Access Pricing and Investment: A Real Options Approach [#]

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Sept 2008

Abstract: This paper examines a three-period model of an investment decision in a network industry characterized by demand uncertainty, economies of scale and sunk costs. In the absence of regulation we identify the market conditions under which a monopolist decides to invest early as well as the underlying overall welfare output. In a regulated environment, we consider a vertically integrated network provider that is required to provide access to downstream competitors and compare two distinct access pricing methodologies: the ECPR and the ODPR, an option to delay pricing rule. We identify the welfare-maximising access prices using the unregulated market output as a benchmark and show that optimal access regulation depends on market conditions (that is, the nature of demand) and there are two possible outcomes: (i) access prices that provide a positive payoff to the incumbent, that is, provide a positive compensation to account for the option to delay; and (ii) access prices that yield a zero payoff to the incumbent. Moreover, unlike the earlier literature that argues 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 is welfare-superior to the ECPR.

JEL Classification: L51
Key-words: real options; option to delay; regulation and investment; access pricing

[#] This paper is part of Fernando Camacho's PhD project at The University of Queensland, which investigates the relationship between regulation and investment. Camacho acknowledges the financial assistance from the University of Queensland and the Brazilian Development Bank and Menezes the support from the Australian Research Council (ARC Grants DP 0557885 and 0663768). We are thankful to a referee for very insightful suggestions and to participants at PET 08 for useful comments. The usual disclaimer applies.

1. Introduction

The role of access price regulation has experienced a significant shift in many countries. At its inception, following a wave of deregulation in retail markets, the prices under which competing firms have access to networks provided by rivals were designed to promote static efficiency. This was accomplished through the establishment of cost reduction mechanisms in an environment where capacity constraints were lax in many industries. Despite the development of several distinct methodologies, access prices have by and large been set in order to secure a zero net present value (NPV) for incumbent firms.

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 access price regulation from promoting static efficiency towards supporting dynamic efficiency and, therefore, providing appropriate investment incentives.

Although it is not the responsibility of regulators to provide firms with incentives to make particular investments, 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.

From a theoretical perspective, the combination of uncertainty, irreversibility and investment timing flexibility provides the building blocks of the option to delay theory. Although the concept of the option to delay has been extensively studied in competitive markets,[1] its implications on regulated prices and investment incentives are less well understood.

Under the option to delay theory, a firm will invest in a project today if its NPV is higher than or equal to the NPV of investing at anytime in the future. Therefore, as a result of such options to delay, profit-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 access price at a level that yields an NPV equal to zero might distort the firm's investment decision. As a result, traditional regulation, which focuses on setting the access 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.

[1] See, for example, Dixit and Pindyck (1994) and Trigeorgis (1996).

This has been recognised in the regulatory economics literature for quite some time. One of the earliest sets of papers that addressed the relation between regulation and the option to delay was Teisberg (1993 and 1994). Both articles focus on a firm's decision to delay investment when this firm is faced with uncertain and asymmetric profit and loss restrictions due to regulation. Teisberg shows that the value of an 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. As a result, regulation might lead a firm to delay its investment.

Other important references include those by Hausman (1999) and Hausman and Myers (2002). These authors focus on access pricing methodologies and asymmetric rights between incumbents and entrants in the telecommunications and railroad industries. They point out that incumbent providers are forced to grant to new entrants a free option, where such option is the right but not the obligation to purchase the use of the incumbent's network. They conclude that a mark up factor must be applied to the investment cost component of current methods to compensate incumbents for this option value. For instance, Hausman and Myers (2002) shows that the required return calculated from a regulator's model ignoring demand uncertainty and irreversibility is lower than the optimal amount; the size of the error vis-à-vis the optimal amount lies between 30% and 84.4%. This result suggests that the incumbent should always receive a positive compensation to account for the option to delay.

Pindyck (2004 and 2005) also address the impact of the network sharing arrangements in the telecommunications industry. As in Hausman's papers, Pindyck suggests that access prices should incorporate an option to delay value to compensate incumbents for the asymmetric risk. Pindyck (2004) examines a hypothetical example where an incumbent installs a telecommunications switch that can be utilized by an entrant and 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).

Finally, Pindyck (2005) develops a method to adjust the cost of capital in the TELRIC[2] access pricing formula to account for the option to delay value. Pindyck shows that this adjustment is always positive and lies in average between 1.2 and 4.5%. In contrast, we show that the extent to which the incumbent should be compensated for its option to delay depends upon market conditions.

[2] Total Element Long Run Incremental Cost.

In particular, this paper examines a simple three-period model of an investment decision in a network industry characterized by demand uncertainty, economies of scale and sunk costs. In our 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.

In a regulated environment, we consider a vertically integrated network provider that is required to provide access to downstream competitors. Our focus is on regulatory interventions where the regulator commits *ex-ante* to a set of access prices that are not contingent on demand. [3] 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.

In this *ex-ante* regulated environment, we explicitly consider the process by which a regulator sets access prices and show that optimal prices depend on market conditions. In particular, we show that there are two possible optimal scenarios: access prices that provide a zero expected payoff to the incumbent and access prices that provide a positive expected payoff to the incumbent. Interestingly, unlike the previous literature we show that in the former case a zero expected payoff already considers the option to delay value and is sufficient to provide the appropriate investment incentives. However, from a policy perspective when optimal access prices are such that the regulated project provides a positive expected payoff to the firm, traditional regulation, which is designed to yield zero economic profits, might not be optimal.

Finally, while Pindyck advocates in favour of an ECPR-type methodology to account for the interaction between irreversibility and demand uncertainty, we show that an Option to Delay Pricing Rule (ODPR) generates higher welfare than the Efficient Component Pricing Rule (ECPR), except under very specific circumstances. The basic idea is that access prices under the ODPR are lower or equal than those following the ECPR. The main reason is that under the ODPR even an inefficient entrant can constraint the monopoly rents that the incumbent can extract, whereas an ECPR price embeds full monopoly rents.

This paper is organized as follows. Section 2 sets out the investment decision model in an unregulated industry and computes the NPV and the option to delay value associated with the unregulated monopolist investment decision. In Section 3 we examine the effects of access price

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

regulation on the incumbent's investment decision. We identify welfare-maximizing access prices and compare two types of regulation, the ECPR and the ODPR. Section 4 concludes the paper.

2. The Investment Decision by an Unregulated Firm

We consider an unregulated 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 $t = 1$. 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 does not change from $t = 0$ to $t = 1$ and is equal to I. That is, the real cost of investment decreases over time. Moreover, the investment is sunk and there is 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 $u > (1 + r)$ and r is the risk-free interest rate) or equal to dQ (where $0 < d < 1$) with probabilities θ and $(1 - \theta)$, respectively. 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 $\bar{P}_2$ and the pattern of uncertainty at each node is the same as in the previous period. As a result, at any price below or equal to $\bar{P}_2$ the demand, denoted by q_2, will be either equal to $u^2 Q$, udQ or $d^2 Q$ 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. On one hand, the combination of demand uncertainty and a declining investment requirement in real terms creates an incentive for the firm to delay its investment decision until $t = 1$. On the other hand, there is a cost of waiting when the firm delays its investment (the first period cash flow).

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 $t=2$. That is, the provision of network services constitutes a natural monopoly.

Our first task is to calculate this investment decision as a standard NPV. We assume that financial markets are efficient, that is, there is a portfolio of traded assets that generates the same cash flow stream as the one being valued and we use the cost of this portfolio to calculate the NPV (risk-neutral pricing formula). This valuation method rests on the assumption that there are no arbitrage opportunities.

We also assume, without any loss of generality, that there exist two assets: a one period risk-free bond with a current price of 1 and a payoff of $(1+r)$ after one period; and a risky asset with a current price of 1 and a payoff after one period equal to u (with probability θ) and d (with probability $(1-\theta)$). The approach here is to build a portfolio using the two assets described above to generate the same cash flows as the investment project at each node. It is straightforward to show that the NPV of this investment decision, denoted by $\overline{NPV}$, is equal to

$$\overline{NPV} = \left[\left(\bar{P}_1 - c_1\right) + \left(\bar{P}_2 - c_2\right)\right]Q - I \qquad (1)$$

The risk-neutral methodology is also 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 $t=1$.[4]

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

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

or

$$\overline{OD} = \frac{pMax\left[\left(\bar{P}_2 - c_2\right)uQ - I;0\right] + (1-p)Max\left[\left(\bar{P}_2 - c_2\right)dQ - I;0\right]}{1+r} \qquad (2)$$

4 The rationale for using the risk-neutral methodology 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.

where $p = \dfrac{(1+r)-d}{u-d}$ is the risk-neutral probability. p is such that the equality between the cost of the replicating portfolio and the cost of the project's cash flow holds (no arbitrage opportunities).

It is easy to see from (2) 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 (2) that when considering $\overline{OD}$ 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 $\overline{OD}$ is equal to zero. In the second range only the high demand scenario yields a positive payoff and the slope of the function is $\dfrac{pu}{1+r}\left(\bar{P}_2 - c_2\right)$. In the third range, both scenarios yield positive payoffs and the slope of the function is $\left(\bar{P}_2 - c_2\right)$.

In order to decide whether, and when, to invest in the network facility the unregulated firm must compare the values of $\overline{NPV}$ and $\overline{OD}$ which are given by (1) and (2), respectively. It is clear that the comparison between the market value of the $\overline{NPV}$ and the $\overline{OD}$ at $t = 0$ depends on $\left(\bar{P}_1 - c_1\right)$, the term that drives the first period net revenue. By taking the $\overline{NPV}$ and $\overline{OD}$ as functions of Q we have three different cases considering that $\left(\bar{P}_1 - c_1\right) \geq 0$.

In Case 1, $\left(\bar{P}_1 - c_1\right) > 0$ and there is a value of Q such that $\overline{NPV} = \overline{OD} = 0$, that is, the $\overline{NPV}$ function crosses the $\overline{OD}$ function in its first range. In Case 2, $\left(\bar{P}_1 - c_1\right) > 0$ and there is a value of Q such that $\overline{NPV} = \overline{OD} > 0$, $\overline{OD}^{+} > 0$ and $\overline{OD}^{-} = 0$, that is, the $\overline{NPV}$ function crosses the $\overline{OD}$ function in its second range (see Figure 1 below). In Case 3, $\left(\bar{P}_1 - c_1\right) = 0$ and then $\overline{NPV} \le \overline{OD}$ for all values of Q. Moreover, $\overline{NPV} = \overline{OD}$ when $\overline{OD}^{-} > 0$, that is, both functions have the same value in the third range of $\overline{OD}$. The investment decision outputs for each case are listed in Lemma 1.

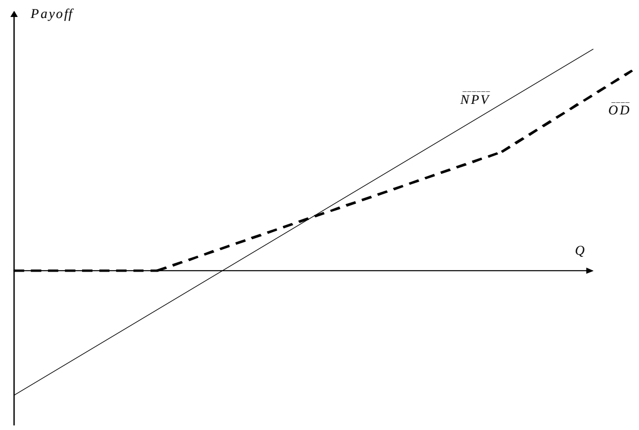

Figure 1

Lemma 1: *Table 1 below summarizes the unregulated monopolist investment decision outputs as a function of market conditions.*

Condition	The firm never invests if	The firm invests at $t=1$ when $q_1 = uQ$ if	The firm invests at $t=0$ if
Case 1	$\overline{OD} = 0$ and $\overline{NPV} < \overline{OD}$	n/a	$\overline{NPV} \ge \overline{OD} \ge 0$
Case 2	$\overline{OD} = 0$	$\overline{OD}^{+} > 0$, $\overline{OD}^{-} = 0$ and $\overline{NPV} < \overline{OD}$	$\overline{OD}^{+} > 0$, $\overline{OD}^{-} \ge 0$ and $\overline{NPV} \ge \overline{OD}$
Case 3	$\overline{OD} = 0$	$\overline{OD}^{+} > 0$ and $\overline{OD}^{-} = 0$	$\overline{OD}^{+} > 0$ and $\overline{OD}^{-} > 0$

Table 1

We can also compute the total welfare when the unregulated firm invests at $t = 0$ ($\overline{NPV} \ge \overline{OD}$). This is given by:

$$W_M = \alpha\, \overline{NPV} \qquad (3)$$

where $\alpha < 1$ denotes the weight assigned by the social planner to firm's profits. Equation (3) is the benchmark that the regulator will try to improve upon. Finally, note that given the values of the parameters, the NPV and OD are fixed at $\overline{NPV}$ and $\overline{OD}$. In the next section we will calculate the changes in the NPV and OD when access prices are set by the regulator.

3. Access Regulation

This Section studies the effect of access price regulation on the firm's investment decision and total welfare. As said in Section 2, our benchmark is an unregulated, vertically integrated firm who invests at $t = 0$ (i.e., it bears the demand uncertainty), 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 serves the entire demand at these prices. Under the benchmark the incumbent has no incentive to allow access to its network by downstream competitors.

The regulator and the firm both observe the choke prices and are fully informed about the nature of demand uncertainty and the cost function. The regulator requires the incumbent to provide access to its network and sets the access prices that will prevail at $t = 1$ and at $t = 2$ in order to maximize total welfare:

$$Max \quad W_R = CS + \alpha\pi \qquad (4)$$

where CS denotes consumer surplus, and π is the firm's profit.[5] Thus, our focus is on *ex-ante* regulation. That is, we assume that the regulator sets the access prices at $t = 0$ before the resolution of demand uncertainty. Thus, we focus on a 'regulatory game' where the regulator makes a one-off offer which consists of *ex-ante* non-demand contingent maximum access prices and the firm then decides whether to invest at $t = 0$ or at $t = 1$ (if demand turns out to be high).

To consider the effects of access price regulation, we assume that 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).

[5] 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.

3.1. 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.[6] Thus, we can define the access price contract following the ECPR as:

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

At these 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 $\bar{P}_1$ and $\bar{P}_2$ (in the latter case the incumbent has to buy the generic inputs at costs c_1 and 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 $P_1^{ECPR} + P_2^{ECPR} < \bar{P}_1 + \bar{P}_2$. In this case, given that the sum of the entrant's net revenue in both periods is equal to zero and there is a transfer from the incumbent's profit to the consumer surplus (note that the incumbent's decision of investing at $t = 0$ is not distorted), the ECPR generates higher welfare than an unregulated industry. This is summarised as follows.

Proposition 1: 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.

3.2 The Option to Delay Pricing Rule - ODPR

[6] See, for example, Willig (1979) and Baumol (1983).

We proceed to define the access price contract that takes into account the option to delay value, the Option to Delay Pricing Rule (ODPR), as:

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

where P_1^R and P_2^R are the optimal regulated prices in case the incumbent firm does not face retail competition and is subject to a price cap in the retail market. That is, the access price under ODPR is equal to the difference between the maximizing-welfare retail price cap and the incumbent's marginal cost at each period.

The optimal retail regulation depends on the impact of the regulated prices on the comparison between the NPV and OD, which in turn depends on the unregulated market conditions. As seen in Section 2 there are three cases to consider – Cases 1 to 3 – where each case corresponds to one of the three different ranges of the $\overline{OD}$ function. The optimal retail price caps for each case are listed in Lemma 2 and the proof is in the Appendix. We use the following terminology, $C = \frac{I}{Q}$ denotes the average fixed cost of investing at $t = 0$, $C_H = \frac{I}{uQ}$ is the average fixed cost of investing at $t = 1$ under high demand, and $C_L = \frac{I}{dQ}$ is the average fixed cost of investing at $t = 1$ under low demand.

Lemma 2: *Optimal Retail Price Caps are given as follows:*

Cases	Conditions	Retail Prices	
		Investment at t=0	Investment at t=1 with prob. p
1	$\overline{NPV} = \overline{OD}$	$P_1^R = \bar{P}_1$ and $P_2^R = \bar{P}_2$	n/a
	$\overline{NPV} > \overline{OD}$	$P_1^R = C + c_1 + c_2 - \bar{P}_2$ and $P_2^R = \bar{P}_2$	n/a
2	$\overline{NPV} = \overline{OD}$	$P_1^R = \bar{P}_1$ and $P_2^R = \bar{P}_2$	$P_1^R = \bar{P}_1$ and $P_2^R = C_H + c_2$
	$\overline{NPV} > \overline{OD}$	$P_1^R = \bar{P}_1$ and $P_2^R = C_H + c_2 + M$	$P_1^R = \bar{P}_1$ and $P_2^R = C_H + c_2$
3	$\overline{NPV} = \overline{OD}$	$P_1^R = \bar{P}_1$ and $P_2^R = C_L + c_2$	$P_1^R = \bar{P}_1$ and $P_2^R = C_H + c_2$

Table 2

We proceed to discuss the rationale of each one of these cases. First, suppose that the unregulated market conditions (demand characteristics) are such that Case 1 is valid, that is, the $\overline{NPV}$ function crosses the $\overline{OD}$ function in its first range. In this case, it is easy to see that even when Q is such that $\overline{NPV} > \overline{OD} > 0$ the regulator is able to set prices P_1^R and P_2^R such that $NPV = OD = 0$ and the incumbent still invests at $t = 0$. This price regulation increases the overall welfare because by setting prices below the choke prices without distorting the incumbent's decision of investing at $t = 0$ the positive impact on consumers' surplus is higher than the negative impact on the firm's profit ($\alpha < 1$). Also, this is the optimal retail regulation since all the surplus is extracted from the firm and transferred to consumers. [7]

However, if demand characteristics are such that Case 2 or 3 are valid, that is, the $\overline{NPV}$ function crosses the $\overline{OD}$ function in its second range or they are equal to each other in the third range of the $\overline{OD}$ function, the regulator is unable to set regulated prices below a certain level without distorting the incumbent's decision of investing at $t = 0$. If the regulator does that, the firm will invest at $t = 1$ only if the high demand eventuates or even decide not to invest.

In such cases the optimal price caps will be extracted from one of the two following price regulations: (i) the minimum P_1^R and P_2^R such that $NPV = OD > 0$ and the incumbent invests at $t = 0$- under these prices the firm will have a positive expected payoff - or (ii) the minimum prices P_1^R and P_2^R such that $\left(P_2^R - c_2\right)uQ = I$, $OD^+ = 0$, $NPV < 0$ and the firm invests at $t = 1$ only if the high demand eventuates - under these prices the firm will have a zero payoff.

Basically, there is a trade off between paying higher prices and having the service provision with certainty earlier ($t = 0$) or paying lower prices and having the service later ($t = 1$) only if the high demand eventuates, that is, there is a probability $(1 - p)$ that the service will not be provided to consumers. Thus, if p, the probability of the high demand state, is sufficiently high, the optimal regulation will be (ii). Otherwise, it will be optimal to set the price caps such that the firm will have a positive payoff to compensate for the option to delay.

Note that this result differs from the earlier literature that states that the incumbent firm should always receive a positive compensation to account for the option to delay value. Instead, the argument above clarifies that the extent of compensation, if any, will depend on market conditions.

After calculating the optimal retail price caps we are able to obtain access prices that account for the option to delay value.Table 3 below shows all possible access prices under the ODPR.[8]

Cases	Conditions	ODPR Access Prices	
		Investment at t=0	Investment at t=1 with prob. p
1	$\overline{NPV} = \overline{OD}$	$A_1^{ODPR} = \bar{P}_1 - c_1$ and $A_2^{ODPR} = \bar{P}_2 - c_2$	n/a
	$\overline{NPV} > \overline{OD}$	$A_1^{ODPR} = C + c_2 - \bar{P}_2$ and $A_2^{ODPR} = \bar{P}_2 - c_2$	n/a
2	$\overline{NPV} = \overline{OD}$	$A_1^{ODPR} = \bar{P}_1 - c_1$ and $A_2^{ODPR} = \bar{P}_2 - c_2$	$A_1^{ODPR} = \bar{P}_1 - c_1$ and $A_2^{ODPR} = C_H$
	$\overline{NPV} > \overline{OD}$	$A_1^{ODPR} = \bar{P}_1 - c_1$ and $A_2^{ODPR} = C_H + M$	$A_1^{ODPR} = \bar{P}_1 - c_1$ and $A_2^{ODPR} = C_H$
3	$\overline{NPV} = \overline{OD}$	$A_1^{ODPR} = \bar{P}_1 - c_1$ and $A_2^{ODPR} = C_L$	$A_1^{ODPR} = \bar{P}_1 - c_1$ and $A_2^{ODPR} = C_H$

Table 3

Note 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 $\left(A_1^{ECPR} + A_2^{ECPR}\right) - \left(A_1^{ODPR} + A_2^{ODPR}\right) = Z$. That is,

$$\left(\bar{P}_1 + \bar{P}_2\right) - \left(P_1^R + P_2^R\right) = Z \qquad (5)$$

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

Proposition 2a characterises the market conditions where access prices under the ODPR and ECPR are identical while Propositions 2b and 2c characterise the market conditions where access prices under ODPR are lower than under the ECPR. In Proposition 2b access prices under ODPR are the minimum prices such that the incumbent firm invests early while in

[7] Note that when $\overline{NPV} = \overline{OD} = 0$, optimal retail prices will be equal to the choke prices.

[8] 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 2c 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 2b and 2c are in the Appendix.

Proposition 2a: *When the unregulated market conditions are such that access prices under the ODPR are equal to* $A_1^{ODPR}=\bar{P}_1-c_1$ and $A_2^{ODPR}=\bar{P}_2-c_2$, *the ODPR generates the same overall welfare as the ECPR.*

Proposition 2b*: Suppose that the unregulated market conditions are such that access prices under the ODPR are equal to (i)* $A_1^{ODPR}=C+c_2-\bar{P}_2$ and $A_2^{ODPR}=\bar{P}_2-c_2$ or (ii) $A_1^{ODPR}=\bar{P}_1-c_1$ and $A_2^{ODPR}=C_H+M$ [9] or (iiI) $A_1^{ODPR}=\bar{P}_1-c_1$ and $A_2^{ODPR}=C_L$. *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 the ECPR. When the potential entrant is less efficient than the incumbent and* $(c_1+c_2)\leq(c_{1E}+c_{2E})<(c_1+c_2)+Z$ *or 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.*

Proposition 2c: *Suppose that the unregulated market conditions are such that access prices under the ODPR are equal to* $A_1^{ODPR}=\bar{P}_1-c_1$ and $A_2^{ODPR}=C_H$. *When the potential entrant is less efficient than the incumbent and* $c_{2E}\geq c_2+Z$ *, the ODPR generates lower or equal overall welfare compared to the ECPR. 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 the ECPR if* $p>p^*$ *where* $p^*=\dfrac{\alpha\,\overline{NPV}}{\left[\dfrac{\left(\bar{P}_2-c_{2E}\right)uQ-I}{(1+r)}\right]+\alpha\left[\dfrac{(c_{2E}-c_2)uQ}{(1+r)}\right]}$*. When the potential entrant is*

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[9] In this case $P_1^R=\bar{P}_1$ and $P_2^R<\bar{P}_2$ such that $NPV=OD<\overline{OD}$, $\overline{OD}^{+}>0$ and $\overline{OD}^{-}=0$, that is, $C_H+c_2<P_2^R<C_L+c_2$. Then, there is a $M>0$, such that $P_2^R=C_H+c_2+M<C_L+c_2$ and $NPV=OD$.

more efficient than the incumbent (i.e., $c_{2E} < c_2$) the ODPR generates higher overall welfare than the ECPR if $p > p^{**}$ where $p^{**} = \dfrac{\left[\left(c_1 + c_2 - c_{1E} - c_{2E}\right) + \alpha\,\overline{NPV}\right]}{\left[\dfrac{\left(\bar{P}_2 - c_{2E}\right)uQ - I}{(1+r)}\right]}$.

Proposition 2a states the obvious point that when market conditions are such that access prices under the ODPR and ECPR are identical, they provide the same overall welfare. Proposition 2b characterises the market conditions where access prices under ODPR are the minimum prices such that the incumbent firm 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 $\left(c_{1E} + c_{2E}\right) \geq \left(c_1 + c_2\right) + Z$, the entrant can only offer retail prices above the choke prices. As a consequence, the incumbent invests early, serves the market at the choke prices and 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 $\left(c_1 + c_2\right) \leq \left(c_{1E} + c_{2E}\right) < \left(c_1 + c_2\right) + Z$ the threat of entry leads the incumbent to reduce its prices to P_1^E and P_2^E such that $P_1^E + P_2^E = \left(A_1^{ODPR} + c_{1E}\right) + \left(A_2^{ODPR} + c_{2E}\right)$ and $P_1^E + P_2^E < \bar{P}_1 + \bar{P}_2$. Under this condition the incumbent still invests early and serves the entire market. However, since the retail prices under ODPR are lower than the choke prices, 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 then the incumbent, that is, $\left(c_{1E} + c_{2E}\right) < \left(c_1 + c_2\right)$ the incumbent invests early but cannot offer the same retail 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. Thus, ODPR generates higher welfare than the ECPR.

Proposition 2c 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 invests 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 serves 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 as an unregulated industry and also the ECPR; and when $\overline{NPV} > \overline{OD}$, the ODPR generates less welfare than an unregulated industry and also the ECPR.

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 to P_2^E 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 p. Under the ODPR consumer surplus is positive while under the ECPR it is zero. However, the incumbent firm invests at $t=0$ under the ECPR and at $t=1$ only when 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 – for it 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 then 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. Similarly to the situation above, 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 the ODPR, even an inefficient entrant can constrain the monopoly rents that the incumbent can extract, whereas an ECPR price embeds full monopoly rents.

4. Conclusion

In this paper we examine a simple three-period 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 an access price regulation that accounts for demand uncertainty and the irreversibility of investments. In addition, unlike previous papers that state that the incumbent firm should always receive a positive compensation to account for the option to delay value, we show that whether optimal access prices should incorporate a positive amount to compensate for the option to delay value will depend on demand conditions.

More importantly, we show that an access price that accounts for the 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, 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.

These results contribute to the existing literature in two different ways. First, it provides specific conditions under which regulated firms should be compensated for foregoing an option to delay.

Second, it shows that there are market conditions under which an ODPR-based access price welfare dominates an ECPR-based access price.

References

Baumol, W. J. (1983). “Some subtle issues in railroad regulation”, *Journal of Transport Economics* 10: 341-55

Dixit, A., and R. Pindyck, (1994), *Investment under Uncertainty*, Princeton University Press: Princeton.

Hausman, J. and S. Myers (2002) “Regulating the US Railroads: The Effects of Sunk Costs and Asymmetric Risk”, *Journal of Regulatory Economics* 22:3 287-310.

Hausman, J. (1999). “The Effect of Sunk Costs in Telecommunications“, in Alleman, J and Noam, E, (eds.) *The New Investment Theory of Real Options and its Implications for the Costs Models in Telecommunications*, Kluwer Academic Publishers.

Pindyck, R. S. (2004). “Mandatory Unbundling and Irreversible Investment in Telecom Networks”, *NBER Working Paper No. 10287*.

Pindyck, R. S. (2005). “Pricing Capital under Mandatory Unbundling and Facilities Sharing”, *NBER Working Paper No. 11225.*

Teisberg, E. O. (1993). "Capital Investment Strategies under Uncertain Regulation," RAND Journal of Economics 24:4 591-604.

Teisberg, E. O. (1994). “An Option Valuation Analysis of Investment Choices by a Regulated Firm.” *Management Science* 40(4) 535-548.

Trigeorgis, L. (1996), *Real Options - Managerial Flexibility and Strategy in Resource Allocation*, MIT Press.

Willig, R. (1979). “The Theory of Network Access Pricing”, in Harry M. Trebing (ed.) *Issues in Public Utility Regulation*, Michigan Sate University Public Utility Papers.

Appendix

Proof of Lemma 2:

Case 1: If Q is such that $\overline{NPV} = \overline{OD} = 0$ there is no need for regulation as the best the regulator can do is to replicate the unregulated market outcome 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 Q is such that $\overline{NPV} > \overline{OD} \geq 0$ 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 $NPV = OD = 0$.[10] In this case the firm invests at $t = 0$ and total welfare is equal to:

$$W_R = \left[\bar{P}_1 - \left(\bar{P}_1 - \frac{\overline{NPV}}{Q} \right) \right] Q + \alpha \left\{ \left[\left(\bar{P}_1 - \frac{\overline{NPV}}{Q} - c_1 \right) + \left(\bar{P}_2 - c_2 \right) \right] Q - I \right\} \quad (6)$$

The welfare obtained with this regulatory policy must be compared to the unregulated market welfare. The difference between (6) and (3) 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.

Case 2: Suppose that Q is such that $\overline{NPV} = \overline{OD}$, $\overline{OD}^{+} > 0$ and $\overline{OD}^{-} = 0$. 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:

[10] In this case, Proposition 1 holds for any regulated prices such that $P_1^R + P_2^R = C + (c_1 + c_2)$.

$$W_R = \frac{p\left(\bar{P}_2 - \left(C_H + c_2\right)\right)uQ}{\left(1+r\right)} = p\pi_{t=1}^H \qquad (7)$$

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

When Q is such that $\overline{NPV} > \overline{OD}$, $\overline{OD}^{+} > 0$ and $\overline{OD}^{-} \geq 0$, 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 $NPV = OD < \overline{OD}$, $\overline{OD}^{+} > 0$ and $\overline{OD}^{-} = 0$. As $\overline{OD}^{+} > 0$ and $\overline{OD}^{-} = 0$, 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:

$$W_R = \left[\bar{P}_2 - \left(C_H + c_2 + M\right)\right]Q + \alpha\left\{\left[\left(\bar{P}_1 - c_1\right) + \left(\left(C_H + c_2 + M\right) - c_2\right)\right]Q - I\right\} \quad (8)$$

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

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

<u>Case 3:</u> Suppose $\bar{P}_1 = c_1$, $\bar{P}_2$ and Q are such that $\overline{NPV} = \overline{OD}$, $\overline{OD}^{+} > 0$ and $\overline{OD}^{-} > 0$. On one hand, the minimum regulated prices that induce investment at $t=0$ are $P_1^R = \bar{P}_1$ and $P_2^R = C_L + c_2 < \bar{P}_2$ such that $NPV = OD < \overline{OD}$.[11] The total welfare is given by:

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

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

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 (7).

These prices are optimal when $p > \dfrac{\left\{\left[\left(\bar{P}_2 - (C_L + c_2)\right)\right]Q + \alpha\left\{\left[\left(\bar{P}_1 - c_1\right) + C_L\right]Q - I\right\}\right\}}{\pi_{t=1}^{H}}$ □

Proof of Proposition 2b: Table 4 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 4

We now 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 $t=0$:

$$W_{ECPR} = \left[\left(\bar{P}_1 - P_1^{ECPR}\right) + \left(\bar{P}_2 - P_2^{ECPR}\right)\right]Q +$$

$$+\alpha\left\{\left(A_1^{ECPR} + A_2^{ECPR}\right)Q - I + \left[\left(P_1^{ECPR} - \left(A_1^{ECPR} + c_{1E}\right)\right) + \left(P_2^{ECPR} - \left(A_2^{ECPR} + c_{2E}\right)\right)\right]Q\right\} \quad (10)$$

Now, we 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 incumbent serves the market at the choke prices. Welfare under the ODPR is equivalent to that under the ECPR. 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 $t=0$:

$$W_{ODPR} = \left[\left(\bar{P}_1 - P_1^E\right) + \left(\bar{P}_2 - P_2^E\right)\right]Q + \alpha\left\{\left[\left(P_1^E - c_1\right) + \left(P_2^E - c_2\right)\right]Q - I\right\} \quad (11)$$

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 (equivalent to under the ECPR). The difference between (11) and (3) 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 $t = 0$:

$$W_{ODPR} = \left[\left(\bar{P}_1 - P_1^E\right) + \left(\bar{P}_2 - P_2^E\right)\right]Q +$$
$$+\alpha\left\{\left(A_1^{ODPR} + A_2^{ODPR}\right)Q - I + \left[\left(P_1^E - \left(A_1^{ODPR} + c_{1E}\right)\right) + \left(P_2^E - \left(A_2^{ODPR} + c_{2E}\right)\right)\right]Q\right\} \quad (12)$$

In this case, we compare the ODPR with the ECPR. The difference between (12) and (10) is equal to $(1-\alpha)ZQ > 0$. □

Proof of Proposition 2c: 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. Table 5 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 5

When the entrant is less efficient than the incumbent and $c_{2E} \geq c_2 + Z$ it is easy to see that 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 $\alpha p \pi_{t=1}^H = \alpha \overline{OD}$. 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 the ECPR) whereas when $\overline{NPV} > \overline{OD}$ the ODPR generates less welfare than an unregulated industry (and the ECPR).

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 $t=0$:

$$W_{ODPR} = \frac{p\left(\bar{P}_2 - (C_H + c_{2E})\right)uQ}{(1+r)} + \alpha \frac{p[((C_H + c_{2E}) - c_2)uQ - I]}{(1+r)} \qquad (13)$$

Once more, we must compare the ODPR with the unregulated monopoly case. The difference between (13) and (3) is positive only if $p > \dfrac{\alpha\,\overline{NPV}}{\left[\dfrac{\left(\bar{P}_2 - c_{2E}\right)uQ - I}{(1+r)}\right] + \alpha\left[\dfrac{(c_{2E} - c_2)uQ}{(1+r)}\right]} = p^*$.

When the potential entrant is more efficient then 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):

$$W_{ODPR} = \frac{p\left(\bar{P}_2 - (C_H + c_{2E})\right)uQ}{(1+r)} \qquad (14)$$

The difference between (14) and (10) is positive only if $p > \dfrac{\left[(c_1 + c_2 - c_{1E} - c_{2E}) + \alpha\,\overline{NPV}\right]}{\left[\dfrac{\left(\bar{P}_2 - c_{2E}\right)uQ - I}{(1+r)}\right]} = p^{**}$. □