative for all Q .

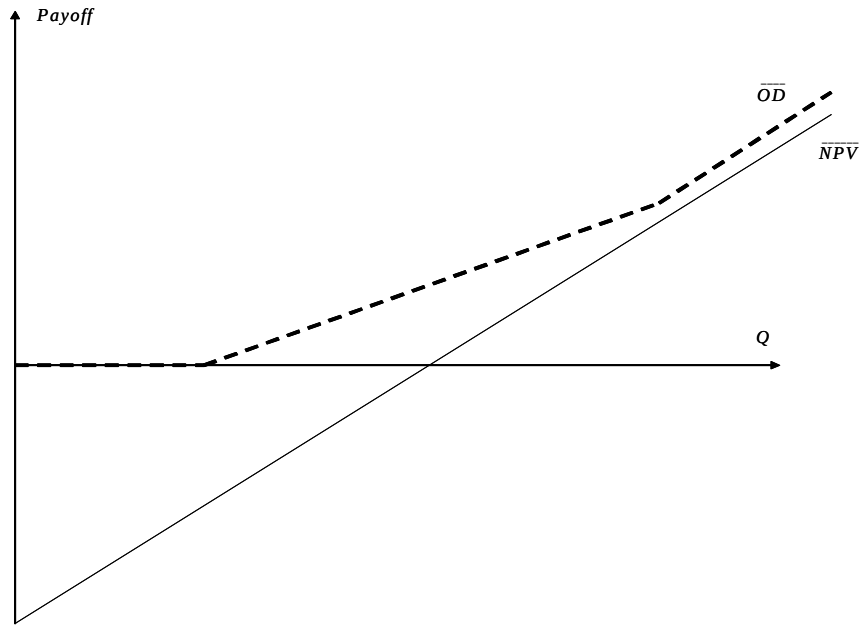


Figure 3

Table 2 below summarizes the investment decision outputs when $\left(\bar{P}_1 - c_1\right) < 0$:

Investment Decision	Condition
The firm never invests if	$\overline{OD} = 0$
The firm invests at $t = 1$ if	$q_1 = uQ$, $OD^+ > 0$ and $OD^- = 0$
The firm always invests at $t = 1$ if	$OD^+ > 0$ and $OD^- > 0$

Table 2

If $\left(\bar{P}_1 - c_1\right) = 0$, the first period net revenue is always equal to zero and then $\overline{NPV} \leq \overline{OD}$ for all

expected demand Q (Figure 4). Moreover, $\overline{NPV} = \overline{OD}$ when $OD^- > 0$.

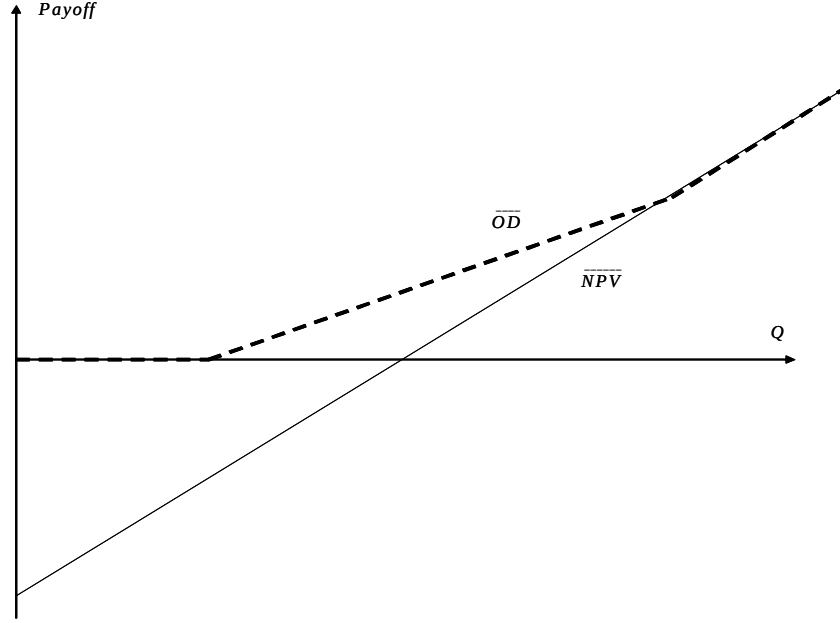


Figure 4

Note that when Q is such that $OD^- > 0$, the firm would invest at $t = 1$ in all states of demand.

Thus, in this case the firm is indifferent between investing at $t = 0$ and at $t = 1$. Table 3 below

summarizes the investment decision outputs when $\left(\bar{P}_1 - c_1\right) = 0$:

Investment Decision	Condition
The firm never invests if	$\overline{OD} = 0$
The firm invests at $t = 1$ if	$q_1 = uQ$, $OD^+ > 0$ and $OD^- = 0$
The firm is indifferent between investing at $t = 0$ or at $t = 1$ (and we will assume that the firm invests at $t = 0$) if	$OD^+ > 0$ and $OD^- > 0$ ($\overline{NPV} = \overline{OD}$)

Table 3

If $\left(\bar{P}_1 - c_1\right) > 0$ then $\overline{NPV} > \overline{OD}$ for a sufficiently large Q . Moreover, under this condition there are three possible cases that basically depend on the magnitude of $\left(\bar{P}_1 - c_1\right)$. We will proceed to define these cases as $\left(\bar{P}_1 - c_1\right)$ increases:

In the first case, there is a Q such that $\overline{NPV} = \overline{OD} > 0$, $OD^+ > 0$ and $OD^- = 0$ (Figure 5). For all expected demand larger or equal than that Q , $\overline{NPV} \geq \overline{OD}$ and as a consequence the firm will invest at $t = 0$.

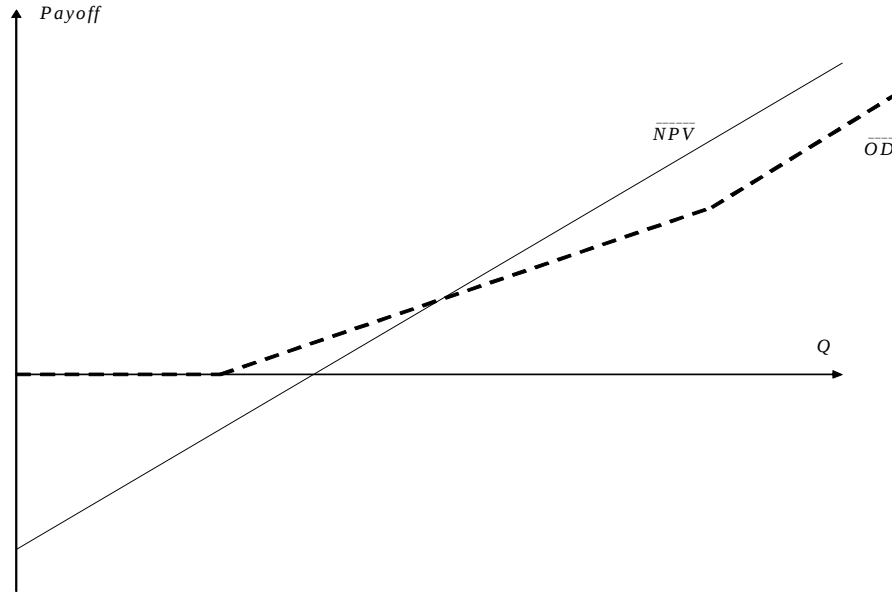


Figure 5

Table 4 below summarizes the investment decision outputs:

Investment Decision	Condition
The firm never invests if	$\overline{OD} = 0$
The firm invests at $t = 1$ if	$q_1 = uQ$, $OD^+ > 0$, $OD^- = 0$ and $\overline{NPV} < \overline{OD}$
The firm invests at $t = 0$ if	$\overline{NPV} \geq \overline{OD}$, $OD^+ > 0$ and $OD^- \geq 0$

Table 4

In the second case $\overline{NPV} = \overline{OD}$ for the large expected demand Q , named Q^* , such that $\overline{OD} = 0$ (Figure 6). Once more, for all expected demand larger or equal than Q^* , $\overline{NPV} \geq \overline{OD}$ and as a consequence the firm will invest at $t = 0$.

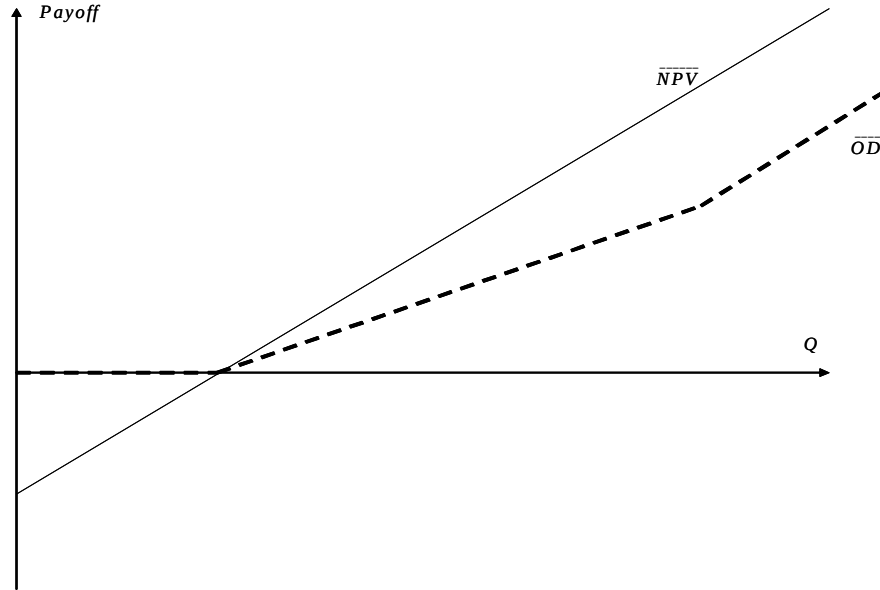


Figure 6

Table 5 below summarizes the investment decision outputs:

Investment Decision	Condition
The firm never invests if	$\overline{OD} = 0$ and $\overline{NPV} < \overline{OD}$
The firm invests at $t = 0$ if	$\overline{NPV} \geq \overline{OD} \geq 0$

Table 5

In the third situation there is a $Q < Q^*$ such that $\overline{NPV} = \overline{OD} = 0$ (Figure 7). Once more, for all expected demand larger or equal than Q , $\overline{NPV} \geq \overline{OD}$ and as a consequence the firm will invest at $t = 0$.

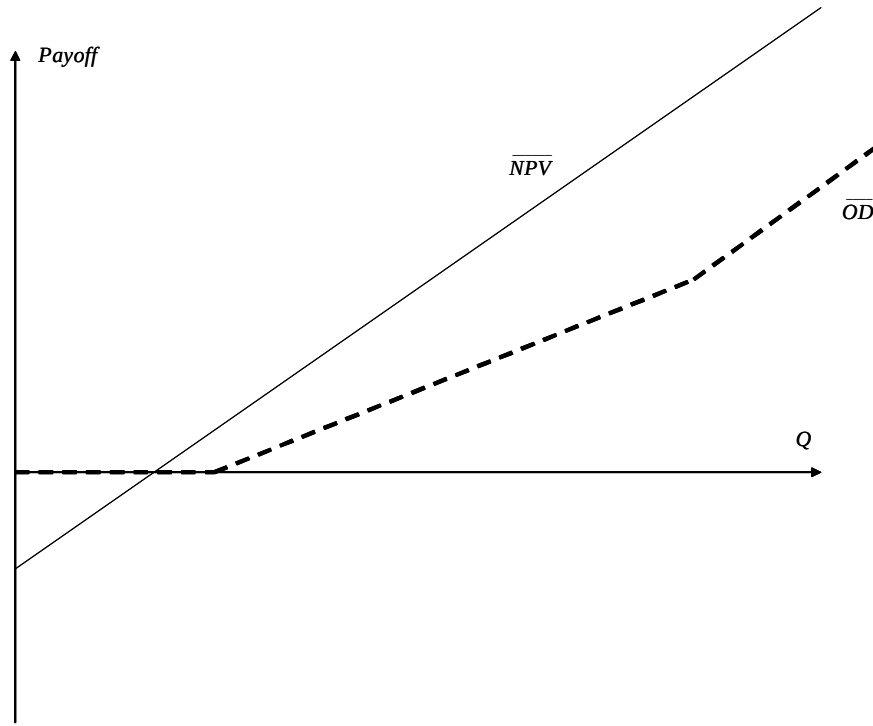


Figure 7

Note that the investment decision outputs are also given by Table 5 above. $\square$

Proof of Proposition 1: If $\overline{NPV} = \overline{OD} = 0$ there is no need for regulation as the best the regulator can do is to replicate the unregulated market outcomes by setting $P_1^R = \bar{P}_1$ and $P_2^R = \bar{P}_2$. Indeed, if the regulator sets the regulated prices below market levels the firm will not invest. If $\overline{NPV} > \overline{OD} = 0$ then the regulator can set, for instance, $P_1^R = \bar{P}_1 - \frac{\overline{NPV}}{Q} = C + (c_1 + c_2) - \bar{P}_2$ and $P_2^R = \bar{P}_2$ such that we have $NPV = \overline{OD} = 0$. In this case the firm invests at $t = 0$ and total welfare is equal to:

$$W_R = \left[\bar{P}_1 - \left(\bar{P}_1 - \frac{\overline{NPV}}{Q} \right) \right] Q + \alpha \left\{ \left[\left(\bar{P}_1 - \frac{\overline{NPV}}{Q} - c_1 \right) + \left(\bar{P}_2 - c_2 \right) \right] Q - I \right\} \quad (9)$$

The welfare obtained with this regulatory policy must be compared to the unregulated market welfare. The difference between (9) and (4) is equal to $(1 - \alpha)\overline{NPV} > 0$. This is the optimal

regulation since these are the minimum prices that induce the firm to invest in the network facility.

□

Proof of Proposition 2a: Suppose there is an expected demand $\tilde{Q}$ such that $NPV(\bar{P}_1, \bar{P}_2, \tilde{Q}) = OD(\bar{P}_1, \bar{P}_2, \tilde{Q}) = 0$ and the actual expected demand is such that $\overline{NPV} > \overline{OD}$, $OD^+ > 0$ and $OD^- = 0$. In this case it is easy to see that the regulator is able to extract the entire profit from the firm and it will still invest at $t = 0$. This price setting is $P_1^R = \bar{P}_1$ and $P_2^R = \bar{P}_2 - \frac{\overline{NPV}}{Q} = C + (c_1 + c_2) - \bar{P}_1$ and the total welfare at $t = 0$ is given by:

$$W_R = \left[\bar{P}_2 - \left(\bar{P}_2 - \frac{\overline{NPV}}{Q} \right) \right] Q + \alpha \left\{ \left[\left(\bar{P}_1 - c_1 \right) + \left(\bar{P}_2 - \frac{\overline{NPV}}{Q} - c_2 \right) \right] Q - I \right\} \quad (10)$$

The welfare obtained with this regulatory policy must be compared to the unregulated market welfare. It can be seen that the difference between (10) and (4) is equal to $(1 - \alpha)\overline{NPV} > 0$. This is the optimal regulation since these are the minimum prices that induce the firm to invest in the network facility. □

Proof of Proposition 2b: Suppose there is an expected demand $\tilde{Q}$ such that $NPV(\bar{P}_1, \bar{P}_2, \tilde{Q}) = OD(\bar{P}_1, \bar{P}_2, \tilde{Q})$, $OD^+ > 0$ and $OD^- = 0$.

When $Q = \tilde{Q}$ we have $\overline{NPV} = \overline{OD}$, $OD^+ > 0$ and $OD^- = 0$. Under this scenario an unregulated monopolist invests at $t = 0$, welfare is given by (4) and is equal to $\alpha \overline{NPV}$.

On one hand, since $\overline{NPV} = \overline{OD}$ the minimum regulated prices that induce investment at $t = 0$ are $P_1^R = \bar{P}_1$ and $P_2^R = \bar{P}_2$. Indeed, it is easy to see that any price setting below market levels

induces the firm to invest at $t = 1$ if demand turns out to be high or even to not invest. In this case the overall welfare is equivalent to the unregulated market welfare, that is, $\alpha \overline{NPV}$.

On the other hand, the minimum regulated prices that induce investment at $t = 1$ if demand turns out to be high is $P_1^R = \bar{P}_1$ and $P_2^R = C_H + c_2$. If the regulator were to set $P_2^R < C_H + c_2$ then the firm would not invest.

In this case the overall welfare is equal to

$$W_R = \frac{p \left(\bar{P}_2 - \left(\frac{(1+r)I}{uQ} + c_2 \right) \right) uQ}{(1+r)} = p \pi_{t=1}^H \quad (11)$$

Thus, this price regulation is optimal only if $p \pi_{t=1}^H > \alpha \overline{NPV}$. Then, we have $p > \frac{\alpha \overline{NPV}}{\pi_{t=1}^H}$.

When Q is such that $\overline{NPV} > \overline{OD}$, $OD^+ > 0$ and $OD^- = 0$, the minimum regulated prices that induce investment at $t = 0$ are $P_1^R = \bar{P}_1$ and $P_2^R < \bar{P}_2$ such that $NPV = OD < \overline{OD}$. As $OD^+ > 0$ and $OD^- = 0$ we have $C_H + c_2 < P_2^R < C_L + c_2$. Then, there is a $M > 0$, such that $P_2^R = C_H + c_2 + M < C_L + c_2$ and $NPV = OD$. The total welfare at $t = 0$ is given by:

$$W_R = \left[\bar{P}_2 - (C_H + c_2 + M) \right] Q + \alpha \left\{ \left[\left(\bar{P}_1 - c_1 \right) + ((C_H + c_2 + M) - c_2) \right] Q - I \right\} \quad (12)$$

On the other hand, the minimum regulated prices that induce investment at $t = 1$ if demand turns out to be high are $P_1^R = \bar{P}_1$ and $P_2^R = C_H + c_2$. In this case the overall welfare is given by (11).

Then, the price setting $P_1^R = \bar{P}_1$ and $P_2^R = C_H + c_2$ is optimal when

$$p > \frac{\left(\bar{P}_2 - (C_H + c_2 + M) \right) Q + \alpha \left\{ \left[\left(\bar{P}_1 - c_1 \right) + (C_H + M) \right] Q - I \right\}}{\pi_{t=1}^H} = p^* \quad \square$$

Proof of Proposition 3a: Suppose there is an expected demand $\tilde{Q}$ such that $NPV(\bar{P}_1, \bar{P}_2, \tilde{Q}) = OD(\bar{P}_1, \bar{P}_2, \tilde{Q}) = 0$ and the actual expected demand Q is such that $\overline{NPV} > \overline{OD}$, $OD^+ > 0$ and $OD^- > 0$. It is easy to see that the optimal prices are the same as in Proposition 2a since the regulator is able to extract all the rents from the firm while it still invests at $t = 0$. $\square$

Proof of Proposition 3b: Suppose there is an expected demand $\tilde{Q}$ such that $NPV(\bar{P}_1, \bar{P}_2, \tilde{Q}) = OD(\bar{P}_1, \bar{P}_2, \tilde{Q})$, $OD^+ > 0$ and $OD^- = 0$ and the actual expected demand Q is such that $\overline{NPV} > \overline{OD}$, $OD^+ > 0$ and $OD^- > 0$. As seen in Proposition 2b, the minimum regulated prices that induce investment at $t = 0$ is $P_1^R = \bar{P}_1$ and $P_2^R = C_H + c_2 + M$ such that $NPV = OD < \overline{OD}$ and the total welfare under these prices at $t = 0$ is given by (12). On the other hand, the minimum regulated prices that induce investment at $t = 1$ if demand turns out to be high is $P_1^R = \bar{P}_1$ and $P_2^R = C_H + c_2$. In this case the overall welfare is equal to (11). The optimal strategy rule is the same as the one included in Proposition 2b. $\square$

Proof of Proposition 3c: Suppose $\bar{P}_1 = c_1$, $\bar{P}_2$ and Q are such that $\overline{NPV} = \overline{OD}$, $OD^+ > 0$ and $OD^- > 0$. On one hand, the minimum regulated prices that induce investment at $t = 0$ is $P_1^R = \bar{P}_1$ and $P_2^R = C_L + c_2 < \bar{P}_2$ such that $NPV = OD < \overline{OD}$.¹⁴ The total welfare is given by:

$$W_R = \left[\bar{P}_2 - (C_L + c_2) \right] Q + \alpha \left\{ \left[\left(\bar{P}_1 - c_1 \right) + \left((C_L + c_2) - c_2 \right) \right] Q - I \right\} \quad (13)$$

On the other hand, the minimum regulated prices that induce investment at $t = 1$ if demand turns out to be high is $P_1^R = \bar{P}_1$ and $P_2^R = C_H + c_2$. In this case the overall welfare is given by (11). These prices are optimal when

¹⁴ Note that there is a market condition such that $\overline{NPV} = \overline{OD} = OD$. In this case $\bar{P}_2 = C_L + c_2$.

$$p > \frac{\left\{ \left[\left(\bar{P}_2 - (C_L + c_2) \right) \right] Q + \alpha \left\{ \left[\left(\bar{P}_1 - c_1 \right) + C_L \right] Q - I \right\} \right\}}{\pi_{t=1}^H} = p^{**} \quad \square$$

Table 6 below shows the different access prices under ODPR. We will proceed to characterize welfare under this access regulation.

ODPR Access Pricing

Cases	Conditions	Access Prices
1	$\overline{NPV} = \overline{OD} = 0$	$A_1^{ODPR} = \bar{P}_1 - c_1$ and $A_2^{ODPR} = \bar{P}_2 - c_2$
2	$\overline{NPV} > \overline{OD} = 0$	$A_1^{ODPR} = C + c_2 - \bar{P}_2$ and $A_2^{ODPR} = \bar{P}_2 - c_2$
3	$\overline{NPV} = \overline{OD}$, $OD^+ > 0$ and $OD^- = 0$	$A_1^{ODPR} = \bar{P}_1 - c_1$ and $A_2^{ODPR} = \bar{P}_2 - c_2$ or $A_1^{ODPR} = \bar{P}_1 - c_1$ and $A_2^{ODPR} = C_H$
4	$\overline{NPV} > \overline{OD}$, $OD^+ > 0$ and $OD^- \geq 0$ (Figure 5)	$A_1^{ODPR} = \bar{P}_1 - c_1$ and $A_2^{ODPR} = C_H + M$ or $A_1^{ODPR} = \bar{P}_1 - c_1$ and $A_2^{ODPR} = C_H$
5	$\overline{NPV} > \overline{OD}$, $OD^+ > 0$ and $OD^- \geq 0$ (Figure 7)	$A_1^{ODPR} = \bar{P}_1 - c_1$ and $A_2^{ODPR} = C + c_1 - \bar{P}_1$
6	$\overline{NPV} = \overline{OD}$, $OD^+ > 0$ and $OD^- > 0$	$A_1^{ODPR} = \bar{P}_1 - c_1$ and $A_2^{ODPR} = C_L$ or $A_1^{ODPR} = \bar{P}_1 - c_1$ and $A_2^{ODPR} = C_H$

Table 6

Propositions 4 and 5a are straightforward. We proceed to demonstrate Proposition 5b.

Proof of Proposition 5b: Table 7 below shows the three possible outcomes under Bertrand competition between the incumbent and (infinitely many) potential entrants:

Entrant's Marginal Cost	Retail Prices at $t = 1$ and at $t = 2$	Retail Service Provided By
$(c_{1E} + c_{2E}) \geq (c_1 + c_2) + Z$	$\bar{P}_1$ and $\bar{P}_2$	Incumbent
$(c_1 + c_2) \leq (c_{1E} + c_{2E}) < (c_1 + c_2) + Z$	P_1^E and P_2^E such that $P_1^E + P_2^E = (A_1^{ODPR} + c_{1E}) + (A_2^{ODPR} + c_{2E})$	Incumbent
$(c_{1E} + c_{2E}) < (c_1 + c_2)$	P_1^E and P_2^E such that $P_1^E + P_2^E = (A_1^{ODPR} + c_{1E}) + (A_2^{ODPR} + c_{2E})$	Entrant

Table 7

We will proceed to characterise welfare under the ECPR. Note first that under this access regulation the incumbent always invest at $t = 0$. Note also that under the ECPR, entry only occurs when $(c_{1E} + c_{2E}) < (c_1 + c_2)$. So, when $(c_{1E} + c_{2E}) \geq (c_1 + c_2)$, the welfare generated by the ECPR and by an unregulated market are equivalent. On the other hand, when $(c_{1E} + c_{2E}) < (c_1 + c_2)$ we have the following welfare function at $t = 0$:

$$W_{ECPR} = \left[\left(\bar{P}_1 - P_1^{ECPR} \right) + \left(\bar{P}_2 - P_2^{ECPR} \right) \right] Q + \alpha \{ (A_1^{ECPR} + A_2^{ECPR}) Q - I + [(P_1^{ECPR} - (A_1^{ECPR} + c_{1E})) + (P_2^{ECPR} - (A_2^{ECPR} + c_{2E}))] Q \} \quad (14)$$

Now, we proceed to analyse the ODPR. When the entrant is less efficient than the incumbent and $(c_{1E} + c_{2E}) \geq (c_1 + c_2) + Z$ it is easy to see that the entrant can only offer retail prices above the choke prices. As a consequence, the incumbent serve the market at the choke prices. Welfare under the ODPR is equivalent to an unregulated market. When the potential entrant is less efficient than the incumbent and $(c_1 + c_2) \leq (c_{1E} + c_{2E}) < (c_1 + c_2) + Z$ the ODPR creates the following overall expected welfare function at $t = 0$:

$$W_{ODPR} = \left[\left(\bar{P}_1 - P_1^E \right) + \left(\bar{P}_2 - P_2^E \right) \right] Q + \alpha \{ (P_1^E - c_1) + (P_2^E - c_2) \} Q - I \quad (15)$$

When $(c_1 + c_2) \leq (c_{1E} + c_{2E}) < (c_1 + c_2) + Z$, we must compare the ODPR with the unregulated monopoly case. The difference between (15) and (4) is equal to $(1 - \alpha)(Z + (c_1 + c_2) - (c_{1E} + c_{2E}))Q > 0$.

When the potential entrant is more efficient than the incumbent (i.e., $(c_{1E} + c_{2E}) < (c_1 + c_2)$), ODPR yields the following overall expected welfare function at $t = 0$:

$$W_{ODPR} = \left[\left(\bar{P}_1 - P_1^E \right) + \left(\bar{P}_2 - P_2^E \right) \right] Q + \alpha \left\{ \left(A_1^{ODPR} + A_2^{ODPR} \right) Q - I + \left[\left(P_1^E - \left(A_1^{ODPR} + c_{1E} \right) \right) + \left(P_2^E - \left(A_2^{ODPR} + c_{2E} \right) \right) \right] Q \right\} \quad (16)$$

In this case, we compare the ODPR with the ECPR. The difference between (16) and (14) is equal to $(1 - \alpha)ZQ > 0$. $\square$

Proof of Proposition 5c: We will proceed to analyse the cases where $A_1^{ODPR} = \bar{P}_1 - c_1$ and $A_2^{ODPR} = C_H$. The incumbent does not know the entrant's costs. So, under this policy the firm will invest at $t = 1$ only if demand turns out to be high. Also, we can define $\bar{P}_2 = C_H + c_2 + Z$ where $Z > 0$. Table 8 below shows the three possible outcomes under Bertrand competition between the incumbent and (infinitely many) potential entrants:

Entrant's Marginal Cost	Retail Price at $t = 2$	Retail Service Provided By
$c_{2E} \geq c_2 + Z$	$\bar{P}_2$	Incumbent
$c_2 \leq c_{2E} < c_2 + Z$	P_2^E such that $P_2^E = c_{2E} + C_H$	Incumbent
$c_{2E} < c_2$	P_2^E such that $P_2^E = c_{2E} + C_H$	Entrant

Table 8

When the entrant is less efficient than the incumbent and $c_{2E} \geq c_2 + Z$ it is easy to see that the entrant can only offer a retail price above the choke price. As a consequence, the incumbent serves the market at the choke price. However, the incumbent only invests at $t = 1$ if demand is high. Thus, welfare under the ODPR is equal to $\alpha p \pi_{t=1}^H$. We know that in an unregulated market welfare is given by $\alpha \overline{NPV}$. We also know that under our benchmark the firm invests at $t = 0$, that is, $\overline{NPV} \geq \overline{OD}$. Thus, if $\overline{NPV} = \overline{OD}$ the ODPR generates the same welfare than an

unregulated industry and when $\overline{NPV} > \overline{OD}$ the ODPR generates less welfare than an unregulated industry.

When the potential entrant is less efficient than the incumbent and $c_2 \leq c_{2E} < c_2 + Z$, the threat of entry leads the incumbent to reduce its prices such that $P_2^E = c_{2E} + C_H$ and $P_2^E < \bar{P}_2$. In this case the ODPR creates the following overall expected welfare function at $t = 0$:

$$W_{ODPR} = \frac{p \left(\bar{P}_2 - (C_H + c_{2E}) \right) uQ}{(1+r)} + \alpha \frac{p \left[((C_H + c_{2E}) - c_2) uQ - (1+r)I \right]}{(1+r)} \quad (17)$$

Once more, we must compare the ODPR with the unregulated monopoly case. The difference

between (17) and (4) is positive only if $p > \frac{\alpha \overline{NPV}}{\left[\frac{\left(\bar{P}_2 - c_{2E} \right) uQ}{(1+r)} - I \right] + \alpha \left[\frac{(c_{2E} - c_2) uQ}{(1+r)} \right]} = p^{***}$.

When the potential entrant is more efficient than the incumbent (i.e., $c_{2E} < c_2$), ODPR yields the following overall expected welfare function at $t = 0$ (note that the incumbent's and entrant's profits are equal to zero):

$$W_{ODPR} = \frac{p \left(\bar{P}_2 - (C_H + c_{2E}) \right) uQ}{(1+r)} \quad (18)$$

The difference between (18) and (14) is positive only if

$$p > \frac{\left[(c_1 + c_2 - c_{1E} - c_{2E}) + \alpha \overline{NPV} \right]}{\left[\frac{\left(\bar{P}_2 - c_{2E} \right) uQ}{(1+r)} - I \right]} = p^{****}. \quad \square$$