Does Practice Follow Principle?
Applying Real Options Principles
To Proxy Costs in US Telecommunications

Mark A. Jamison*
Director of Telecommunications Studies
Public Utility Research Center
And Associate Director for Economic and Business Studies
Center for International Business Education and Research
Warrington College of Business Admin.
University of Florida

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Section I. Introduction

In this paper, I analyze whether current US practices in estimating incremental costs for telecommunications companies provide efficient investment incentives to regulated incumbent local exchange companies (ILECs). The implementation of the Telecommunications Act of 1996 (Act) has raised this issue.[1] In implementing the Act, the Federal Communications Commission (FCC) and many state Public Utility Commissions (PUCs) are using incremental cost studies, with some mark-up for shared costs, for establishing prices for interconnection, reciprocal compensation, unbundled network elements (UNEs),[2] and universal service.[3] Regulators use these incremental cost estimates, which come from proxy cost models,[4] to set ceilings on these prices. This is a significant change in regulatory practices. Before the Act, regulators used incremental cost studies to set price floors for competitive or potentially competitive services.

This change in the use of incremental cost studies has affected stakeholder interests in the studies. Previously, ILECs had an incentive to keep the cost estimates low in order to obtain greater flexibility to lower prices in competitive markets. Now these companies' interests are to keep the estimates high to obtain greater flexibility to protect revenue streams and affect competitors' costs. This does not mean that ILECs would always choose to price at the ceiling if the ceiling were high. ILECs may price below the ceiling to discourage the development of competitive networks or to simply meet competition for UNEs. Even if the price ceiling were higher than the price the ILEC actually charged, the higher ceiling still has value to the ILEC because it gives the ILEC the option to raise prices should the market situation change. Also when incremental cost studies formed the basis for price floors, some competitors to ILECs wanted high cost estimates to secure price umbrellas in competitive markets. Now competitors want to keep the estimates low to decrease the payments that they have to make to their competitors, the ILECs.

This new stakeholder dynamic has prompted new investigations into the appropriateness of how regulators perform and apply incremental cost studies. The current debate focuses on

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1 Telecommunications Act of 1996, P.L. No. 104-104, 110 Stat. 56 (1996).

2 Interconnection, reciprocal compensation, and UNEs all involve a competitor connecting to the ILEC's network. In this paper, I address UNE pricing. Models for reciprocal compensation are more complex than the model I use in this paper because both ILECs and new entrants pay and receive reciprocal compensation.

3 By "price" for universal service, I mean the compensation that the regulator allows the service provider to receive in exchange for charging subcompetitive prices. Section II explains this in more detail.

4 A proxy cost model is a cost model that computes cost for a non-existent representative company rather than for a specific company, which used to be the practice.

Total Element Long Run Incremental Cost (TELRIC) studies because the FCC and many PUCs are adopting them (Jamison, 1998b; Salinger, 1998). One element of this debate has concerned the applicability of Real Options investment analysis.[5] This debate has raised concerns that TELRIC-based prices do not induce efficient investments on the part of ILECs because TELRIC studies do not reflect economic depreciation of ILEC investments, uncertainty in demand, and inter-temporal opportunity costs.

In this paper I analyze these issues by considering a model in which the regulator affects ILEC investment decisions and market outcomes through price controls. By comparing this model to TELRIC practice, I show that prices based on existing TELRIC models could discourage efficient ILEC investment by understating incremental costs. These models understate ILECs' incremental costs by inappropriately updating input prices without adjusting depreciation and by overstating expected demand. I also show that the inefficiency is not as great as some claim. For example, Hausman (1996) states that TELRIC models omit depreciation, demand uncertainty, and Real Options. I show that the first two claims are incorrect and that the effect of omitting Real Options is ambiguous.

I have organized the remainder of the paper as follows. Section II describes the economic model. By "model," I mean the stylized assumptions I make about how regulators regulate ILECs, how ILECs make investment decisions, and how ILEC competitors buy UNEs. This is a non-technical explanation that non-economists should find readable. The Appendix contains the technical explanation. Section III examines how various properties of TELRIC models affect the efficiency of ILECs' investment decisions. Section IV is the conclusion.

Section II. The Model

This section describes the model and applies it to identify efficient prices.

A. Description of the Model

My model in this paper considers an ILEC that produces multiple products and that makes investment decisions subject to regulatory price controls and uncertain demand.[6] I assume

[5] For examples of this debate, see Hausman (1996) and Hubbard and Lehr (1996). The issues I address in this paper are based upon the issues raised in these documents.

[6] In this paper, I use the term “product” to infer a product being sold in a particular market. So, for example, a UNE in one market would be considered a separate product from the same UNE sold in another

that the ILEC enjoys economies of joint production from producing multiple products, but I make no assumptions about whether the ILEC is a natural monopoly; i.e., I do not assume that a single ILEC could serve the entire market demand more efficiently than two or more other firms (Baumol, 1977; Jamison, 1998a), although I do not preclude it. The ILEC produces both retail products and UNEs. Some of the ILEC's retail products are subject to universal service obligations (USOs). I define a product subject to USOs as a product where the regulator requires the ILEC to charge a price that is lower than what would be found in a perfectly competitive market. In other words, the ILEC cannot charge the regulator's mandated price without an external source of funding or without charging supercompetitive prices for other products. If demands are independent, then by definition the per unit funding needed to allow the ILEC to charge the mandated price and earn its cost of capital is the difference between the competitive market price and the mandated price.

I assume that the ILEC's prices and investment affect demand, that demand is stochastic, and that buyers buy less at higher prices than they do at lower prices, all other things being equal. ILEC investment affects demand because higher levels of investment improve the quality of the UNEs and retail products, making customers of either type of product more willing to buy from the ILEC.

I further assume that quantity produced and ILEC investment determine the ILEC's production costs.[7] Increases in quantities produced increase costs. Investment is also a cost, but one that lowers other production costs. In effect, this assumption means that the ILEC can trade sunk investments for variable costs and vice versa, although the trade may not be one-for-one.

The ILEC's decision to produce or not produce a product, even if the regulator makes the choice for the ILEC, changes the ILEC's costs and revenues. I call the change in costs the incremental cost of the product. The incremental cost covers the ILEC's entire production of this product. For example, if the ILEC produces ten thousand unbundled loops in a market and this causes the ILEC's total cost for all products to increase from $900 million per month to $900.2 million per month, then the incremental cost of providing unbundled loops in this market is $200,000 per month. Likewise, I call the ILEC's change in revenues from providing a product the incremental revenues for the product. As in the case of incremental cost, it is the change in the

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market. By defining products this way, I segregate products along the dimensions of technical characteristics, geographic market, customer type, and distribution channel.

[7] For simplicity, I assume that investment both improves quality and decreases operating costs. An example of such an investment might be the purchase of a digital switch, which offers a higher quality signal than older technologies and also has lower prices for spare parts. Not all investments do both.

company's total revenue that is important. So the incremental revenue from the product is the change that it causes in the ILEC's total revenues. To simplify discussion, I generally assume that adding or dropping a product does not affect demand for other ILEC products. This assumption allows me to refer to prices rather than incremental revenues. I drop this assumption when I consider Real Options.

My model has the regulator, the ILEC, and the customers make decisions in sequence. The regulator makes the first decision. She selects the prices for UNEs and USOs using TELRIC models. Because the regulator uses these models, prices are tied to neither the ILEC's actual economic costs nor its earnings as in rate of return regulation. I assume that, properly applied, it is technically feasible for the TELRIC model to reliably estimate the ILEC's incremental cost.[8] Also, the regulator enforces her other price requirements by setting maximum prices and not by rate of return regulation.

The ILEC makes the second decision. It chooses whether and how much to invest and executes its investment choice. The ILEC knows the regulators' price ceilings, but does not know quantities that UNE and USO customers will buy. I assume that the ILEC and the regulator know the minimum and maximum amounts that these buyers could purchase and the probabilities of them buying any particular amount between the minimum and maximum. The regulator requires the ILEC to supply all that customers want to buy from the ILEC. I further assume that the ILEC wants to maximize expected profits and is risk neutral.

Customers make the last decisions. They make their buying decisions based upon the prices the ILEC charges, the investment-induced quality of the ILEC's products, and other factors. These other factors were unknown at the time that the ILEC made its investment decision. This gives demand its stochastic properties. Once these buyers make their purchasing decisions, the ILEC incurs the remainder of its costs for providing the products and receives its revenues.

To simplify the analysis, I assume that the demand and supply effects of investment are such that the ILEC sells no products and incurs no incremental costs if it chooses to make no investment.

[8] Without this assumption, the effects of miscalculating incremental cost would ambiguous. Regulated prices cause over investment or under investment in specific regions. Miscalculating incremental cost provides incentives for inefficiency if and only if the miscalculation prompts the regulator to move regulated prices from one region to another.

This model is a reasonable approximation of what is happening in telecommunications in the U.S. Regulators are setting UNE and USO prices using TELRIC models, generally with contributions to shared costs. Even though these prices apply to ILECs' existing networks and not just new investments, the prices signal the ILEC how much profit it can expect from new investments that may be used for UNEs and USO products. Also, investment can increase quality and lower other production costs. Furthermore, ILECs do not know demand with certainty when they invest. ILECs invest to replace facilities serving current demand and to serve projected new demand. In the case of existing demand, ILECs can have a reasonable amount of certainty that demand in the near future will be similar to what they are experiencing today. However, it is always possible that demand will decrease if competitors place facilities that eventually serve existing demand, or if customers move to other locations.[9] Projected new demand is also uncertain. Population shifts, housing developments that do not live up to forecasts, and slowdowns in economic growth can all result in realized demand being less than forecasted demand. Also, new demand may not last for the entire average economic life[10] of the facilities for the same reasons that current demand may decline.

B. Application of the Model

Assume that the regulator wants the ILEC to choose an investment level, $I*$, that maximizes the total benefit that ILEC investment can bring to the economy. The benefits of $I*$ are the decrease in ILEC unit production costs and the increase in the value of ILEC products brought about by the increase in ILEC product quality. The cost of $I*$ is simply the cost of the investment. If the regulator had complete and perfect information, and if the regulator had complete control over the ILEC and customers, the regulator would choose $I*$ and the optimal quantity, $q*$, by equating marginal benefits with marginal costs and requiring the ILEC to make the investment $I*$ and customers to buy $q*$. But in the real world, the regulator does not have complete and perfect information and does not have complete control over the other players.

[9] Telecommunications plant has only limited potential for serving demand in more than one geographic location. The most fungible equipment is circuit equipment. Technicians can remove this equipment from one location and place it in any other location that uses the same technology. Some switching equipment can also be moved to another location that uses the same technology. Feeder cable can be used to serve any demand that occurs in the feeder planning area. As a result, if demand decreases along part of the feeder cable's route, the idled portion of the feeder cable becomes available to serve demand in another part of the route. However, feeder cable in one route cannot be moved to serve demand in another feeder route. Distribution cable has limited fungibility.

[10] Regulatory accounting applies one depreciation life to all telecommunications of a particular type. Even if this depreciation life is correct on average, it may be too long for some locations and too short for others.

Instead, the regulator must use incentive mechanisms to induce the ILEC to choose I^* and customers to buy q^*, or at least to induce them to choose amounts close to I^* and q^*.[11]

To determine which price ceilings will induce the most efficient investment, the regulator uses backwards induction; in other words, she starts at the end of the sequence of decisions that will take place in response to her price controls and works backwards through the decisions to determine which price control will give her the most desirable outcome. She begins by considering the ILEC's customers' situations. These customers will choose quantities of ILEC products based upon the prices the ILEC charges and I. However, because there is a stochastic element to demand, the regulator does not know with certainty how much customers will purchase at particular price and investment levels. Instead, like the ILEC, she knows how prices and investment affect demand and has expectations about the stochastic effects. She bases her expectation on her knowledge of the range of possible quantities demanded and the likelihood of each potential level of demand.

Having formed her expectations about how customers will respond to the ILEC's prices and investments, and knowing that the ILEC shares these expectations,[12] the regulator considers how the ILEC will respond to her price controls and their shared expectations about customer demand. From the ILEC's perspective, once the regulator establishes her price ceilings, which I call $\overline{\mathbf{p}}^M$, where M represents all of the ILEC's products, the ILEC chooses its investment level, $\overline{I}$, to maximize its profits. I call the prices that relate to UNEs and USOs $\overline{\mathbf{p}}^S$ where S represents the UNEs and USO products. The ILEC's actual profits will be the difference between its realized revenues and the sum of its realized production costs and investment. However, at the time the ILEC makes its investment decision, it does not know what its actual profits will be because it does not know how much customers will buy. So the ILEC bases its investment decision on its expected profits, which are equal to the prices the ILEC will charge times expected demand, minus expected production costs, and minus investment.

Next the regulator attempts to choose the price that induces I^* and q^*. Unfortunately, there is no price that does this because the regulator has only one tool and is trying to determine

[11] There may be constraints that keep the regulator from inducing ILEC to choose I^*. For example, the ILEC may posses private information about how much I lowers operating costs. Also, the Act requires regulators to base prices on cost. In certain situations, such as when cost-based prices provide ILEC customers with surplus at the margin, this restriction may cause the ILEC to under invest .

[12] In practice, the regulator may have less information about customers than does the ILEC. In such a case, the regulator will have to allow the ILEC to earn extra profits in order to induce an efficient investment decisions. But even with this, the ILEC will under invest.

two outcomes. The tool is the price per unit sold.[13] The two outcomes are the investment made and quantity sold. If the regulator had a two-dimensional price -- one dimension that reflected quantity sold and another that reflected quality -- then she might be able to achieve her efficient outcome. I do not model this possibility because I have found no regulators doing this in practice. (Jamison, 1998b)

What the regulator does instead is choose a price that maximizes total social surplus subject to the ILEC's and customers' decision-making processes. Total social surplus is the difference between the value customers place on UNEs and USO products and the cost of providing them. The amounts they choose are $\bar{I}*$ and $\bar{q}*$. As the next subsection explains in more detail, the regulator chooses a price that covers the ILEC's expected incremental cost. The effects that price changes have on investment determine whether the price is above or below the ILEC's marginal cost. If price increases increase investment, then the optimal price is above marginal cost. The reverse is true if the price increases decrease investment. The Appendix describes this in more detail.

C. Cost-Based Prices

Now consider how the regulator's efficient price control compares with the ILEC's costs. Recall that the ILEC chooses $\bar{I}$ by equating the investment's marginal effect on expected revenues with its marginal effect on expected cost. The marginal effect on revenues is simply $\bar{\mathbf{p}}^S$ times the expected marginal effect on demand. The marginal effect on cost is simply the marginal effect on expected production costs (including effects on demand) plus the marginal investment. This means that $\bar{\mathbf{p}}^S$ must reflect the expected marginal cost. Because the ILEC cannot charge directly for quality, the ILEC chooses investment levels that cause marginal costs to be either above or below $\bar{\mathbf{p}}^S$. The direction and magnitude of the deviation from marginal cost depends on how investments affect demand and costs. The interactions among demand, costs, and investment are complex, but in general, large investment-induced changes in demand cause the ILEC to keep marginal costs below $\bar{\mathbf{p}}^S$, especially if investment causes the demand curve to become steeper.[14] Both of these conditions might occur if quality is important to customers,

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[13] According to my international survey results (Jamison, 1998b), prices for interconnection and network elements are generally linear, but not always. I assume linear prices for simplicity.

[14] The Appendix provides sufficient conditions for when the ILEC would choose to keep marginal cost above price and for when the ILEC would choose to keep marginal cost below price.

especially at higher prices. I call this necessary relationship between prices and marginal costs the optimization constraint.

The optimization constraint induces the ILEC to make an efficient investment only if the ILEC is willing to invest. The regulator ensures that the ILEC is willing to invest by applying the same process that she used to develop her optimization criteria, but with two slight differences. The first difference is that she must consider the total effect of the investment, and not just the marginal effect. In other words, she must consider the investment's total effect on the ILEC's expected revenues and the investment's total effect on the ILEC's costs to induce the ILEC to invest. The second difference is that she does not need to concern herself with equating the effects. She only needs to ensure that the revenue effect is at least as great as the cost effect. As long as this is true, the ILEC is willing to participate in the regulator's mechanism. I call this the participation constraint. With a small amount of algebraic manipulation which I show in the Appendix, the participation constraint can be expressed as $\overline{\mathbf{p}}^S$ being greater than or equal to the expected incremental cost of the ILEC choosing $\overline{I} = \overline{I}*$ over $\overline{I} = 0$, divided by the expected demand. In other words, the regulator's price ceiling must be greater than or equal to the ILEC's expected TELRIC (which may be different the regulator's estimated TELRIC) divided by expected demand.

Salinger (1998) applies a dynamic model to provide a useful explanation of the ILEC's incremental costs. He explains that the incremental cost is a current price that makes the current value of the incremental revenues just equal to the current value of the incremental operating costs plus the incremental investment, given that these values will continue to be equal in all future periods. In other words, the optimization constraint and the participation constraint should be understood to imply present values of prices to be charged, expected quantities to be sold, and expected production costs over the life of the investment.[15] He also shows that the assumption that the expected life is known, which is the typical assumption in TELRIC studies, understates incremental cost. He further shows that the possibility that technology improvements will increase the capacity of assets decreases incremental cost.

[15] This does not mean that prices have to be constant. Rather, it means that the regulator and the company view the regulator's price control decision as establishing current prices and prices for each period over the life of the asset, allowing that the prices may change from period to period.

D. Real Options

Now consider the effect of Real Options on the optimization constraint and the participation constraint. Real Option theory states that, if investing at the current time creates or destroys future opportunities, the foregone or gained value of these opportunities should be considered in estimating the value of the investment decision. (Trigeorgis, 1996) To examine this effect, I label as ψ the products associated with the ILEC's alternative investment, which the ILEC cannot make because it is investing for S. ψ could be another set of products or simply an inter-temporal change in when an investment to provide S could be made. That is to say, ψ could represent the same products as S, but provided on a different time schedule or a different way. ψ might also include retail products that the competitors sell in competition with the ILEC. Regardless of whether ψ represents a temporal or inter-temporal difference from S, or both, it is possible to re-express the optimization constraint and the participation constraint to explicitly include Real Options. Doing so changes the optimization constraint to the requirement that $\overline{\mathbf{p}}^S$ must equal the expected marginal cost, plus the adjustment for the ILEC not being able to charge directly for quality, plus the expected marginal unit value of the foregone options. The participation constraint becomes the requirement that $\overline{\mathbf{p}}^S$ be greater than or equal to the expected incremental cost of the ILEC choosing $\overline{I} = \overline{I}*$ over $\overline{I} = 0$, plus the value of the options that are foregone by increasing investment from 0 to $I*$, divided by the expected demand. In other words, the regulator's price ceiling must be greater than or equal to the ILEC's expected TELRIC plus the change in option values, divided by expected demand.

Incorporating Real Options improves ILEC incentives to invest efficiently, but the effect on the optimization and participation constraints is ambiguous. Hausman (1996) argues that Real Options values are positive, meaning that investments always foreclose options (Salinger, 1998). If this is the case, TELRIC-based prices induce ILECs to invest too little. Other writers (Abel et. al, 1996; Trigeorgis, 1996) point out that Real Option values can be positive or negative. In the context of pricing UNEs, Real Options might be negative if the investment creates opportunities. For example, the investment might be necessary to maintain a market presence and avoid costs of re-entering a market. Because the direction of the effect on $\overline{\mathbf{p}}^S$ is ambiguous, regulators would need to assess the effects of Real Options on a case-by-case basis if they choose to consider Real Options in regulating UNE and USO prices.

E. Real Options as ECPR

Incorporating Real Options into UNE and USO pricing is effectively an application of the efficient component pricing rule (ECPR). The ECPR, which is also called the Baumol-Willig rule, recommends that competitors pay ILECs their opportunity costs. In other words, the prices an ILEC would charge to competitors would ensure that the ILEC would make the same amount of profit regardless of whether it succeed in the competitive portion of the market. The ECPR formula for setting UNE prices (called wholesale prices in the formula) is (Baumol and Sidak, 1994):

Wholesale price = *Retail price* **-** [*Retail IC* – *Wholesale IC*]

Or alternatively,

$$\textit{Wholesale price} = \textit{Retail markup} + \textit{Wholesale IC} \qquad (1)$$

Where *IC* is the acronym for incremental cost and *Retail markup* = *Retail price* – *Retail IC*. Comparing Equation 1 to the participation constraint with Real Options, *Wholesale price* represents $\overline{\mathbf{p}}^S$ (setting aside USO products for the moment), *Wholesale IC* represents the incremental cost of *S*, and *Retail markup* represents the Real Option value of ψ.

Because Real Options is an application of the ECPR, several conclusions from the ECPR literature are applicable to Real Options; namely:

- The underlying model assumes that competitors are fringe competitors that can offer only some subset of what the ILEC produces. (Willig, 1979) If this assumption does not hold, then *Retail markup* is too large of a markup above *Wholesale IC* to promote efficiency. (Jamison, 1998c)
- *Retail markup* should contain no monopoly profits. (Tye, 1994)
- The retail market should be homogeneous, or the *Retail markup* should be adjusted for the differences in value to customers. (Willig, 1979; Armstrong and Doyle, undated)
- The ILEC is less likely to try to protect markets from competition and discriminate against competitors than with a lower *Wholesale price*. (Ordover, Sykes, and Willig, 1985)

Section III. How TELRIC Prices Affect Investment Incentives

This section describes how various properties of TELRIC studies affect ILEC investment incentives. I describe the relevant features of TELRIC studies first. Then I discuss the concerns with economic depreciation, demand uncertainty, and Real Options.

A. TELRIC Studies

The basic TELRIC formula begins by estimating the incremental capital expense (CAPEX) that $\mathbf{q}^S$ causes. The formula then multiplies an annual carrying charge by the incremental CAPEX. This carrying charge consists of the cost of capital, investment related taxes, and depreciation expense. The result is an annual carrying cost of the CAPEX. The formula then adds annual operating expenses to this annual carrying cost and expresses the result on a relevant unit basis; for example, per unit per month.

Traditionally, CAPEX has been the main driver in incremental cost studies. This was because analysts assumed that CAPEX drove almost all carrying costs and expenses, or at least that there was a strong positive correlation. Critical assumptions for CAPEX calculations have been:

1. Technology – By necessity, a TELRIC study assumes a particular technology is used to provide the network elements. Assumptions can vary, but my understanding is that the FCC prefers to assume that studies assume the most efficient or least-cost technology that is generally available.

2. Network architecture -- TELRIC studies tend to assume a scorched node; i.e., existing central offices and cable routes are assumed to be fixed, but technologies can change.

3. Utilization or Fill factor -- “Utilization” or “fill factor” refers to the percent of the capacity of a facility that the study assumes will be used. For example, an assumption of 50% utilization of a 200-pair cable means that it is assumed that 100 pairs are used. The FCC appears to favor average fill. However, calculating average fill is very difficult because, in practice, every node and link has a different fill and the fills change on a regular basis. The last time I examined TELRIC models, the Hatfield TELRIC model interpreted average fill to mean that the scorched-node network would be optimized with respect to fill, but with the constraint that network

facilities must be purchased in standard sizes. So, for example, if a cable route needed 202 copper pairs, the model would use the next size cable above 200 pair for estimating TELRIC.[16]

4. Depreciation -- The models use whatever depreciation rates the regulator sets.

5. Cost of capital -- The models use whatever cost of capital the regulator sets.

6. Operating expenses -- Traditionally, incremental cost studies estimated operating expenses by multiplying CAPEX by an expense/asset ratio calculated from ILECs' accounting records. I believe this is the method used by the TELRIC models that the FCC is considering. Recently, some ILECs have begun using activity based costing.

B. Comparison of Economic Principles with TELRIC Practice: Depreciation

Hausman (1996) argues that TELRIC studies do not include depreciation, or at least include too little depreciation. The first argument is incorrect. The previous subsection describes how TELRIC studies incorporate depreciation on assets.

With respect to the amount of depreciation, Hausman (1996) is correct that TELRIC studies should include economic depreciation and the effects of decreases in input prices. These effects are part of incremental cost. It is unlikely that the studies do this because, even if the studies use appropriate depreciation lives and depreciation methods, the studies' technology assumptions continually update the investment amounts according to technology and price improvements. As technology becomes more efficient and unit prices decline, updating the technology assumptions lowers depreciation expenses, all other things being equal. Unless this effect is incorporated into the depreciation, this updating causes TELRIC models to understate depreciation. In my experience, regulatory depreciation practices do not consider this dynamic of using depreciation in TELRIC models. As a result, there is a risk that prices will be too low.

C. Comparison of Economic Principles with TELRIC Practice: Demand Uncertainty

Hausman (1996) also argues that TELRIC studies do not adequately reflect the effects of demand uncertainty on ILECs' irreversible investments. This appears to be at least partially true, but not to the extent claimed.

[16] In a dynamic sense, this creates a simultaneity problem because price affects quantity demanded.

My model incorporates demand uncertainty and irreversible investments. In the model, the ILEC makes the investment before the ILEC knows demand and the ILEC is unable to reverse the investment. The participation constraint states that the price must be greater than or equal to expected average incremental cost. The numerator for the average incremental cost includes all of the costs the ILEC incurs to provide $\mathbf{q}^S$, including costs incurred for demand that does not materialize or that does not remain for the entire economic life of the plant. The denominator is the expected sales. As a result, average incremental cost represents an average over projects which live up to their demand expectations, projects which exceed their demand expectations, and projects which fail to live up to their demand expectations. All irreversible investments are covered in the participation constraint.[17] Likewise, the optimization constraint incorporates expected demand and costs over all projects incorporating the UNE or USO.

Unfortunately, it appears that the TELRIC models that the FCC is considering do not live up to the optimization and participation constraints with respect to uncertain demand. As subsection A above explains, the FCC has determined that TELRIC studies should assume an average utilization amount. This results in per unit TELRICs equal to average incremental costs. However, the implementation of this decision in the Hatfield model does not take into account all factors that cause utilization to be less than optimal.[18] Specifically, by optimizing the network based on current demand and future growth, the studies fail to consider projects that fail to live up to the investors' demand expectations. As a result, the application of the TELRIC models understates average incremental cost and marginal cost.

Hausman (1996) also states in the context of uncertain demand that TELRIC-based prices truncate the amount of profits that ILECs can expect from innovation, thus discouraging innovation-related investments. His assertion is correct. In fact, any regulation that limits the amount of profit that an ILEC receives from an investment has this effect. TELRIC-based prices are more onerous than, for example, regular price cap constraints in that normal price caps allow companies to adjust prices and so earn extra profits on a particular service should market conditions permit. However, the problem is with price limits on innovations, not with demand uncertainty. At least in theory, the proper remedy for this problem would be to have few, if any,

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TELRIC models are static and so ignore this problem.

[17] Even though using average fill would remedy the irreversibility of investments for individual projects, it does not remedy irreversibility for the ILEC's investment as a whole. This irreversibility should be reflected in the cost of capital. Henry Ergas (1998) argues that traditional cost of capital tools such as CAPM do not adequately reflect this irreversibility. Hubbard and Lehr (1996) argue that they do. Not being an expert on cost of capital, I will leave this debate to others.

[18] According to a FCC staff report, the BCPM2 model uses similar fill factors.

price constraints on innovations. In practice, it is hard to determine when something is an actual innovation and not just opportunistic use of regulatory rules.

D. Comparison of Economic Principles with TELRIC Practice: Real Options

Hausman (1996) also asserts that TELRIC studies understate incremental cost because they fail to reflect the value of Real Options -- inter-temporal investment options foreclosed when the ILEC chooses $\overline{I}$. This may be true in some instances, but it is difficult to imagine that the effect is large.

The ECPR equations in Section II illustrate how an ILEC's choice to make UNE and USO product investments, which I call $\overline{I}^S$, must provide greater profit than the ILEC's best alternative investment, which I call $\overline{I}^\Psi$, that $\overline{I}^S$ forecloses for the ILEC to choose $\overline{I}^S$. The ECPR equations also illustrate how Real Options created by $\overline{I}^S$ lower the profit needed from $\overline{I}^S$ to induce the ILEC to make the investment. To foreclose investments, $\overline{I}^S$ must occupy some space that $\overline{I}^\Psi$ requires. This space could be:

1. *Physical.* This would be space in, for example, conduit, buildings, or radio spectrum, that $\overline{I}^\Psi$ could occupy in the future. If this is the only available space for $\overline{I}^\Psi$, then the full value of $\overline{I}^\Psi$ is in the Real Option. By "value of $\overline{I}^\Psi$, I mean the net present value of cash and options from $\overline{I}^\Psi$. If there are other spaces that $\overline{I}^\Psi$ could occupy, then only the incremental loss if $\overline{I}^\Psi$'s full value would be included.

2. *Capital.* This would include the consumption of capital that could not be replaced in the future except at a higher cost

3. *Demand*. The investment $\overline{I}^S$ might supply some consumer demand that could be served with higher valued investment sometime in the future

4. *Cost*. The investment $\overline{I}^S$ might supply consumer demand that could be served with lower cost investment sometime in the future.

5. *Rights*. The investment $\overline{I}^S$ might cause the ILEC to lose some legal right that has value. For example, if a rural ILEC purchased other exchanges in its state, it might become sufficiently large to lose its rural ILEC status. As a non-rural ILEC, the ILEC would be subject to the unbundling and other local exchange competition requirements of the Act.

To create an option, an investment must create an opportunity that did not exist previously. For example, an investment in opening local exchange markets to competition creates a long distance option for Regional Bell Operating Companies who are currently prohibited from providing this service. If $\overline{I}^{S}$ does foreclose or open a profitable investment I^{ψ}, it may be necessary to apply something like the ECPR to incent the ILEC to make the investment.[19]

If it is necessary to consider the opportunity cost of a foreclosed investment in pricing interconnection or USOs, it is also necessary to incorporate all of the cost and revenue effects of taking the foreclosed investment. For example, if the alternative investment is a delayed investment in cable used to serve a particular market, then the cost of re-entering the market should be incorporated as should the revenue loss from helping competitors increase their market penetration.

Also because the inter-temporal opportunity cost applies only certain conditions and can be positive or negative, it should be modeled separately from the TELRIC cost. A general adjustment to all TELRIC estimates would not necessarily improve investment incentives. Also, making the inter-temporal opportunity cost a separate model makes it easier for regulators to assess the validity of the cost and the assumptions made when estimating it.

E. Comparison of Economic Principles with TELRIC Practice: Other Factors

There are other factors that affect the appropriateness of TELRIC practices. These may also decrease investment incentives below an optimal level.

One factor is the application of the mark-up above TELRIC. Some regulators omit the mark-ups. Others provide mark-ups only to cover shared costs. The first practice provides an inefficient incentive to decrease investment and the second practice might. Recall that TELRIC is the sum of all marginal costs. The common assumption in telecommunications is that marginal costs are constant as production increases. In local exchanges, production economies come from density and scope rather than scale. If higher prices induce greater investment, which is also a common assumption, then the efficient price is above marginal cost and, therefore, above TELRIC, expressed on a per unit basis. Contributions to shared costs might provide the appropriate mark-up, but it would be only by accident because the formulas for spreading shared costs do not consider investment's effects on quality.

[19] However, as has been shown in the ECPR literature, it is inappropriate to consider any portion of these

Another factor is the omission of the effects of rivalry on appropriate prices. If ILECs are subject to general multilateral rivalry (Jamison, 1996), the rivalry forces ILECs to price below stand-alone cost for individual products and for groups of products. This, in turn, means that ILEC prices for individual products and for groups of products must exceed TELRIC for the ILEC to remain financially viable. Also, the lack of opportunity to charge for quality may lower the quality of services customers ultimately receive because ILECs benefit from investing in quality only through increased demand. This increased demand passes along to the ILEC only a portion of the value that the investment creates. This may provide companies with an uneconomic incentive to merge in areas with large amounts of network interconnection because the merger allows the merged company to internalize some of the benefits of investment in quality.

The last factor is the regulatory process for using TELRIC models affects risk. I assume in this paper that the regulator commits to a price schedule that the ILEC is certain will hold over the entire life of the investment. This is unlikely to be true. US and international experience with such models indicate that regulators can cause wide swings in cost study results by changing a few critical assumptions. In the days of rate of return regulation, assumptions in fully distributed cost studies and in rate cases primarily affected when costs would be recovered and from what service. While these issues were important to market efficiency, they did not rise to the level of today's use of cost studies where changes in assumptions determine total revenues without a clear remedy for inter-temporal errors, except to seek stranded cost recovery. If ILECs believe that regulators will act arbitrarily or opportunistically with the TELRIC models, then the ILECs will under invest.

Section IV. Conclusion

In this paper I consider issues that the Real Options debate has raised regarding the estimation and application of incremental costs. I show that current TELRIC models underestimate incremental costs, but not to the extent that some claim. I also show that concerns with inter-temporal opportunity costs are effectively an application of the ECPR. This means that much of the literature about the ECPR should be applicable to this issue.

There are other issues that I have not discussed or modeled that also influence the effects of using current TELRIC models for pricing UNEs and USO products. One such issue is the

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higher profits that represent monopoly profits.

effect of stranded cost remedies on ILEC investment decisions. Economic literature on contract breach remedies appears to imply that some stranded cost remedies would alleviate under investment concerns and may actually encourage over investment. Customer contributions for line extensions and contributions by real estate developers may also have these effects.

My model does not consider rivalry in the ILEC's markets. As I mention in the previous section, multilateral rivalry would provide alternatives for both the ILECs and the customers. This would generally create additional pricing constraints. Also, customer's opportunities to self-provide UNEs affect outcomes. Reciprocal compensation also affects the economics of buying and selling UNEs.

Also, my assumption about the nature of investment is quite specific. I assume that investment produces both quality and reduces costs. This may be true for some investments, but may not be true for all. A more thorough study is needed that considers both specific investments and joint investments, such as the investment I assume.

Lastly, I have not addressed whether the regulator should try to estimate TELRIC accurately, or try to over estimate or under estimate TELRIC. I have assumed that the regulator can come fairly close. It may be that the regulator, knowing that she has a probability of error, should seek to overstate TELRIC or understate TELRIC because one has less of a negative effect on efficiency.

Appendix

My model considers a multiproduct ILEC that makes investment decisions subject to regulatory pricing constraints and uncertain demand. The ILEC produces products $M \subset N$, where N is the set of all products in the economy. The ILEC's products $S \subset M$ are the products that fall either into the category of UNEs or into the category of products subject to USOs. A product i is subject to an USO if the regulator requires the ILEC to charge a price $\overline{p^i} < \phi^i$, where ϕ^i is the price that ILEC would charge in a perfectly competitive market.

Demand is given by $\mathbf{q}(\mathbf{p}, \theta, I)$, where nature determines θ and I represents investment that the ILEC can undertake. Investment improves quality, so $\mathbf{q}_I(\mathbf{p}, \theta, I) > 0$, where subscripts denote first derivatives. Also, $\partial q^i(\mathbf{p}, \theta, I)/\partial p^i < 0$, $\forall\ i \in M$.

$C(\mathbf{q}^M, I)$ is the ILEC's cost function and $\Delta C(\mathbf{q}^S, I) = C(\mathbf{q}^M, I) - C(\mathbf{q}^{M\backslash S}, I) < C(\mathbf{q}^S, I)$ is the incremental cost of producing $\mathbf{q}^S$. I assume that $C_I < 0$, $\Delta C_I < 0$, $\partial \mathrm{C}(\mathbf{q}^M, I)/\partial q^i > 0$, and $\partial^2 \mathrm{C}(\mathbf{q}^M, I)/\partial q^i\, \partial I < 0$, $\forall\ i \in M$. The incremental revenue effect of producing $\mathbf{q}^s$ is:

$$\Delta \mathrm{R}^S(\mathbf{p}^M, \theta, I) = \mathbf{q}^M(\mathbf{p}^M, \theta, I) \bullet \mathbf{p}^M - \mathbf{q}^{M\backslash S}(\mathbf{p}^M, \theta, I) \bullet \mathbf{p}^{M\backslash S}$$

I assume there are no demand cross-elastic effects between S and $M\backslash S$, so

$$\Delta \mathrm{R}^S(\mathbf{p}^M, \theta, I) = \mathbf{q}^S(\mathbf{p}^S, \theta, I) \bullet \mathbf{p}^S.$$

I assume that if the ILEC makes no investment, it produces no UNEs and USO products because customers would not buy them. In other words, $\mathbf{q}^S(\mathbf{p}^S, \theta, 0) = 0$ and $\Delta C(0, 0) = 0$.

I suppress competitors' profits by assuming that they operate in perfectly competitive markets. I also assume that the regulator wants to maximize weighted surplus

$$Z \equiv \int_{\theta^{\min}}^{\theta^{\max}} \left[w^C V\left(\mathbf{q}^S, \theta, I\right) - w^{ILEC}\left(\Delta C\left(\mathbf{q}^S, I\right) + I\right) + \left(w^{ILEC} - w^C\right) \bullet \mathbf{q}^S\left(\mathbf{p}^S, \theta, I\right) \bullet \mathbf{p}^S \right] dF \geq 0$$

where w^{ILEC} and w^C are the weights given to ILEC profits and customer surplus respectively, and $V(\mathbf{q}^S, \theta, I)$ is the customer's gross surplus. For simplicity, I assume that these weights are equal. This simplifies the regulator's problem to maximizing

$$Z \equiv \int_{\theta^{\min}}^{\theta^{\max}} \left(V\left(\mathbf{q}^{S}, \theta, I\right) - \Delta C\left(\mathbf{q}^{S}, I\right) - I \right) dF \ \geq 0 \tag{2}$$

There are three time periods. In the first period, the regulator selects the price vector $\overline{\mathbf{p}}^{S}$ for UNEs and USOs using TELRIC models. The regulator does not know I or θ. However, the regulator knows that $\theta \in [\theta^{min}, \theta^{max}]$ and is distributed according to the cumulative density function F(θ). The regulator also knows the ILEC is profit maximizing and risk neutral, so the regulator is able to accurately estimate the ILEC's best response function to customer demand and the regulator's price controls. The regulator also selects the price vector $\overline{\mathbf{p}}^{M\backslash S}$ using some price capping mechanism and not rate of return regulation. The purpose of this assumption is to remove opportunities for cost shifting and incentives for padding the rate base.

In the second period, the ILEC chooses $\overline{I}$. The ILEC knows $\overline{\mathbf{p}}^{S}$. The ILEC does not know θ, but knows the range and density function just as the regulator does. In the third period, nature chooses $\overline{\theta}$, customers buy $\mathbf{q}^{S}(\overline{\mathbf{p}}^{M}, \overline{\theta}, \overline{I})$, and the ILEC receives incremental revenues of $\mathbf{q}^{S}(\overline{\mathbf{p}}^{S}, \overline{\theta}, \overline{I}) \bullet \overline{\mathbf{p}}^{S}$.

To solve Equation 2, the regulator chooses the optimal price vector, $\overline{\mathbf{p}}^{S}*$, by backwards induction. For simplicity, I represent the group of customers as a single customer. The regulator calculates that in the last stage of the game, this customer maximizes utility according to

$$\max_{\mathbf{q}^{S} \in \left[0, \mathbf{q}^{S\max}\right]} \left\{ V\left(\mathbf{q}^{S}, \overline{\theta}, I\right) - \overline{\mathbf{p}}^{S} \bullet \mathbf{q}\left(\overline{\mathbf{p}}^{S}, \overline{\theta}, I\right) \right\} \geq 0$$

The customer’s first order conditions are

$$V_{q^{i}}\left(\mathbf{q}^{S}, \overline{\theta}, I\right) = \overline{p}^{i} \quad \forall\, i \in S \tag{3}$$

I assume that second order conditions are satisfied. Equation 3 implies an optimal quantity choice $\mathbf{q}^{S}*(\mathbf{p}, \theta, I)$.

The regulator then calculates the ILEC’s best response function to the customer’s choice. The ILEC maximizes profits according to

$$\max_{I\in[0,I^{\max}]} \pi\left(\mathbf{q}^{M},\theta,I\right)\equiv\int_{\theta^{\min}}^{\theta^{\max}}\left[\mathbf{q}^{M*}\left(\overline{\mathbf{p}}^{M},\theta,I\right)\bullet\overline{\mathbf{p}}^{M}-C\left(\mathbf{q}^{M*}\left(\overline{\mathbf{p}}^{M},\theta,I\right),I\right)\right]dF-I\geq 0$$

Isolating *S* gives

$$\max_{I\in[0,I^{\max}]} \pi\left(\mathbf{q}^{S},\theta,I\right)\equiv\int_{\theta^{\min}}^{\theta^{\max}}\left[\mathbf{q}^{S*}\left(\overline{\mathbf{p}}^{S},\theta,I\right)\bullet\overline{\mathbf{p}}^{S}-\Delta C\left(\mathbf{q}^{S*}\left(\overline{\mathbf{p}}^{S},\theta,I\right),I\right)\right]dF-I\geq 0$$

because of the assumption that demands are independent.

This gives the first order conditions

$$0\equiv\int_{\theta^{\min}}^{\theta^{\max}}\left[\begin{array}{l} q_I^{i*}\left(\overline{\mathbf{p}}^{S},\theta,I^*\right)\cdot\overline{p}^{i}-\Delta C_{q^i}\left(q^{i*}\left(\overline{\mathbf{p}}^{S},\theta,I^*\right),I^*\right)\cdot q_I^{i*}\left(\overline{\mathbf{p}}^{S},\theta,I^*\right) \\ -\Delta C_I\left(q^{i*}\left(\overline{\mathbf{p}}^{S},\theta,I^*\right),I^*\right)\end{array}\right]dF-1\quad\forall\, i\in S\qquad(4a)$$

or

$$\overline{p}^{i}\equiv\frac{\mathbb{E}\left(\Delta C_{q^i}\left(q^{i*}\left(\overline{\mathbf{p}}^{S},I^*\right),I^*\right)\cdot q_I^{i*}\left(\overline{\mathbf{p}}^{S},I^*\right)\right)+\mathbb{E}\Delta C_I\left(q^{i*}\left(\overline{\mathbf{p}}^{S},I^*\right),I^*\right)+1}{\mathbb{E}q_I^{i*}\left(\overline{\mathbf{p}}^{S},I^*\right)}\quad\forall\, i\in S\qquad(4b)$$

where $\mathbb{E}$(*arg*) is the expected value of *arg*. Equations 4a and 4b are the optimization constraints and imply an optimal investment $I^*(\mathbf{p}^S)$. The ILEC is willing to make the optimal investment as long as these hold and

$$\overline{p}^{i}\geq\frac{\mathbb{E}\Delta C\left(q^{i*}\left(\overline{\mathbf{p}}^{S},I^*\right),I^*\right)+I^*}{\mathbb{E}q^{i*}\left(\overline{\mathbf{p}}^{S},I^*\right)}\quad\forall\, i\in S\qquad(5a)$$

which is the participation constraint.

If the regulator were able to choose investment directly, the regulator's choice would be to optimize Equation 2 with respect to quantity and investment. This would give the first order conditions

$$0=\int_{\theta^{\min}}^{\theta^{\max}}\left[V_{q^i}\left(\mathbf{q}^S,\theta,I\right)-\Delta C_{q^i}\left(\mathbf{q}^S,I\right)\right]dF \tag{6}$$

$$0=\int_{\theta^{\min}}^{\theta^{\max}}\left[V_I\left(\mathbf{q}^S,\theta,I\right)-\Delta C_I\left(\mathbf{q}^S,I\right)\right]dF-1 \tag{7}$$

The regulator is unable to satisfy these conditions in this model. I show this by combining the regulator's first order conditions with the customer's and ILEC's first order conditions. Combining Equations 3 and 4a gives

$$0\equiv\int_{\theta^{\min}}^{\theta^{\max}}\begin{bmatrix} q_I^{i*}\left(\overline{\mathbf{p}}^S,\theta,I^*\right)\cdot\left(V_{q^i}\left(\mathbf{q}^S,\theta,I\right)-\Delta C_{q^i}\left(q^{i*}\left(\overline{\mathbf{p}}^S,\theta,I^*\right),I^*\right)\right) \\ -\Delta C_I\left(q^{i*}\left(\overline{\mathbf{p}}^S,\theta,I^*\right),I^*\right)\end{bmatrix}dF-1 \quad \forall\, i\in S \tag{8}$$

From Equation (6)

$$V_{q^i}\left(\mathbf{q}^S,\theta,I\right)-\Delta C_{q^i}\left(q^{i*}\left(\overline{\mathbf{p}}^S,\theta,I^*\right),I^*\right)=0$$

so Equation (8) becomes

$$-\mathbb{E}\Delta C_I\left(q^{i*}\left(\overline{\mathbf{p}}^S,\theta,I^*\right),I^*\right)=1 \quad \forall\, i\in S$$

which means Equation (7) becomes $V_I(\mathbf{q}, I) = 0$. So the regulator can satisfy her first order conditions only in the special case where the customer’s marginal value of investment is zero and investment’s marginal effect on the ILEC is to decrease cost dollar for dollar.

Because the regulator cannot dictate quantity and investment, the best the regulator can do is maximize the following

$$\max_{\mathbf{p}}\int_{\theta^{\min}}^{\theta^{\max}}\left[V\left(\mathbf{q}^{S*}\left(\mathbf{p}^S,\theta,I^*\left(\mathbf{p}^S\right)\right),I^*\left(\mathbf{p}^S\right)\right)-\Delta C\left(\mathbf{q}^{S*}\left(\mathbf{p}^S,\theta,I^*\left(\mathbf{p}^S\right)\right),I^*\left(\mathbf{p}^S\right)\right)\right]dF-I^*\left(\mathbf{p}^S\right)\geq 0$$

which gives the following first order conditions

$$\int_{\theta^{\min}}^{\theta^{\max}} \left[V_{q^i} \cdot q_{p^i}^{i*} + V_{q^i} \cdot q_I^{i*} \cdot I_{p^i}^* + V_I \cdot I_{p^i}^* - \Delta C_{q^i} \cdot q_{p^i}^{i*} - \Delta C_{q^i} \cdot q_I^{i*} \cdot I_{p^i}^* - \Delta C_I \cdot I_{p^i}^* \right] dF - I_{p^i}^* = 0 \quad \forall i \in S \qquad (9a)$$

I assume that second order conditions are satisfied.

To isolate price, I use the customer's first order conditions from Equation 3 to obtain

$$\int_{\theta^{\min}}^{\theta^{\max}} \left(p^i \cdot q_{p^i}^{i*} - \Delta C_{q^i} \cdot q_{p^i}^{i*} + V_I \cdot I_{p^i}^* \right) dF + I_{p^i}^* \left\{ \int_{\theta^{\min}}^{\theta^{\max}} \left(p^i \cdot q_I^{i*} - \Delta C_{q^i} \cdot q_I^{i*} - \Delta C_I \right) dF - 1 \right\} = 0 \quad \forall i \in S$$

From the ILEC's first order conditions in Equation 4a, the value inside the {} is zero, so the regulator's first order conditions become

$$\int_{\theta^{\min}}^{\theta^{\max}} \left(q_{p^i}^{i*} \left(p^i - \Delta C_{q^i} \right) + V_I \cdot I_{p^i}^* \right) dF = 0 \quad \forall i \in S \qquad (10a)$$

or

$$\overline{p}^i = \frac{\mathbb{E}\left(\Delta C_{q^i} \cdot q_{p^i}^{i*} \right) - \mathbb{E} V_I \cdot I_{p^i}^*}{\mathbb{E} q_{p^i}^{i*}} \quad \forall i \in S \qquad (10b)$$

Equation 10a shows that the regulator's optimal price ceiling will equal marginal cost only if the customer's marginal value of investment is zero. By assumption, $V_I > 0$ and $q^{i*}_{pi} < 0$, so the sign of I^*_{pi} determines whether the optimal price ceiling is above or below marginal cost. The regulator's optimal price ceiling is above marginal cost if an increase in price increases investment, and the regulator's optimal price ceiling is below the marginal cost of an increase in price decreases investment. To determine the sign of I^*_{pi}, I divide the total derivative of the ILEC's first order conditions (Equation 4a) with respect to price by the total derivative of its first order conditions with respect to investment. In other words,

$$I^*_{p^i} = -\frac{\pi_{I\,p^i}}{\pi_{I\,I}}$$

From second order conditions, $\pi_{I\,I} < 0$, so the sign of $\pi_{I\,pi}$ determines the sign of I^*_{pi}. $\pi_{I\,pi}$ is

$$\int_{\theta^{\min}}^{\theta^{\max}} \left[q^{i*}_{I\,p^i} \cdot \overline{p}^i + q^{i*}_I - \Delta C_{q^i q^i} \cdot q^{i*}_I \cdot q^{i*}_{p^i} - \Delta C_{q^i} \cdot q^{i*}_{I\,p^i} - \Delta C_{I\,q^i} \cdot q^{i*}_{p^i} \right] dF \quad \forall\, i \in S$$

Rearranging terms and reversing signs to get rid of the negative sign in front of the quotient gives

$$\int_{\theta^{\min}}^{\theta^{\max}} \left(q^{i*}_{p^i} \left(\Delta C_{I\,q^i} - \Delta C_{q^i q^i} \cdot q^{i*}_I \right) + q^{i*}_{I\,p^i} \left(\Delta C_{q^i} - \overline{p}^i \right) - q^{i*}_I \right) dF \quad \forall\, i \in S$$

The sign of the first expression depends upon the sign of the expression inside the parentheses because $q^{i*}_{pi} < 0$. The second expression's sign depends upon the sign of $q^{i*}_{I\,pi}$ because the sign of the expression inside the parentheses depends upon the sign of I^*_{pi}. If $I^*_{pi} > 0$, then the regulator's price is above marginal cost and the expression is negative. If $I^*_{pi} < 0$, the reverse is true. q^{i*}_I is positive by assumption. So sufficient conditions for $I^*_{pi} > 0$ are

$$\left.\begin{aligned} &\Delta C_{q^i q^i} \cdot q^{i*}_I > -\Delta C_{I\,q^i} \\ &q^{i*}_{I\,p^i} > 0 \end{aligned}\right\} \tag{11}$$

$$\left.\begin{aligned} &\Delta C_{q^i q^i} \cdot q^{i*}_I < -\Delta C_{I\,q^i} \\ &q^{i*}_{I\,p^i} > 0 \\ &q^{i*}_{p^i} \left(\Delta C_{I\,q^i} - \Delta C_{q^i q^i} \cdot q^{i*}_I \right) - q^{i*}_I < -q^{i*}_{I\,p^i} \left(\Delta C_{q^i} - \overline{p}^i \right) \end{aligned}\right\} \tag{12}$$

$$\left.\begin{aligned} &\Delta C_{q^i q^i} \cdot q^{i*}_I > -\Delta C_{I\,q^i} \\ &q^{i*}_{I\,p^i} < 0 \\ &q^{i*}_{I\,p^i} \left(\Delta C_{q^i} - \overline{p}^i \right) - q^{i*}_I < -q^{i*}_{p^i} \left(\Delta C_{I\,q^i} - \Delta C_{q^i q^i} \cdot q^{i*}_I \right) \end{aligned}\right\} \tag{13}$$

Conditions 11 hold if the extra marginal costs caused by the investment-induced demand growth dominate the investment-induced decrease in marginal costs, and if investment causes the inverse demand curve to be steeper. Conditions 12 hold if the investment-induced decrease in marginal costs dominates the extra marginal costs caused by the investment-induced demand growth, if investment causes the inverse demand curve to be steeper, and if the combined effects of the steeper inverse demand curve and price exceeding marginal cost dominate the other effects. Conditions 13 hold if the costs caused by the investment-induced demand growth dominate the investment-induced decrease in marginal costs, if investment causes the inverse demand curve to flatten, and if the combined effects of the marginal cost decreases and demand changing with price increases and investment increases dominate the other effects.

Sufficient conditions for $I^{*}_{pi} < 0$ are

$$\left.\begin{array}{l} \Delta C_{q^i q^i} \cdot q_I^{i*} < -\Delta C_{I q^i} \\ q_{I p^i}^{i*} > 0 \\ q_{p^i}^{i*}\left(\Delta C_{I q^i} - \Delta C_{q^i q^i} \cdot q_I^{i*}\right) + q_{I p^i}^{i*}\left(\Delta C_{q^i} - \overline{p}^{i}\right) > q_I^{i*} \end{array}\right\} \tag{14}$$

$$\left.\begin{array}{l} \Delta C_{q^i q^i} \cdot q_I^{i*} > -\Delta C_{I q^i} \\ q_{I p^i}^{i*} > 0 \\ -q_{p^i}^{i*}\left(\Delta C_{I q^i} - \Delta C_{q^i q^i} \cdot q_I^{i*}\right) + q_I^{i*} < q_{I p^i}^{i*}\left(\Delta C_{q^i} - \overline{p}^{i}\right) \end{array}\right\} \tag{15}$$

$$\left.\begin{array}{l} \Delta C_{q^i q^i} \cdot q_I^{i*} < -\Delta C_{I q^i} \\ q_{I p^i}^{i*} < 0 \\ -q_{I p^i}^{i*}\left(\Delta C_{q^i} - \overline{p}^{i}\right) + q_I^{i*} < q_{p^i}^{i*}\left(\Delta C_{I q^i} - \Delta C_{q^i q^i} \cdot q_I^{i*}\right) \end{array}\right\} \tag{16}$$

Conditions 14 hold if the investment-induced decrease in marginal costs dominate the extra marginal costs caused by the investment-induced demand growth, investment causes the inverse demand curve to be steeper, and investment's effect on demand is dominated by all other effects. Conditions 15 hold if the extra marginal costs caused by the investment-induced demand growth dominates the investment-induced decrease in marginal costs, investment causes the inverse demand curve to be steeper, and the combined effects of the steepening inverse demand curve and price exceeding marginal cost dominate the other effects. Conditions 16 hold if the costs caused by the investment-induced demand growth are dominated by the investment-induced decrease in marginal costs, investment causes the inverse demand curve to flatten, and the combined effects of the marginal cost decreases and demand changing with price increases and investment increases dominate the other effects.

Now I consider the effects of Real Options. The customer's first order conditions in Equation 3 still hold. However, the ILEC's maximization problem and first order conditions become

$$\max_{I\in[0,I^{\max}]} \pi\left(\mathbf{q}^S,\theta,I\right)\equiv\int_{\theta^{\min}}^{\theta^{\max}}\left[\mathbf{q}^{S*}\left(\overline{\mathbf{p}}^S,\theta,I\right)\bullet\overline{\mathbf{p}}^S-\Delta C\left(\mathbf{q}^{S*}\left(\overline{\mathbf{p}}^S,\theta,I\right),I\right)\right]dF-I\pm\rho\geq 0$$

$$0\equiv\int_{\theta^{\min}}^{\theta^{\max}}\left[\begin{array}{l}q_I^{i*}\left(\overline{\mathbf{p}}^S,\theta,I^*\right)\cdot\overline{p}^i-\Delta C_{q^i}\left(q^{i*}\left(\overline{\mathbf{p}}^S,\theta,I^*\right),I^*\right)\cdot q_I^i\left(\overline{\mathbf{p}}^S,\theta,I^*\right)\\-\Delta C_I\left(q^{i*}\left(\overline{\mathbf{p}}^S,\theta,I^*\right),I^*\right)\end{array}\right]dF-1\pm\rho_I\quad\forall\, i\in S\quad\text{(4c)}$$

where ρ is the net absolute value of the Real Options foreclosed or opened by $\overline{I}^S$. I give ρ a plus sign if the net value of the Real Options is positive and give ρ a negative sign if the net value of the Real Options is negative.

I assume that some portion $\alpha\in[0, 1]$ of ρ is a social benefit or cost, so 1-α of ρ is private to the ILEC. The regulator's maximization problem and first order conditions are now

$$\max_{\mathbf{p}}\int_{\theta^{\min}}^{\theta^{\max}}\left[V\left(\mathbf{q}^{S*}\left(\mathbf{p}^S,\theta,I^*\left(\mathbf{p}^S\right)\right),I^*\left(\mathbf{p}^S\right)\right)-\Delta C\left(\mathbf{q}^{S*}\left(\mathbf{p}^S,\theta,I^*\left(\mathbf{p}^S\right)\right),I^*\left(\mathbf{p}^S\right)\right)\right]dF-I^*\left(\mathbf{p}^S\right)\pm\alpha\cdot\rho\geq 0$$

$$\int_{\theta^{\min}}^{\theta^{\max}}\left[\begin{array}{l}V_{q^i}\cdot q_{p^i}^{i*}+V_{q^i}\cdot q_I^{i*}\cdot I_{p^i}^*+V_I\cdot I_{p^i}^*-\Delta C_{q^i}\cdot q_{p^i}^{i*}\\-\Delta C_{q^i}\cdot q_I^{i*}\cdot I_{p^i}^*-\Delta C_I\cdot I_{p^i}^*\end{array}\right]dF-I_{p^i}^*\pm\alpha\cdot\rho_I\cdot I_{p^i}^*=0\quad\forall i\in S\quad\text{(9b)}$$

where the first order condition solves to

$$\int_{\theta^{\min}}^{\theta^{\max}} \left(q_{p^i}^{i*} \left(p^i - \Delta C_{q^i} \right) + I_{p^i}^{*} \left(V_I \pm (\alpha - 1)\rho_I \right) \right) dF$$
$$+ I_{p^i}^{*} \left\{ \int_{\theta^{\min}}^{\theta^{\max}} \left(p^i \cdot q_I^{i*} - \Delta C_{q^i} \cdot q_I^{i*} - \Delta C_I \right) dF - 1 \pm \rho \right\} = 0 \quad \forall i \in S$$

which, when combined with the ILEC's first order conditions, becomes

$$\int_{\theta^{\min}}^{\theta^{\max}} \left(q_{p^i}^{i*} \left(p^i - \Delta C_{q^i} \right) + I_{p^i}^{*} \left(V_I \pm (\alpha - 1)\rho_I \right) \right) dF = 0 \quad \forall i \in S$$

or

$$p^i = \frac{\mathbb{E}\left(\Delta C_{q^i} \cdot q_{p^i}^{i*} \right) - I_{p^i}^{*} \left(\mathbb{E} V_I \pm (\alpha - 1)\rho_I \right)}{\mathbb{E} q_{p^i}^{i*}} \quad \forall i \in S$$

Because $\rho_I > 0$ and $\alpha - 1 < 0$, the effect of Real Options is to decrease the mark-up above marginal cost if the Real Option is opened by investment, and to increase the mark-up above marginal cost if the Real Option is foreclosed by investment. Real Options do not affect the sign of I^{*}_{pi}.

The participation constraint becomes

$$\overline{p}^{\,i} \geq \frac{\mathbb{E}\Delta C\left(q^{i*}\left(\overline{\mathbf{p}}^{S}, I^{*} \right), I^{*} \right) + I \pm \rho}{\mathbb{E} q^{i*}\left(\overline{\mathbf{p}}^{S}, I^{*} \right)} \quad \forall\, i \in S \tag{5b}$$

which is the ECPR.

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