DYNAMIC PRICING WITH UNCERTAINTY

James Alleman
Paul Rappoport*

Abstract

The efficiency results of marginal-cost pricing have been used to justify the imposition of regulatory policy tools to determine optimal pricing. In the more sophisticated form, Ramsey-Boiteux pricing methodology is recommended as a pricing-policy tool. These methods are static. Nevertheless, they are applied to major infrastructure industries such as telecommunications. At best, these methods assume prospective events with certainty; they do not account for stochastic changes in cash flows. However, uncertainty can make a substantial difference in the determination of optimal prices. Moreover, significant sunk (irreversible) costs are incurred by the incumbent firm in these industries. Once the sunk costs are incurred, the firm no longer has the delay option available, that is the firm cannot wait-and-watch how the market develops, but must invest immediately. This opportunity cost has not been acknowledged by the regulatory community in its pricing decisions. In addition to the neglect of opportunity costs, regulators have additional impacts on the incumbent firm's cost of capital.

We first develop a model with sunk costs which determines the optimal price in the spirit of traditional marginal-cost pricing. This model demonstrates the role of sunk cost in determining opportunity cost for the firm of immediate investment.

We use the techniques of real options methodology to analyze the cash flows which in turn have an impact on investment valuations. We then solve for the social welfare maximum, namely, the maximization of the discounted value of producer's and consumers' surplus. Because the options values/opportunity costs are not recognized in a static view of the world, the resultant price vectors of the traditional models are a poor policy guide.

Without regulatory constraints on prices, the model shows that the uncertainty prices differ significantly from the results of both the traditional marginal-cost price and the Ramsey-Boiteux pricing vector. The policy implications of the result are material. For the telecommunications industry, the telecommunications element long-run incremental cost (TELRIC) rates are theoretically incorrect, and, even if the rates derived from the static theoretical construct were exactly as TELRIC would require, they would be erroneous. These results are applicable to other network industries.

Keywords: *Ramsey-Boiteux Pricing, Network Access Pricing, Real Options, Investment under Uncertainty. Marginal-cost Pricing, Economic Methodology; Pricing under Risk and Uncertainty, Regulation, Regulatory Distortions*

JEL Classification: *B41, C44, D81,* L43, L51, L96

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OVERVIEW

The efficiency results of marginal-cost pricing have been used to justify the imposition of regulatory policy tools to determine optimal pricing. In the more sophisticated form, Ramsey-Boiteux pricing methodology is recommended as a pricing-policy tool (Willig 1974). These methods are static. Nevertheless, they are applied to major infrastructure industries such as telecommunications. At best, these methods assume prospective events with certainty; they do not account for stochastic changes in cash flows. However, uncertainty can make a substantial difference in the optimal prices. Significant sunk (irreversible) costs are incurred by the incumbent firm in these industries. Once the sunk costs are incurred, the firm no longer has the delay option available, it must invest immediately rather than wait to see how the market will play out. This opportunity cost has not been acknowledged by the regulatory community in its pricing decisions. In addition to the neglect of opportunity costs, regulators have an impact on the incumbent firm's cost of capital because of their failure to recognize this opportunity cost.

We first develop a model with sunk costs which determines the optimal price in the spirit of traditional marginal-cost pricing. This model demonstrates the role of sunk cost in determining opportunity cost for the firm of immediate investment.

We use the techniques of real options methodology to analyze the cash flows which in turn have an impact on investment valuations. We solve for the social welfare maximum, namely, the maximization of the discounted value of producer's and consumers' surplus. (Because they fail to note the interaction between demand and economic depreciation, models which assume that depreciation is exogenously determined are in error.) Since the options values/opportunity costs are not recognized in a static view of the world, the resultant prices determined in the traditional models are a poor policy guide.

Without regulatory constraints, the model shows that the uncertainty prices differ significantly from the results of both the traditional marginal-cost price and the Ramsey-Boiteux pricing vector. The policy implications of the result are substantial. For the telecommunications industry, the telecommunications long-run incremental costs (TELRIC) rates are theoretically incorrect, and, even if the rates derived from this static theoretical construct were exactly as TELRIC would require, they would be erroneous. This paper is divided into this introductory section; Section 2 is a review of the literature; Section 3 develops the background of the issues and the framework for dealing with them. Our aim is to develop the intuition for the real options approach with sunk costs. Section 4, formalizes the models and shows how they can be useful in understanding not only the role of irreversible investments as an opportunity cost, but insights on the role of regulation on investment incentives. Section 5 concludes and suggests areas for further research.

LITERATURE REVIEW

The literature is divided into four areas: first, regulation's impact on investment – either rate-of-return or incentive regulation – usually in a static context though occasionally with dynamic models of investment behavior; second, interconnection, or access pricing; third, generic real options analysis; and fourth, real options applied to telecommunications and increasingly to the area of access prices within this literature. The first three areas have been adequately reviewed elsewhere and briefly discussed below.

Regulatory research

For a review of telecommunications regulation prior to the late-eighties, see Kahn (1988); a review of the current state-of-the-art in telecommunications regulation is found in Laffont and Tirole (2000). The static and dynamic aspects of investment under various forms of regulation and optimal (Ramsey-Boiteux) pricing may be found in Biglaiser and Riordan (2000). Most of this literature assumes static models of which Averch-Johnson is the most well known (Averch 1962). These models show that rate-of-return regulation does not provide incentive for the firm to minimize costs or optimize capital investments. If the firm's growth is handled at all, it is through exponential models with time as the explanatory variable. Economic depreciation is treated exogenously. The dynamic models are deterministic, complete information growth models.

Interconnection/Access Pricing

The second area, too, has been debated extensively in the literature. In the nineties, the correct pricing methodology was strenuously debated by well-compensated consultants. The terms of the debate were between variants of the efficient component pricing rule (EPRC or Baumol-Willig Rule) first proposed by Willig (1979), based on contestability theory (Baumol Panzer and Willig 1984) and the more traditional approach detailed by Laffont and Tirole (1994) and refined in Laffont, Rey and Tirole (1998a and 1998b) and summarized by Laffont and Tirole (2000). The pricing methodologies are critiqued in Alleman (1998a and 1998b). Noam (2001) has an extensive review of the interconnection issues in his book. Vogelsang (2003) surveys and critiques the access pricing methodologies and issues. These analyses, as with the literature discussed above, are based on static or comparative static models. We, initially, adapt the ECPR concept to a dynamic, uncertainty context in this paper. We now turn to the fourth area which has not been extensively reviewed,

Real Options Research

The literature on real-options research from the financial perspective is reviewed and integrated in Trigeorgis (1996), and from the economist's perspective covered extensively in Dixit and Pindyck (1994) or, for a briefer account, in their 1995 article (Dixit 1995). Dixit and Pindyck and other economists usually only look at the delay option. The finance literature is fuller in its coverage of the various aspects of all of the options available to a firm, for example Hull (2006) has an extensive coverage of options, as does Luenberger (1998).

Real Options Applied to Telecommunications

Overview

A limited but growing literature exists in the applications of real options to telecommunications. Ergas and Small (2000) apply the real options methodology to examine the sunk cost of assets and the regulator's impact on the distribution of returns. They attempt to establish linkages between regulation, the value of the delay option and economic depreciation. Small (1998) studies investment under uncertain future demand and costs with the real options method. More recently, d'Halluin, *et al.* (2004a) use real options methodology for an *ex post* analysis of capacity in long distance data service. The same authors also utilize the methodology for wireless service issues (2004b). Pak and Keppo (2004) use the approach for network optimization; and Kulatilaka and Lin apply the methodology to strategic investment in technology standards (2004).

Access and pricing

Several papers have addressed the principal issue examined in this paper. Hausman has applied the real options methodology to examine the sunk cost of assets and the delay option in the context of unbundled network elements (UNEs) (1999 and 2003). Similarly, Hausman and Meyers (2002) estimate the magnitude of mistakes by the failure of regulators to account for sunk costs in the railroad industry. Hori and Mizuno (2004) have applied real options to access charges in the telecommunications industry. Lozano and Rodríguez (2005) use a lattice approach (for its intuitive appeal) to show the access pricing are higher than the traditional net present value approach.

Clark and Easaw (2003) address access pricing in a competitive market. They show, as have others, that when uncertainty is considered, the price should be higher than under certainty. Entrants should pay a premium to enter the market in order to reward the incumbent for bearing the risk of uncertain revenues. Pindyck (2004) shows that failure to account for sunk costs leads to distortions in investment incentives and distortions in unbundled network elements, a variant of access pricing. Similarly, Pindyck (2005a) shows that sharing of infrastructure at rates determined by regulators subsidizes entrants and discourages investment when sunk costs are not properly considered in the determination of the prices. He suggests how these prices can be adjusted to account for sunk costs. In a later presentation, Pindyck (2005b) demonstrates how sunk costs serve as an entry barrier and demonstrates its effect on market structure.

Our paper is in the spirit of these papers in that we consider the sunk costs as an opportunity cost. Our contribution is to find the efficient access price within the regulatory context by combining the results of real options methodology and the efficient component-pricing rule.

REGULATION AND PRICING

Interconnection and access[1]

From the beginning of the telecommunications industry, starting with the telegraph, interconnection has been important in ensuring the connectivity of networks. In 1865, the predecessor of the International Telecommunication Union was formed to ensure interconnection of telegraph service across national boundaries. The issues related to network access have become more critical in the age of multiple communications technologies – internet, mobile phone, WiFi and WiMax wireless networks, wide and local area networks (WANs and LANs), satellite systems, cable

[1] This section is adapted from Alleman (2002)

broadband – all of which are capable of interacting with one another if the interconnection arrangements can be made. Not only must these arrangements be made on a physical, technical basis, but also on an economic foundation.

Because interconnection is an inter-firm matter, the access issues do not have the visibility of the retail side of telecommunications, nor can the casual observer have the same level of intuitive understanding.

Recent policy goals have aimed to replace regulation with competition as the policy instrument of choice. As noted, many networks have the potential to enter each other's markets; thus interconnection is a means by which the objective of competition can be obtained. Interconnection is the tool and pricing is the blade. From the incumbent's point of view, the same blade can be used to cut off competition. Truly a versatile instrument! Indeed this is the dilemma. Thus the pricing of intermediate services is a thorny, but extremely important issue.

Interconnection or intermediate pricing represents the price of the intermediate good or service needed by a firm to provide its service. In the telecommunications industry, this price is also known as the "access price" and would be the price charged by one service provider for connection to its network so that another provider can complete the service for its own end-user customers. For example, in the United States, it would represent the price that long-distance carriers must pay to exchange carriers to complete a call on the public switched telecommunications network (PSTN).

The pricing becomes more complex when the company charging the interconnection price also competes with the company to which it supplies the intermediate service. The company charging for interconnection has an obvious incentive to overcharge the competing company – not only to enhance its own revenue, but also to make the competing company's cost, and hence its price, higher.

From the economics perspective, what should be the goals of interconnection?

We suggest the following (Alleman 1998a):

- Incentives should be correct to avoid inefficient bypass
- Prices should be equivalent for comparable facilities, and
- Prices should be transparent.

This means that companies will not have the incentives to invest in uneconomical assets. The access charge should be applicable to all services -- wire and wireless, telephone and cable, internet and voice services. If these are not priced correctly, it leaves room to arbitrage the uneconomical prices. Equivalent access prices may ensure that inefficient bypass would be avoided. Transparency is a criterion to assure that prices will be comparable. Market power should not be a factor in negotiations for determining the interconnection price. But the critical question is what are the correct costs to measure to meet these goals? This is where most analysts fail to account for the nature of sunk costs.

Sunk costs

Sunk costs are a significant portion of the investment cost in many public utilities including telecommunications and play a critical role in the determination of market structure (Pindyck 2005b). The Federal Communications Commission (FCC) in the United States and the Canadian Television and Radio Commission (CTRC) in Canada, and Office of Communications (OfCom) in the United Kingdom have, to varying degrees, implicitly recognized this fact. In the US, the FCC has attempted to promote competition by requiring that the incumbents make their network available to competitors at "incremental cost;" Canada has a similar policy but limits its duration, while the UK regulator is explicitly asking for comments on a real options approach to determining wholesale prices.

But what are sunk costs and how do they impact pricing issues, entry conditions, and market structure? Sunk costs should be distinguished from fixed costs. Sunk costs are costs that cannot be recovered once they are incurred, whereas fixed costs end once the firm ceases production. Sunk costs generally are industry and firm specific which implies they are not fungible. In particular, when the economy is in a down cycle, the firm's plant and equipment cannot be sold to others in the industry, because they have no value. An important distinction between fixed and sunk cost is that the sunk cost that has to be incurred at the initiation of the project, before the profitability of the project is known (Pindyck 2005b).

The implications are profound. For the incumbent firm, it has already exercised its option to delay. For the potential competitor, it has to value not just the direct cost of investing, but consider the value of its delay option. The consideration of sunk costs, as opposed to fungible investment alternatives, raises the entry barriers. We demonstrate this by modelling the impact of the sunk cost on the lost option value to the incumbent. Now we turn to how the regulatory process distorts prices if these costs are not explicitly considered.

Regulatory Distortion[2]

The economist is concerned with social welfare. The nominal purpose of regulation is to optimize social welfare and ensure that monopoly rents are eliminated from the firm's prices. This requires knowledge of economic cost and benefits. Generally benefits are measured by the consumers' surplus; economic costs are estimated, incorrectly we feel, by the firm's historical accounting costs. Economic costs would be preferred. Both the benefits and costs can be difficult to measure, but what we argue here is that not recognizing some costs, i.e., not knowing what to measure, means that the social welfare is distorted. In particular, without considering the dynamics of the firm, signifcant costs will be unrecongized. The interaction of regulation with valuation bears on welfare in several dimensions. First, unrecognized costs on the part of the regulatory community means that the prices set by it will not be correct. Second, if the financial community recognizes that the

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[2] This section draws on and expands works by two of the authors – Alleman & Rappoport (2002).

regulatory is not accounting for all the costs of the enterprise, then it will be more expensive to raise debt and equity capital, which, in turn, will increase the cost in a vicious cycle, raising the cost to consumers.

Among a major cost that has not been adequately identified or quantified is the obligation to serve. Under the current practice in most countries, whenever a customer demands service, the incumbent carriers are obligated to provide the service. It is part of the common carrier obligation. The United States Congress has had legislation before it that would require that the telephone companies provide mandatory broadband service. This would not allow the firms to assess the market, determine the best time to enter and where best to enter. They would be on a specific time and geographic schedule. The firms would lose the option to delay. Moreover, if the customer proves unprofitable, the carrier still must retain this customer. Thus, the carriers also looses their right or option to abandon the service.[3]

The incumbent carriers are precluded from exercising the option to delay. A related option is the ability to shutdown and restart operations. This, too, is precluded under the regulatory franchise. Finally, the time-to-build option, which includes the ability to default in the middle of a project, would not be available in the current regulatory context. The lack of options has not been considered in the various cost models that have been utilized by the regulatory community for a variety of policy purposes. Clearly, the lack of these options imposes a cost to the firm and to society.[4] The loss of these options can be thought of as an opportunity cost to the firm. In a previous paper (Alleman and Rapport 2002), we used the deployment of DSL to illustrate the delay option, and then the learning option. We indicate how both may be quantified and suggest the parameters which are relevant for these options. Below we outline the real options approach and how it can be use to address cost issues.

Real options pricing approach

The real options pricing approach utilizes financial option principles to value real assets under uncertainty. In this paper, we evaluate regulatory actions *ex post* in order to determine the impact of regulatory constraints on investment decision-making. For example, if regulation does not account for management's flexibility to respond to constraints that regulation imposes on the regulated firm, we show that the firm may make inefficient management and financial decsions from society's perspective.

Regulation leads to constraints on prices or on profits. Regulation also surfaces in the context of the obligation to serve. Under the current practice in most countries, whenever a customer demands service, the incumbent carriers are obligated to provide the service. It is part of the common carrier obligation. Under the obligation

[3] The argument that the expansion of the network provides an external benefit – an externality – beyond the value of an additional subscriber may be an offset to this cost, but the externality argument is not compelling in the United States or any area that has significant penetration of telephone service.

[4] This is not to imply that these public policies be abandoned, but in order to weigh the policy alternatives, their costs must be understood.

to serve requirement, if the customer proves unprofitable, the carrier still must serve this customer.

In the dynamic world, demand, technology, factor prices and many other parameters of interest to a company are subject to uncertainty. The principal uncertainty is the demand for goods, which, in turn, impacts cash flow, investment valuations, profits, and economic depreciation among other economic variables.

We illustrate this approach with a stylized binomial model. This model provides an intuitive understanding of the result that regulation has a cost, thus showing that regulation can restrict the flexibility of the firm through the imposition of price constraints, or by imposing costs associated with delay, abandonment, or shutdown/restart options. Since the cost models used for public policy decision-makers do not account for the time-to-build options available to the firm, if these regulatory impacts are left unaccounted for, there are significant costs to the firm and to society. (One of the clearest examples of the telecommunications regulators' failures to apply dynamic analysis is in the use of cost models and a type of long run incremental cost methodology to determine prices and obligations-to-serve subsidies (Alleman 1999)).

Assumptions and Model

To explain the application of real options to model regulatory distortions, the following stylized assumptions are made.

Cash flows shift each period based on a probability – the cash flow is high (a good result) with probability of q or low (a bad result) with probability of $(1–q)$. The model is for two periods and the intertemporal cross-elasticities of demand are assumed to be zero. These simplifying assumptions are enough to capture the effects of time and uncertainty; it leads to an easy understanding of the methodology; and serves as a foundation of the more complex analysis. We explore only one facet of this simple, but not unrealistic assumption, that cash flows are uncertain.

Under the traditional engineering-economics methodology, the quality of the investment would be determined with an expected value of the discounted present value of the profit function. This requires, *inter alia*, the determination of the "correct" discount rate. To account for uncertainty the rate is adjusted for risk, generally using the capital asset pricing model (CAPM). In the regulatory context, this would be equivalent to the determination of the rate-of-return for the firm. In the rate base, rate-of-return regulation context, a "historical" year is chosen and the rate-of-return determined. Prospective costs and revenues are assumed to be estimated with the past and the historical year representing the mean of that past. Before competition entered the telecommunications industry, discounted present value techniques were a useful analytical technique. The industry had stable, predictable revenues and costs, and hence, cash flow; but more recently, the industry has become volatile (Noam 2002 and Alleman 2002b).

Our analysis differs from this present value approach in that it treats the investment and cash flow prospectively as a model in which an investment has two possible outcomes: a good result or a bad result. A simple binomial real option model can analyze the investment.[5] Viewed in this fashion, the question is: what is the investment worth with and without management flexibility?

How can options be valued? Black and Scholes examined a method over 30 years ago for pricing financial options, and it has been much refined since then. See, for example (Nembhard 2000), for various methods and techniques to solve these real options problems.

The technique can also be applied to physical or real assets. To understand the intuition of the method, consider the stock-option comparison. Three things influence the price of stock options: the spread between the current and the exercise price, the length of time for which the option is good, and the volatility of the stock in question. The current price of the asset is known, and the exercise price at which the stock can be purchased sometime in the future is set. The greater the difference between the two, the lower the options price because only a great change in the market will make the stock's value climb above the exercise price and pay off for the owner. And big shifts are less likely than small ones. The date at which the option expires also is a factor. The longer the option lasts, the greater the chance that the stock price will become higher ("in-the-money") and go beyond the exercise price, and that the owner will make a profit. So, the price is higher. Finally, the volatility of the stock price over time influences the option price. The greater the volatility, the higher the price of the option, because it's more likely the price will move above the exercise price and the owner will be in-the-money. Black and Scholes consider these factors to solve the problem of pricing the option.

One important attribute of real options as opposed to the traditional discounted cash-flow analysis is the treatment of uncertainty. In discounted cash-flow analysis, increased risk is handled by increasing the discount rate; the more risk, the higher the return the company has to earn as a reward for investing. This has the effect of decreasing the value of the cash flow in later periods. Thus, uncertainty reduces the value. But in a real-options approach, the value would be increased, because managers have the flexibility to delay or expand the project – the greater the uncertainty, the greater the value.

Delay Distortion, Obligation to Serve

Consider the following two-period model in which an investment will have two possible outcomes: a "good" result, V^+, or a "bad" result, V^-, with the probability of q and $(1 - q)$, respectively (See Figure 1).

Under traditional practices, this would be evaluated by the expected value of the discounted cash flow of the two outcomes. Current investment analysis suggests it can be valued with the options pricing methods using Black-Scholes-Merton; Cox,

5. The simplicity of the model should not mis-lead the reader. The two period models can be expanded into an n-period model. Cox, Ross, and Rubinstein (1979) show how to solve these models and how, in the limit, the results converge to the Black-Scholes option pricing result.

Ross and Rubinstein or other techniques.[6] Many methods exist for solving this problem. The intuition is that delay has a value, since it allows the firm to have the state-of-nature revealed.

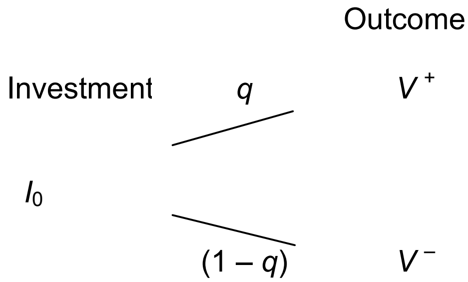

Figure 1: Two period binomial outcomes

Consider the following possible equally likely outcomes shown in FIGURE 2. If the good state occurs, it receives a net return of \$80 (before discounting) whether it defers or not. If the firm can defer the investment and the bad state occurs, it does not have to invest. However, if it could not defer, its loss is \$40. Clearly, deferral has a value.

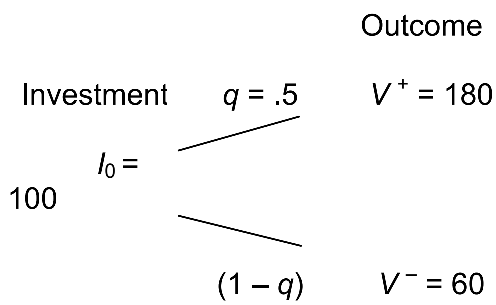

Figure 2: Two period binomial outcomes

If the discounted cash flow (DCF) was calculated in the traditional manner, assuming a risk adjusted interest rate of 20 percent, it would have a value of \$0; (DCF= $-I_0 + [(qV^+ + (1-q)V^-)/(1+r)]$).

	Investment	Committed	Net	Deferred
V^+ "good"	100	180	80	Max (80, 0) = 80
V^- "bad"	100	60	–40	Max (–40, 0) = 0

Table 1: Outcomes with and without pre-commitment

As noted above, several methods are available to value this option. Using the twin security approach, we find a security that has the same pattern of outcome – that is it

[6] Dixit and Pindyck (1994) develop an example using traditional methods but account for the ability to delay the decision.

has the same characteristics as the investment. We then find the replicating portfolio that matches the outcome of the project of interest. The value of this portfolio is the value of the flexibility. The value of this flexibility to defer is equal to the difference between the traditional present value of the project and the value of this flexibility.

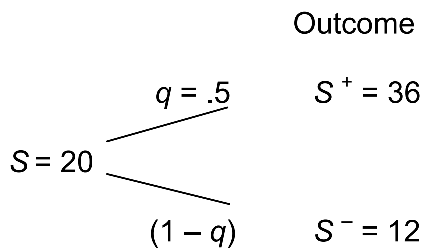

Figure 3: Twin security outcomes

Assuming a risk free rate of interest of five percent (5%), we find the twin portfolio which exactly replicates the outcome of deferring the project by solving the simultaneous equation system

$$mS^{+} - (1 + r_f)B = \$80, \text{ and,}$$
$$mS^{-} - (1 + r_f)B = \$\,0.00.$$

Let B represent borrowing at the risk free rate and m represent the number of shares of the twin security, respectively. Given the parameter $S^{+} = \$36$, $S^{-} = \$12$, and $r_f = 5\%$, we can solve for B and m. These are, $B = \$42.11$ and $m = 3.33$ shares. The value of the option to delay is then $mS - B = \$24.56$. The options value to delay the project is the value of the twin portfolio less the traditional DCF, in this case \$24.56 – \$0 = \$24.56. Thus, the option to delay is valuable.[7]

The relevance in the regulatory context is that the regulated firm does not have the delay option available to it – it must supply the basic services as required by its franchise.[8] What is the cost of this inflexibility? It is the value of the option to delay! This represents the opportunity cost of investing immediately, since the firm has given up the opportunity to wait to determine if the market will improve or go sour. In economics, it is well understood that the opportunity cost should be considered in addressing the total cost picture.[9]

Conversely, consider an entrant decision criterion; it must not only incur the direct cost of investment, but, it too must consider its opportunity cost. However, in general

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[7] Obviously, the numbers in the example are arbitrary, but illustrate the issue. Adding additional periods to this example will serve to increase the value of the delay option. For example, Dixit and Pindyck (1994) use an infinite horizon model to demonstrate the delay option, as does Pindyck (2004 and 2005)

[8] The exception of discretionary services such as DSL.

[9] Other opportunity cost may exist for the firm, but in this paper we will only be concerned with the opportunity cost created by options.

the threshold the regulatory agency has considered explicitly has only been the direct cost and not the opportunity (option) cost.[10]

Long-run Marginal Costs with Sunk Costs

Accepting the opportunity cost as given in the above characterization, let us consider what the long-run marginal cost (LRMC) would be for the firm that entered the market and gave up its option to wait. To do so, we make some simplifying assumptions. We assume that the short run marginal cost is zero, the firm produces one unit per period, and that no technological change occurs and the initial investment will be sufficient to serve the market to infinity. In this case the LRMC is equal to the amortization of the direct investment cost (I) and the opportunity cost (OC) (in the spirit of Baumol-Sidak's Average Incremental Cost (1994a and 1994b)). With the infinity assumption, this is equal to (I plus OC)/r_f. Clearly, this will be greater than the LRMC with a certainty assumption (which would be I/r_f) by the amount OC/r_f. This in turn is determined by the volatility of the revenue stream – the greater the volatility, the greater the opportunity cost. To place this in the context of the calculation of TELRIC pricing using the engineering process models, these models only use the equivalent of the amortized investment costs, thus underestimating the correct prices[11].

Implications of dynamic models

Even this simple model reveals a great deal regarding the prices. To set prices that are equal to LRMC in the dynamic world requires higher prices than the static world. In the static case the prices are too low because the opportunity cost is not considered by the regulator for either the monopoly firm or the potential entrant. Moreover, inefficient entry occurs because prices are not set at their correct marginal cost; as a consequence of incorrect prices, inefficient entry, occurs and social welfare will be lower. Even if the price is too low, the potential entrant has the option to delay which presents a barrier to facilities-based entry. In other words, the potential entrant not only considers the discounted present value of its investment, but, if it enters, it gives up its option to delay, too. Thus, the real options method impacts both the incumbent and the potential entrant's investment decision. If the delay option is exercised by an entrant, and if unavailable to the incumbent due to forced investment required by the regulatory authorities, these factors must be considered in any attempt to promote facilities-based competition. Moreover, to the extent the financial markets recognize that the incumbent firm's prices will be too low due to regulation; the market's valuation of the firm will be lower than if the regulator considered the dynamics of the market place. (It is rather ironic that the regulators seek competitive solutions, without considering how competition works in the market

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[10] In considering the efficient component-pricing rule (ECPR), the opportunity cost of the forgone revenues is considered in its calculation (see Baumol and Sidak 1994). This opportunity cost is different from the one considered here. It only considers the static case, and not the dynamic case discussed above. (The validity of the ECPR has been extensively debated in the literature. See Alleman (1998a) and the references cited therein.) This is not to say that this opportunity cost should not be considered, but only to draw the distinction between the two.

[11] This error is in addition to any errors in the cost models used to estimate prices. These cost models are known to be fundamentally and conceptually flawed on other grounds, while subject to enormous estimation and measurement errors.

place.) This, in turn, will increase the cost of capital for the firm in this situation which increases the economic cost and lowers social welfare even more.

Optimal prices in dynamic context

We now turn to how prices would be set in the dynamic context. First we will consider the simple case of a monopolist and then contrast this with dynamic Ramsey-Boiteux pricing.

As before, consider a binomial model for the monopolist with two possible states-of-nature: a strong and a weak demand. Further assume that the monopolist can adjust immediately to the state-of-nature and is a profit maximizer. In either state, the firm would price where marginal cost equaled marginal revenue. This would mean the firm's profit for each state could be determined. With this information, the option value of the profit could be determined in the usual manner. This is illustrated in Figure 4. Thus, *a priori*, the value of this opportunity cost can be determined, since it is the solution to the binomial option value and represents the incremental value of the firm at that moment in time.

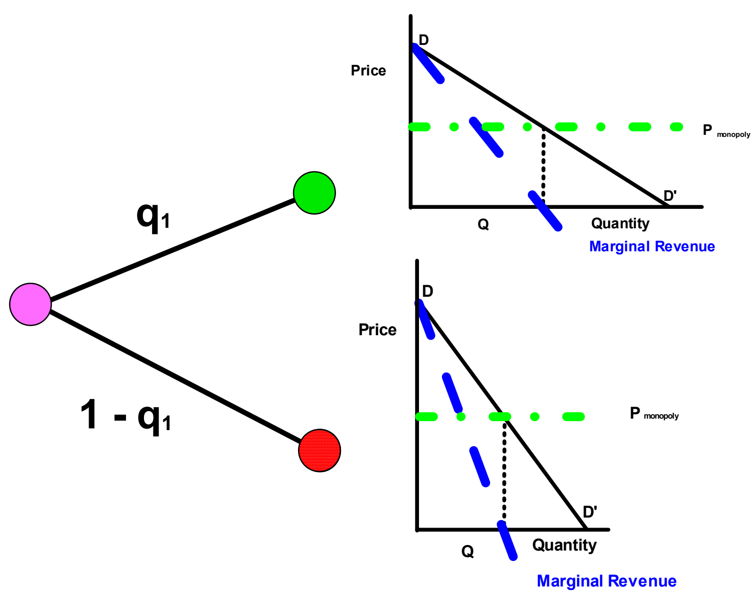

Figure 4: Two period binomial outcomes for monoplist

Using the same Figure contrast this with the full information, perfectly-regulated monopolist. In this case, the price is set at zero (since we have assumed zero marginal cost). The delay option value of this regulated state-of-nature would clearly be less than the unregulated monopoly, since it produces no monopoly profit with either outcome. How would the financial markets look at the regulated versus the unregulated markets? Clearly, the unregulated firm would have a higher value, thus an easier time in the financial markets.

The more interesting case for the regulated monopolist is displayed in Figure 5, where the firm has declining unit operating costs. Once again, the incremental value of the firm will depend on its option value, which will be determined by the state-of-nature in the next period (and final period in this model), but the Ramsey-Boiteux price will be different depending on the outcome in the next period because the average unit operating cost will be different depending on the outcome. The instantaneous Ramsey-Boiteux price would be at the intersection of the demand curve and the average unit operating cost plus the unit options value (shown as the curved dotted line).[12] This would maximize the consumer surplus in both cases. The optional price would be different depending on the outcome, but also higher than the average unit operating cost which the omnipotent regulator would set without considering the opportunity cost.

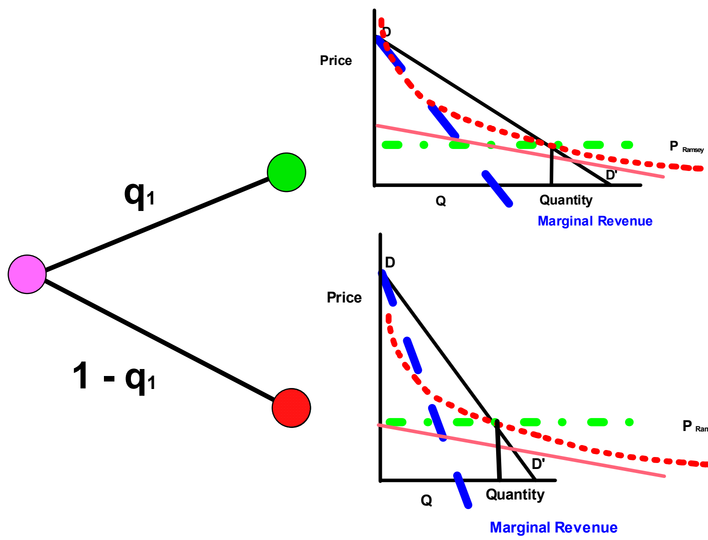

Figure 5: Two period Ramsey-Boiteux pricing model

[12] The unit cost of the option value, which would behave like a fixed cost in the traditional models, declining rapidly and becoming asymptotic with the average unit operating cost curve. It is shown above the average unit operating cost curve.

Conclusion and Further Research

If only the static model of the firm is considered, regulators will make serious errors in the determination of the proper price because it neglects the opportunity cost of the delay option. For the incumbent, the option is exercised and represents an opportunity cost; and for the potential entrant, the delay option does not have to be exercised if the regulator allows the entrant to purchase access at below its economic cost (operating cost plus delay options cost). Thus service-based entry will be excessive, while facilities-based entry will be sub-optimal.

To summarize, in the static-regulated paradigm:

- Price will be below its economic cost,
- Inefficient (service) entry will occur since
    - prices will not be set at their correct marginal cost and,
    - the entrant will not have to exercise its delay option,
- Social welfare will not be optimal,
- Incumbent firm's valuation by the financial markets will be reduced, and
- The cost of capital for incumbent firms will be higher.

On the other hand if the regulated paradigm is dynamic, the reverse will be true:

- Optimal prices will be higher than the static calculations,
- Only efficient (service) entry will occur since prices will be set at their correct economic marginal cost,
- Facilities based entrants will have the correct pricing signals,
- Social welfare will be maximized,
- The incumbent firm's valuation by the financial markets will be higher, and
- Its cost of capital will be lower than the regulated paradigm.

While this paper sketches out the bare-bones framework of the analysis of the issues, it has profound implications for regulatory practices. Dynamics makes a difference, uncertainty makes a difference. However, much more work has to be done to develop the precise models to fit the telecommunications context as well as quantify their impacts.

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