Chapter 3

# Dynamic Effects of Regulation on Exchange Carrier Incentives

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## I. INTRODUCTION AND OVERVIEW

The purpose of this chapter is to examine the effect of alternative forms of regulation on an exchange carrier's pricing and investment decisions, where investment is analyzed in terms of capacity expansion and in terms of improvements in infrastructure quality. Two forms of regulation are considered: rate of return and price cap regulation. It is becoming increasingly important to analyze the differential effects of these policies as exchange carriers expand their operations in both regulated and unregulated markets, further exacerbating the problems associated with implementing cost allocation rules. These rules serve to apportion the costs of resources used in the joint production of multiple services, which influences the rates charged for these services and thereby affect the firm's investment decisions. Hence, the choice of regulatory policy has a direct effect on the efficiency with which the telecommunications infrastructure evolves, as well as important implications for the quality of that infrastructure.

The analytical model presented here offers a stylized version of an exchange carrier in which the firm sells both a regulated, basic service[1] and an unregulated, enhanced service. The basic service is sold directly to retail customers in a regulated market and as an input to value-added resellers (VARs). The VARs combine the basic service with additional resources to produce an enhanced service that is sold in an unregulated, competitive retail market. The exchange carrier may be affiliated directly with one of the VARs. Moreover, I assume that the exchange carrier is subject to Open Network Architecture (ONA) constraints,[2] which preclude the exchange carrier from price discriminating when it sells the basic service. This means that the price for the basic service will be the same whether it is sold to consumers directly in the regulated retail market or as an input for enhanced services in the wholesale market to VARs. Moreover, the exchange carrier cannot charge different prices to affiliated and unaffiliated VARs. The VARs compete in a competitive retail market.

In addition to the exchange carrier, I assume that there are alternative suppliers of underlying infrastructure, including interexchange carriers (IXCs), cable companies (CATV), and competitive access providers (CAPs) such as Teleport and Metropolitan Fiber Systems from whom the VARs may purchase the basic services that are used as an input to produce the enhanced service. Some of these alternative infrastructure suppliers also may participate as VARs. Thus, the exchange carrier participates in the enhanced market both directly via an affiliated VAR and indirectly via sales of its basic services in the wholesale market to other VARs.

Recent trends toward deregulation that are encouraging the unbundling of access to local exchange networks and the proliferation of new retail operations offering wireless and interactive video services, which are overlaid on the wireline infrastructure, are leading us toward this type of industry structure.

The vertically integrated exchange carrier is assumed to use variable resources (e.g., labor, materials, energy, etc.) and network capital to produce its basic and enhanced services. This chapter differs from similar analyses by distinguishing between two types of network capital investments. The firm can invest in both expanding its physical, or nominal, capital ($K_N$) as well as the productivity of its capital ($B$). These latter types of investments, which are not traditionally included in the computation of the firm's rate base, may be thought of as investments to enhance the quality of network capital or as investments in innovation. Cost allocation rules determine how costs are allocated between basic and enhanced services.

The model that is presented and analyzed in the balance of the chapter yields five main conclusions, or recommendations, as follows:

1. *Policymakers should make sure that the price cap formula is relatively insensitive to fluctuations in total sales of the basic service*. The price cap mechanism specifies how the maximum price that may be charged is periodically adjusted. If increases in output lead to steep declines in the price cap, then a spiral of decreasing prices and increasing output may result. Or, going in the other direction, contracting output may lead to a spiral of increasing prices until the cap no longer constrains the firm's behavior. This kind of instability should be avoided.

2. *Policymakers need to make sure that the price cap formula does not induce the carrier to defer investments that enhance the quality of network capital.* Downward adjustments in the price cap to reflect productivity gains reduce incentives to invest in improving the quality of network capital. There are at least three

dynamic price cap adjustment effects that may discourage such investments. First, increases in near-term, quality-enhancing investments that are treated as ordinary operating cost increases will appear to make the price cap more binding. Second, in the longer term, these investments will make the installed stock of capital more productive, leading to a decline in the price cap over time. And, third, increased productivity of capital may lead to a decline in the expected real price of capital over time, lowering incentives to undertake current investment. If policymakers embed these sorts of adjustments in the price cap formula, then current expenditure on welfare-enhancing investments will be discouraged. Current investment may also be deferred if regulatory policy changes that are more conducive to such investments are expected to occur sometime in the future.

3. *Policymakers can encourage increased investment in both physical capital and quality-enhancements via suitable adjustments to the price cap formula.* This is simply the flip side of point (2). Current period adjustments in the price cap formula that provide allowances for increases in the rate of investment and for expenditures that are likely to increase infrastructure quality (e.g., R&D) would strengthen incentives in the proper direction. It would also counteract incentives to defer decisions caused by expectations mentioned in (2).

4. *Price cap regulation produces more efficient behavior than either pure Rate of Return (RoR) or a hybrid of price cap and RoR regulation.* Both types of regulation distort the exchange carrier's investment decisions. Although both policies distort pricing behavior and hence may distort the level of resources devoted to serving regulated and unregulated markets, price cap regulation is more likely to result in an efficient path for the evolution of network capital. Incorporating the adjustments noted earlier and eliminating the confusion introduced by divergent state and federal policies will improve the efficiency of price cap regulation. Achieving these goals, however, is likely to be politically quite difficult.

5. *In the long run, an increased rate of investment in the near term will result in increased productivity that will feed through the price cap formula leading to a stable and possibly declining price cap.* In other words, positive adjustments in the price cap to provide investment incentives of the sort discussed in (3) will eventually lead to a stable and possibly declining price cap as the stock of network capital accumulates with higher average levels of productivity.

These five conclusions are based on an analysis of an abstract mathematical model that represents an exchange carrier's pricing and investment behavior as a constrained, dynamic optimization problem. The carrier seeks to maximize the present value of its profit streams over its planning horizon subject to the constraints imposed by price cap and RoR regulation. The exchange carrier sets the price for its basic service, chooses rates of investment to augment physical capital and the quality of that capital, and chooses the level of sales of the enhanced service. These decisions are reevaluated at each point in time along the firm's planning horizon, conditional on the consequences of last period's decisions. I assume that in the absence of regulatory distortions, the exchange carrier's pricing, investment, and innovation decisions would be efficient in the sense that they maximize the present value of the firm's profit streams. Having defined my notation and presented the model, I proceed to analyze the first order necessary conditions that help identify an optimal solution. The effects of regulatory distortions on pricing, output, and investment behavior are deduced via consideration of selected terms in these first-order conditions. Although the basic framework is quite general, important assumptions that help specialize my model (e.g., regarding regulatory behavior) are discussed along with notational conventions employed.

The balance of this chapter is organized into four sections. Section II describes the model's notation and structure as well as important assumptions (e.g., regarding regulatory behavior and structure of markets). Section III analyzes the first-order conditions, whereas Section IV suggests policy innovations that may alleviate the regulatory distortions analyzed in the preceding section. Section V offers a concluding summary.

## II. MODEL: STRUCTURE, NOTATION, AND ASSUMPTIONS

The generic form of the constrained, dynamic optimization model used in this analysis is as follows:

$$\max_{(P_R, I_N, I_B, Q_X)} \int e^{-rt} \{Profit_t - \lambda_{1,t}[RoR\ Constraint_t] + \lambda_{2,t}[Price\ Cap\ Constraint_t]\}\, dt \qquad (1)$$

Equation 1 shows that at each point in time the exchange carrier chooses values for the price of the basic service ($P_R$), rates of gross investment in nominal capital ($I_N$) and quality ($I_B$), and sales of the enhanced service ($Q_X$) so as to maximize the present value of future profit streams. These decisions are made conditional on existing technological and market conditions, the cumulative levels of network capital and quality and, importantly, the prevailing set of regulatory constraints. If there were no binding regulatory constraints impinging on exchange carrier decisions, then both of the Lagrange multipliers $\lambda_{1,t}$ and $\lambda_{2,t}$ would be equal to zero at each point in time.[3] By constraining one or the other of these coefficients equal to zero, it is possible to separately analyze the distortions each form of regulation introduces into the firm's decision making as well as distortions created when both forms of regulation exist together in a hybrid system.

Specification of the model and its analysis requires defining a large number of variables and functional relationships. These are grouped into relevant categories (by type of variable) into Tables 3.1 through 3.7. When the variables and

TABLE 3.1
Output Quantity and Price Variables

| | |
|---|---|
| $Q_R$ | Quantity demanded of the basic service as a function of the regulated price (demand emanates from both retail and wholesale markets) |
| $\eta_R$ | Composite (retail and wholesale) price elasticity of demand for basic service |
| $Q_{R,X}$ | Derived demand for the basic service used to produce exchange carrier's enhanced service output, depends on price of basic service and production level of enhanced service |
| $\rho_{R,X}$ | Fraction of basic service output used to produce exchange carrier's enhanced service $= Q_{R,X}/Q_R < 1$ |
| $Q_X$ | Quantity of enhanced service produced by exchange carrier, depends on the intersection of marginal production cost and the competitive equilibrium enhanced service price |
| $P_R$ | Price of the basic service (also a control variable for the exchange carrier; see Table 3.4) |
| $P_X$ | Competitive equilibrium price for enhanced service determined by the intersection of the market demand and industry supply curves for the enhanced service (net of value-added resource costs) |

TABLE 3.2
Input Quantity and Price Variables

| | |
|---|---|
| $K_N$ | Quantity of nominal or physical network capital used to produce the basic, regulated service |
| B | Level of quality of physical network capital due to exchange carrier's state of technical knowledge (i.e., the efficiency or productivity of network capital) |
| K | Effective amount of network capital = $K_N B$ (i.e., quality adjusted capital) |
| $P_K$ | Acquisition price per unit of nominal capital |
| $P_K/B$ | Acquisition price per unit effective network capital |
| $dLn(P_K)/dt$ | The expected rate of change in the acquisition price of nominal capital |
| $dLn(B)/dt$ | The expected rate of change in the quality of nominal capital |
| $dLn(P_K/B)/dt$ | The expected rate of change in the acquisition price of effective capital |

TABLE 3.3
Environmental Variables

| | |
|---|---|
| r | Discount rate |
| w | Depreciation rate for physical capital |
| h | Depreciation rate of exchange carrier technical knowledge |

TABLE 3.4
Control Variables

| | |
|---|---|
| $P_R$ | Price of the basic service |
| $I_N$ | Gross additions to the nominal stock of network capital |
| $I_B$ | Gross additions to the state of technical knowledge or quality of network capital |

TABLE 3.5
Equations of Motion

| | |
|---|---|
| $dK/dt$ | Net change in the stock of effective network capital $= I_N B - wK$ |
| $dB/dt$ | Net change in the level of network quality $= I_B - hB$ |

TABLE 3.6A
Primary Cost Functions

| | |
|---|---|
| $C^R$ | Expenditure on variable resources producing basic, regulated service $= C^R(Q_R, K, I_N)$, with partial derivatives: |
| $\delta C^R/\delta Q_R > 0$ | Marginal cost of increasing production of the basic service |
| $\delta C^R/\delta K < 0$ | Marginal savings in variable resources when effective capital is increased (a substitution effect between capital and labor) |
| $(1/B)\delta C^R/\delta I_N > 0$ | Internal adjustment cost of changing the rate of gross investment in nominal capital $\equiv \phi_R$ |
| $d\ln\phi_R/dt$ | Expected rate of change in internal marginal investment adjustment cost |
| $C^B$ | Expenditure on resources to augment the quality of network capital $= C^B(I_B)$, with partial derivative: |
| $\delta C^B/\delta I_B > 0$ | Internal adjustment cost of changing the rate of gross investment in network quality $\equiv \phi_B$ |
| $dLn\phi_B/dt$ | Expected rate of change in internal marginal quality adjustment cost |

TABLE 3.6B
Derived Cost Functions

| | |
|---|---|
| $U_K$ | User cost of effective network capital (External adjustment cost) $= (P_K/B)\ (r + w - dLn(P_K/B)/dt)$ |
| $U_C$ | User cost of effective network capital (Internal adjustment cost) $= (1/B)\delta C^R/\delta I_N\ (r + w - dLn(\phi_R/B)/dt)$ |
| $U_B$ | User cost of network quality (Internal adjustment cost) $= \delta C^B/\delta I_B\ (r + h - dLn(\phi_B)/dt)$ |

TABLE 3.7A
Regulatory Design Variables: Rate of Return Variables

| | |
|---|---|
| S | Maximum rate of return allowed on the regulated base rate |
| $\alpha_K$ | Fraction of the nominal capital stock assigned to the regulated rate base |

TABLE 3.7B
Regulatory Design Variables: Price Cap Variables and Relations

| | |
|---|---|
| $\psi$ | Maximum allowed price for the basic, regulated service under a stylized price cap system $= \psi(Q_R, K, I_N, B, I_B)$, with the partial derivatives: |
| $\delta\psi/\delta Q_R < 0$ | Marginal decrease in maximum allowed price due to an increase in production that raises productivity |
| $\delta\psi/\delta K < 0$ | Marginal decrease in maximum allowed price due to an increase in effective network capital that raises productivity |
| $(1/B)\delta\psi/\delta I_N > 0$ | Marginal increase in maximum allowed price due to an increase in the rate of gross capital investment that drains cash flow and lowers productivity (MIPCA) $\equiv \psi_N$ |
| $dLn\psi_N/dt$ | Expected rate of change in marginal investment price cap adjustment |
| $\delta\psi/\delta B < 0$ | Marginal decrease in maximum allowed price due to an increase in the quality of network capital that raises productivity |
| $\delta\psi/\delta I_B > 0$ | Marginal increase in maximum allowed price due to an increase in the rate of gross additions to the state of technical knowledge that drains cash flow and lowers productivity (MQPCA) $\equiv \psi_B$ |
| $dLn\psi_B/dt$ | Expected rate of change in marginal quality price cap adjustment |

TABLE 3.7C
Regulatory Constraints

| | |
|---|---|
| $\lambda_1$ | Lagrangean multiplier for rate-of-return regulation, a positive number less than 1, showing the change in maximum attainable profit due to a small relaxation of the RoR constraint. If RoR is not a binding constraint, this variable equals zero. The RoR constraint is defined as: $P_R Q_R - C^R(Q_R, K, I_N) - C^B(I_B) \leq S\alpha_K P_K K_N$ |
| $\lambda_2$ | Lagrangean multiplier for price cap regulation, a negative number in the model formulation. The change in maximum attainable profit due to a small relaxation of the price cap constraint is $-\lambda_2 > 0$. If price cap regulation is not a binding constraint, this variable equals zero. The price cap constraint is defined as: $P_R \leq \psi(Q_R, K, I_N, B, I_B)$ |

functional relations described in these tables are inserted into the generic form of Equation 1, the dynamic profit maximization problem is expressed as:

$$\max_{P_R, I_N, I_B, Q_X} \int e^{-rt}\{P_R Q_R - C^R(Q_R,K,I_N) - C^B(I_B) - U_K K$$
$$+ P_X Q_X - P_R Q_{R,X}$$
$$- \lambda_1 [P_R Q_R - C^R(Q_R,K,I_N) - C^B(I_B) - S\alpha_K P_K K_N]$$
$$+ \lambda_2 [P_R - \psi(Q_R,K,I_N,B,I_B)]\}dt \quad (2)$$

Equation 2 explicitly shows the revenue and cost components as well as the elements of the regulatory constraints. Revenue is generated from the sale of both basic ($P_RQ_R$) and enhanced services ($P_XQ_X$). Costs are generated by the variable resources used to produce the basic service ($C^R(Q_R,K,I_N)$), by resources associated with improving the quality of network capital ($C^B(I_B)$), and by resources associated with the physical stock of network capital ($U_KK$). The capital related costs are essentially the costs of "holding" the stock of capital and include foregone interest income on the dollar value of the stock, depreciation charges, and the expected rate of change in the real price of capital. There is also an internal transfer price that the exchange carrier pays to itself under ONA pricing assumptions for that portion of the basic service used as an input in enhanced service production.

Equation 2 is maximized by choosing values for the control variables ($P_R$, $I_N$,$I_B$) subject to the two types of regulatory constraints that are explained more fully later. The optimal solution is found as the solution to a system of first-order necessary conditions. These first-order conditions (discussed more fully in section III) identify when the marginal benefits and marginal costs associated with each control variable are balanced in equilibrium. In principle, this optimizing process is repeated at each point in time over the firm's planning horizon, generating trajectories for prices, output, investment flows, and cumulative stocks of capital and quality. Regulatory policy intrudes into the optimizing process by skewing cost–benefit calculations, thus shifting the control variables away from their efficient trajectories. In section III, I analyze the nature of these distortions in more detail, providing a basis for recommendations that are made in section IV.

The first regulatory constraint to consider is rate-of-return regulation, which is expressed as:

$$P_RQ_R - C^R(Q_R,K,I_N) - C^B(I_B) \leq S\alpha_K P_K K_N \tag{3}$$

The left-hand side (LHS) of Equation 3 is the gross profit realized from regulated operations (regulated revenues less variable resource and innovation related costs). The right-hand side (RHS) is the authorized rate of return (S) applied to the fraction of the capital stock assigned to the regulated rate base, $\alpha_K$. Policymakers control the maximum allowed gross profit by adjusting S or $\alpha_K$. Note that unregulated revenues must cover the remaining $(1 - \alpha_K)$ of capital costs not assigned to the regulated rate base. Furthermore, I assume that (a) once set by regulators, the value of $\alpha_K$ is independent of the mix of regulated and unregulated services; and (b) all of the variable resource- and innovation-related costs are assigned to regulated operations.[4]

The second regulatory constraint—price cap regulation—is expressed as:

$$P_R \leq \psi(Q_R,K,I_N,B,I_B) \tag{4}$$

The LHS of Equation 4 is the price charged by the exchange carrier for the basic, regulated service. The RHS is defined as the maximum allowable price for the basic service as set by the price cap formula. The maximum allowable price is, in turn, a function of a set of output, capital, and quality related variables. In this stylized representation, the maximum allowable price varies inversely with the level of the firm's productivity. Hence, the differential effect on the price cap of each variable on the RHS of Equation 4 depends both on how each variable influences the firm's productivity and on how much weight the productivity effect is given in the price cap formula. Increases in output, the effective capital stock, and the quality of capital are assumed to improve productivity and therefore lead to a decline in the price cap. Increases in the rate of gross investment in either physical capital or quality drain resources from current production, lower productivity, and result in a higher price cap. Each of these partial differential effects are described in Table 3.7B. Regulators can give more or less weight to each of these partial differential effects and thereby control each variable's influence on the price cap.

An essential part of the firm's constrained optimization process is that choice values for the control variables ($P_R$, $I_N$,$I_B$) can never lead to violations of the constraints defined in Equations 3 and 4. The sizes of the "multipliers," $\lambda_1$ and $\lambda_2$, indicate how stringent the regulatory constraints are in terms of influencing the firm's decision making. By setting one or the other multiplier equal to zero, the distortions each form of regulation introduces into the first-order cost–benefit calculations can be ascertained.

The exchange carrier is assumed to be the only entity selling the basic, regulated service directly to retail consumers. It also sells the basic service to value-added resellers for use in the production of the enhanced service. Because of ONA pricing restrictions, the price charged is the same regardless of customer type. The elasticity of demand for the basic service is a composite of retail and wholesale demand elasticities, with the latter presumably larger because of the ability of VARs either to turn toward alternative infrastructure suppliers or to exit the industry. However, the presence of potential competitive pressures in the local distribution network tempers the exchange carrier's decision making even though it is the only actual retail basic service supplier.

The exchange carrier participates in the enhanced services market indirectly by supplying its basic service arrangement to all value-added resellers, including its own affiliated VAR. The market for the enhanced service is assumed to be competitive in the sense that no one firm is large enough to exert influence over the equilibrium price, and each firm chooses its level of sales so as to equate marginal cost with the competitively determined price. Nevertheless, VARs can differ in terms of managerial quality, even if identical technologies are used. Therefore, the industry supply curve for the competitive industry may be upward sloping. Intersection of the industry supply and market demand curves determines the equilibrium price for the enhanced service.

Because the basic, regulated service is used as an input by all VARs in the enhanced service industry, an increase in its price will shift the industry supply curve upward. An increase in the regulated price, therefore, will cause marginal VARs to exit the industry because their internal cost curves will have increased. Alternatively, marginal VARs may turn to alternative suppliers of infrastructure. Equilibrium output of the remaining entities will be lower due to their higher input costs, and a new, higher price for the enhanced service will result. The higher price will curtail market demand by enough to match the reduced industry output. Therefore, both the equilibrium price of the enhanced service and the level of sales of each VAR is partially a function of the price of the basic, regulated service. I examine these market interactions more formally in Section III.

## III. FIRST-ORDER CONDITIONS FOR PRICING, INVESTMENT, AND QUALITY DECISIONS

In the following four subsections I analyze the model described earlier. The first three subsections examine the first-order conditions associated with the carrier's choice of a price for its basic service ($P_R$), the level of investment in physical capital ($I_N$), and the level of network quality (B), which implies a level of investment in improving network quality. I ignore the choice of $Q_X$, the level of sales of the enhanced service by the VAR, because this is determined by competitive supply and demand factors that are not directly controllable by the exchange carrier. The last subsection analyzes alternative regulatory frameworks.

### III.A. Pricing Decision for the Basic Service

The first-order condition that determines the price charged for the basic, regulated service at each point in time ($P_R$) is[5]:

$$
\begin{aligned}
[P_R - (\delta C^R/\delta Q_R)]/P_R = 1/\eta_R \\
+ [1/(1-\lambda_1)][(Q_X/Q_{R,X})(\delta P_X/\delta P_R) - 1]\rho_{R,X}/\eta_R \\
+ [\lambda_2/(1-\lambda_1)][(\delta\psi/\delta Q_R) - (\delta P_R/\delta Q_R)](1/P_R) \qquad (5)
\end{aligned}
$$

The first line in Equation 5 is the percentage markup of price over the marginal cost of producing the basic service that maximizes the firm's profits. In the absence of regulatory constraints and vertical integration into the enhanced services market, standard economic theory dictates that this markup should be set equal to the the inverse of the price elasticity of demand, $1/\eta_R$, which is another way of expressing the well-known profit maximization condition equating marginal revenue and marginal cost. The next two lines of Equation 5 reflect the added complexity introduced by vertical integration and regulation.

Despite its complexity, Equation 5 yields some intuitively appealing interpretations. For example, because ONA rules prohibit price discrimination among VARs, higher prices for the basic service increase the costs of offering the enhanced service by the affiliated VAR. Therefore, the exchange carrier's incentive to increase its price markup for the basic service will be inhibited the larger the fraction of its basic service used in enhanced service production, $\rho_{R,X}$. On the other hand, an increase in the basic service price leads to an increase in the equilibrium price of the enhanced service. To the extent that the increase in the exchange carrier's internal costs can be recovered by corresponding increases in enhanced service revenue, its incentive to raise price is strengthened. This "flow-through" effect is shown in Equation 5 by the ratio $(Q_X/Q_{R,X})$ $(\delta P_X/\delta P_R)$. The denominator is the increase in exchange carrier's internal costs due to an increase in the equilibrium price of the basic service, and the numerator is the resulting increase in enhanced services revenue stemming from the change in the equilibrium price of the enhanced service. It is very unlikely that this ratio can ever equal 1. As was discussed earlier, marginal VARs will exit the industry because their internal cost curves will have increased. However, the increase in enhanced service price will not match the shift in cost curves because the demand for the enhanced service is not perfectly inelastic. Moreover, some marginal VARs may turn to alternative suppliers of infrastructure, thus sustaining the level of production in the industry and restraining the rate of price increase. These reactions mean that the flow-through effect will not equal 1.

Another aspect of Equation 5 is that the more stringent the RoR regulatory constraint is, the lower the feasible price markup. The higher the algebraic value of the RoR regulatory multiplier, $\lambda_1$, the tighter the constraint. RoR regulation also has another important but implicit effect on the pricing solution. Because this form of regulation can lead to suboptimal investment in network capital and quality (see discussion later), the computation of marginal production cost itself may be skewed, even though no regulatory multiplier shows up explicitly. The reason is that the cost function from which marginal cost is derived, $C^R(Q_R, K, I_N)$, depends on capital and the rate of investment as well as output. Because marginal cost is the derivative of this function with respect to output, conditional on the prevailing stock of capital and rate of investment, any distortions in these latter variables will contaminate marginal cost estimates.

The effect of price cap regulation on the price markup is shown in the third line of Equation 5. Note that the impact of price cap regulation depends on the size of its regulatory multiplier as well as the RoR multiplier, or $\lambda_2/(1 - \lambda_1)$. What this term indicates is that in a hybrid system with both price cap and RoR regulation, price cap effects are going to be magnified because the price cap multiplier is being divided by a number less than 1.

A key term in line three, Equation 5, is $(\delta\psi/\delta Q_R) - (\delta P_R/\delta Q_R)$. The first term shows how sensitive the price cap is to changes in the level of basic service production, that is, the slope of the price cap schedule. The second term is the slope of the market demand curve for the basic service. These terms are evaluated at the equilibrium pricing solution. If the latter effect is greater in absolute value than the former, then a stable pricing solution will result. For example, an increase in output above the solution point would imply a fall in the market clearing price below the cap. The higher price cap would choke off incremental demand and send the system back to the solution point. If, however, the price cap is more sensitive to the level of production than is the market clearing price, then an unstable solution will result.

Consider a traditional market equilibrium with a downward sloping demand curve. The price cap is assumed to decline with increases in per period production, reflecting productivity adjustments. If the price cap schedule is less steep than the demand curve and is binding at a price below the exchange carrier's monopoly price, then the solution is stable. On the other hand, if the price cap schedule is steeper, then reductions in output will lead the firm to raise its price as it moves back up its demand curve toward the monopoly solution. Conversely, increases in demand would lead to a reduction in the price cap, which would lead to further increases in demand, stimulating a downward spiral of price adjustments and increasing demand. Therefore, a price cap adjustment formula that is overly sensitive to changes in the level of output may produce an unstable solution.

### III.B. Investment in Physical Capital

The first-order condition that determines the investment in physical capital, $I_N$, at each point along the firm's trajectory is:

$$
\begin{aligned}
-(\delta C^R/\delta K) = {} & (U_K + U_C) - \\
& [\lambda_1/(1-\lambda_1)][S\alpha_K(P_K/B) - U_K] + \\
& [\lambda_2/(1-\lambda_1)][(1/B)(\delta\psi/\delta I_N)(r + w - dLn\psi_N/dt + dLnB/dt) + \\
& (\delta\psi/\delta K)]
\end{aligned} \tag{6}
$$

Line 1 represents the first-order conditions for the investment decision in the absence of regulation. The left-hand side of line 1 (LHS) is the benefit of adding a unit of effective capital in terms of the perpetual flow of variable resource savings. The right-hand side (RHS) are the user costs of capital associated with both external acquisition and internal adjustment costs. The components of these cost terms are detailed in Table 3.6. They include items such as foregone interest income on the dollars tied up in incremental investment and depreciation charges. Also included are expected rates of change in the real price of capital goods and the real cost of internal resources consumed in the adjustment process, where *real* means quality adjusted. Expectations are included in these cost calculations because current decisions are made partially on the basis of expected price and quality changes. For example, inflationary expectations make it cheaper to undertake investment today. On the other hand, expectations of significant technological advances make it more expensive to invest today in lower quality assets. In the absence of regulation, optimal investment would balance both sides of line 1 at the margin.

Line 2 depicts the effect of rate-of-return regulation on investment. The main point here is that if the effective authorized return on a dollar's worth of (real) capital is greater than the acquisition cost, the firm has an incentive to overinvest. This result is similar to the familiar Averch–Johnson model, although I make a number of additions here. First, the authorized return, $S$, is weighted by the fraction of capital included in the regulated rate base. If this fraction is set low enough, an incentive to underinvest would be created. Second, the expected rate of change in the quality of network capital is one of the elements affecting the cost side of the investment decision (implicitly included in the cost term, $U_K$). Third, there will be implicit distortions in the level of production of the basic service and/or the quality variable, $B$, induced by RoR regulation. Therefore, there will be implicit distortions in the calculation of both investment benefits and investment costs.

Line 3 of Equation 6 shows the effects of price cap regulation on the investment decision. Note that the size of the price cap multiplier is magnified in a hybrid system with rate-of-return regulation, $\lambda_2/(1 - \lambda_1)$, because it is divided by a number less than 1. Thus, hybrid systems exacerbate regulatory inefficiencies.

The first term after the multiplier expression in line 3 is $(1/B)(\delta\psi/\delta I_N)$, the marginal change in the (quality adjusted) price cap triggered by an increase in the firm's rate of investment (or, the marginal investment price cap adjustment, MIPCA). Its sign is positive. Inclusion of this term in the price cap formula by regulators acknowledges that there are cash flow consequences incurred when an exchange carrier undertakes network modernization. Further, the equation shows that the benefit is converted into an annuity flow by $(r + w - dLn\psi_N/dt + dLnB/dt)$. This is nothing more than saying that the price cap adjustment (MIPCA) provides a partial offset to the firm's cost of acquiring capital. Because that cost includes a flow of interest and depreciation charges, among other things, the offsetting benefit is a flow of reduced interest and depreciation charges.

Finally, $dLn\psi_N/dt$ represents the expected rate of change in MIPCA. If the expectation is that regulatory treatment of investment expenditure will improve in the future, such investment will tend to be deferred, for the same reason that expected declines in the real price of capital will defer current investment. Conversely, an expectation of deteriorating regulatory treatment would stimulate current investment. Admittedly, this type of regulatory structure is conjectural, but emanently reasonable.

The final term in line 3, Equation 6 is $(\delta\psi/\delta K)$, the change in the price cap constraint due to an increase in the cumulative stock of network capital. It represents the decline in the price cap associated with an increase in the stock of real capital that enhances the firm's productivity. Thus, it works against the first term (MIPCA). The sign of this term is assumed to be negative.

The net effect of price cap regulation on the investment incentive therefore depends on the relative sizes of the marginal investment price cap adjustment

(MIPCA) and the marginal capital stock adjustment, as well as expectations of future regulatory treatment, that is, changes in MIPCA.

### III.C. Investment in Innovation to Improve Network Quality

The following equation depicts the firm's innovation decision or choice of network quality at each point along its trajectory:

$$\begin{aligned}-(\delta C^R/\delta I_N + P_K)(\delta I_N/\delta B) = U_B + \\ [\lambda_1/(1-\lambda_1)][P_K(\delta I_N/\delta B) - S\alpha_K P_K(\delta K_N/\delta B)] + \\ [\lambda_2/(1-\lambda_1)][(\delta\psi/\delta I_B)(r + h - dLn\psi_B/dt) + (\delta\psi/\delta B) + (\delta\psi/\delta I_N)(\delta I_N/\delta B)] \quad (7)\end{aligned}$$

Equation 7 determines the firm's rate of change in the efficiency parameter at each point in time. The parameter $B$ is a one-dimensional representation of the quality of network capital and is related to the level of investment in improving network quality ($I_B$) by the law of motion shown in Table 3.5. I focus on the level of network quality $B$ rather than on the level of investment to improve $B$ because it more closely mirrors how I believe exchange carriers think about these types of investments. Quality can refer to the effective traffic capacity of a physical asset, route diversity, and redundancy, as well as embodied software capabilities for maintenance and network administrative functions.

Line 1 of Equation 7 shows the first-order condition governing the innovation decision in the absence of regulation. The LHS is the benefit on the last incremental increase in $B$, in terms of lowering the required amount of nominal investment ($\delta I_N/\delta B$). Reduced nominal investment brings with it corresponding reductions in external capital acquisition costs and internal adjustment costs. The RHS of line 1 represents the user cost of undertaking investment in innovation, and it includes foregone interest income, depreciation of the stock of technical knowledge, and expectations about the cost of resources consumed in the internal adjustment process. Without regulation, innovational activity would balance both sides of line 1 at the margin.

Line 2 shows the impact of rate-of-return regulation on the innovation decision. The expression $[P_K(\delta I_N/\delta B) - S\alpha_K P_K(\delta K_N/\delta B)]$ is the difference between improved cash flow caused by the innovation and the reduction in the firm's allowable gross profit due to the shrinkage of the nominal rate base. In the presence of RoR regulation, innovation has this kind of double-edged effect. Less nominal investment is needed to get the same effective capacity, so cash flow improves, but at the same time the regulated rate base is reduced. The net impact of these two effects essentially is the net profit effect on the firm. This effect exists only because of the mechanics of rate-of-return regulation.

Line 3 shows the impact of price cap regulation on the quality decision. Price cap effects are magnified when there is a hybrid system of RoR and price cap regulation, through the term $\lambda_2/(1 - \lambda_1)$. The first term to the right of the multiplier variables in line 3 is ($\delta\psi/\delta I_B$), the marginal quality price cap adjustment (MQPCA). It is the adjustment in the cap triggered when the firm increases its rate of gross investment in quality, analogous to the investment decision discussed earlier (MIPCA). Here, too, the marginal cap adjustment is interpreted as partially compensating the firm for the increased expenditure made to improve network quality. Because it is an offset to the firm's own internal marginal quality adjustment costs, MQPCA is converted into an annuity flow of savings by the expression $(r + h - dLn\psi_B/dt)$. MQPCA provides partial offsets to foregone interest income $(r)$ and obsolescence costs $(h)$ related to innovational activity. The last term in the parenthesis, $dLn\psi_B/dt$, is very important: It is the expected rate of change in MQPCA. If the firm expects that regulatory treatment for undertaking quality improving innovation is going to be more favorable in the future, such activity will tend to be deferred. Conversely, if regulatory terms are expected to worsen in the future, then current innovational activity will be stimulated.

The next term in line 3, $(\delta\psi/\delta B)$, is the negative price cap adjustment associated with an increase in the cumulative level of $B$. Because a higher level of $B$ would, loosely speaking, tend to raise the firm's productivity, the associated marginal price cap adjustment would be negative. Finally, the last term in line 3 has two components: $(\delta\psi/\delta I_N)(\delta I_N/\delta B)$. The first shows the increase in the cap triggered by an increase in the rate of investment, discussed in Equation 6, and the second piece shows the decrease in nominal investment needed by virtue of the higher quality of network capital. Hence, as the cumulative level of $B$ increases over time it creates direct downward pressure on the price cap by raising productivity and indirect downward pressure by lowering the amount of nominal investment expenditure needed.

The net impact of price caps on the rate of investment in quality will depend on the interactions between stimulating, flow effects in the price cap adjustment (MQPCA) and the restraining influence of the cumulative value of B. Expectations with respect to future price cap adjustments in MQPCA will also play an important role.

## III.D. Joint Decision Making and Pseudo-Efficient Regulatory Systems

The preceding set of first-order conditions were discussed in sequence for expository reasons. However, they are determined jointly and are clearly interrelated. The joint nature of the solution process allows some interesting policy questions to be addressed. For example, suppose price cap regulation did not exist $(\lambda_2 = 0)$. Would it then be possible to modify the parameters of the remaining RoR system such that investment in physical capital and the quality of capital could be optimized at the same time? If so, this would provide policymakers with a way to regulate and at the same time achieve efficient investment and quality decisions—a desirable state of affairs.

To see whether construction of such a pseudo-efficient RoR system is possible, first rewrite the relevant distortions:

Investment distortion (line 2, Equation 6):
$[\lambda_1/(1-\lambda_1)]\,[S\alpha_K(P_K/B) - U_K]$
Innovation distortion (line 2, Equation 7):
$$[\lambda_1/(1-\lambda_1)][P_K(\delta I_N/\delta B) - S\alpha_K P_K(\delta K_N/\delta B)] \quad (8)$$

From the policy perspective, rate-of-return regulation would achieve an efficient trajectory for both investment and innovation if the two parts of Equation 8 were to become zero at the same time.

After performing some algebraic manipulations, it turns out that the necessary and sufficient condition for the rate-of-return system in this model to achieve an efficient trajectory is as follows:

$$dLnP_K/dt + dLnK_N/dt = r \quad (9)$$

with the fraction of the capital stock allocated to the regulated rate base:

$$\alpha_K = \{U_K/[S(P_K/B)]\}$$

Equation 9 has a very straightforward meaning. It says that the dollar value of the firm's nominal capital stock expands at a rate equal to the interest rate. If this "golden rule" of capital accumulation is followed, then the rate of return system as described in this model can achieve efficiency for investment and innovational decisions. An important part of this solution is that the fraction of the capital stock allocated to the rate base is equal to the ratio of the user cost of acquiring capital over the authorized rate of return.

How feasible is this course of action? Aside from the considerable practical difficulties of quantifying the components of Equation 8 at each point in time, there is yet a more fundamental problem: The "golden rule" solution in Equation 9 may be inherently unstable. In other words, if the dollar value of the nominal capital stock were to grow at a rate faster than the critical rate, $r$, the incremental cash flow benefits of undertaking quality enhancements would be more significant to the firm than the contracting influence on the rate base. An incentive to overinvest in quality enhancements would be created, rapidly lowering the quality adjusted price of capital ($P_K/B$) that stimulates even more investment. Of course, as the growth rate of $B$ increased, the growth rate of nominal capital would slow, but it is not clear that the equality in Equation 9 would be reestablished. Alternatively, if the dollar value of the capital stock were to grow at a rate slower than the critical rate, $r$, cash flow savings on (a lower amount of) incremental investment would become less important to the firm than the contracting influence on the regulated rate base. Too little quality enhancement would be undertaken, rapidly raising the quality adjusted price of capital ($P_K/B$), leading to a further curtailment of investment. It is not clear whether the growth rate of $B$ would slow enough to reestablish the (higher) equilibrium growth rate of nominal capital needed for the "golden rule" in Equation 9.

As has been demonstrated, the rate-of-return model is undesirable for a number of reasons related to distortions in input decision making. Nevertheless, the preceding discussions also have indicated the potential for price-cap-induced distortions in investment and innovation as well, specifically:

Investment distortion (line 3, Equation 6):
$[\lambda_2/(1-\lambda_1)][(1/B)\delta\psi/\delta I_N)(r + w - dLn\psi_N/dt + dLnB/dt) + (\delta\psi/\delta K)]$
Innovation distortion (line 3, Equation 7):
$$[\lambda_2/(1-\lambda_1)][(\delta\psi/\delta I_B)(r + h - dLn\psi_B/dt) + (\delta\psi/\delta B) + (\delta\psi/\delta_N)(\delta I_N/\delta B)] \quad (10)$$

A policy question that immediately presents itself is under what conditions would the distorting effects of price cap regulation be removed. Two conditions are relevant. First, the investment distortion (line 3, Equation 6) totally disappears if:

$$dLn\psi_N/dt + dLn(K_N)/dt = r \quad (11)$$

Equation 11 has a straightforward interpretation. A shadow value of capital is being defined as $\psi_N K_N$, in which capital is multiplied by the marginal investment price cap adjustment (MIPCA), not the marginal dollar cost. Equation 11 says that this shadow value of capital must grow at the interest rate to eliminate the investment distortion. In fact, the first term of Equation 11 is the expected change in MIPCA. Thus, there is a critical expectations rate. If the expectation regarding future marginal investment price cap adjustments is above the critical rate implied by Equation 11, then today's investment will be curtailed below the optimal amount. If the expectation regarding future MIPCA is below the critical rate, then today's investment will exceed the optimal amount.

The second condition relates to the innovation incentive or the degree of quality (along its various dimensions) incorporated into the network:

$$dLn\psi_B/dt + dLnB/dt = r \quad (12)$$

Here, a shadow value of the level of quality is being defined as $\psi_B B$. The quality variable is being multiplied by the marginal quality price cap adjustment, MQPCA. Equation 12 states that the shadow value of network quality must grow at the interest rate in order to eliminate distortions in the innovation decision (line 3, Equation 7). The first term in Equation 12 is the expected rate of change in the marginal quality price cap adjustment, MQPCA. If the expectation regarding future marginal quality price cap adjustments is above the critical rate implied by Equation 12, then today's rate of quality enhancement will be curtailed below the optimal amount. If the expectation regarding future marginal quality price cap adjustments is below the critical rate, then today's rate of quality enhancement will exceed the optimal amount.[6]

In the price cap framework presented, the aforementioned stimulation of current investment and innovational activity necessarily will induce higher near-term prices than otherwise because the upward marginal price cap adjustments (MIPCA and MQPCA) would be designed to compensate the firm for the cash flow consequences of its current decisions. Clearly, there is a trade-off between upward pressure on service rates that contribute to the financing of network modernization and longer term subscriber benefits in terms of a more efficient and feature-rich network. Examination of the function presented in Table 6.7B representing the maximum allowable price cap, $\psi(Q_R, K, I_N, B, I_B)$, indicates that as the system stabilizes, the rates of capital investment and innovational activity diminish relative to accumulated stocks. Therefore, the components of price cap adjustments that depend on the cumulative stock of capital and the attained level of quality will take on greater relative importance. In the longer term, at a minimum, increases in the price cap will taper off, and possibly there will be a tendency for downward price cap adjustments to occur.

## IV. POLICY INNOVATIONS

Having discussed the distortions that regulation introduces into the first-order necessary conditions for an efficient network evolution path, I now offer a series of conclusions, recommendations, and policy suggestions.

First, to increase the likelihood of achieving a stable pricing solution, the maximum allowed price cap applied to the basic service should be insensitive to changes in the level of production of the basic service.

Second, policymakers must strive to avoid creating strong expectations regarding future adjustments in price cap mechanisms that are tied to investment in capital and quality enhancements. Near-term incentives to invest and improve the quality of network capital will be lowered if there are sufficiently strong expectations regarding the magnitude of future price cap adjustments. It follows that rules compensating the firm for the extra costs of undertaking investment and innovation related activities should be put in place as soon as possible. In practice, attainment of the critical expectations values regarding investment- or innovation-induced price cap adjustments is problematic. Yet, if there is a policy objective of fostering growth and modernization in the telecommunications network, efforts should be expended to develop "exogenous cost factors" in the price cap model that offer partial compensation for investment- and innovation-related expenditure so as to stimulate current activity in the proper direction. Moreover, such an approach would serve to minimize expectations regarding future improvements in regulatory treatment, curtailing the incentive to defer investment and innovational activity. When the externality effects and wideranging social benefits of a modernized network are taken into account, it would seem that this kind of purposeful, stimulatory regulatory approach is sound policy.

Third, when one considers the explicit and implicit distortions associated with rate-of-return regulation, the magnification of price cap distortions resulting when a hybrid RoR/price cap system is in place, and the infeasibility and possible instability of a rate-of-return-based efficient trajectory, it becomes clear that stand-alone RoR or hybrid price cap/RoR models embody undesirable policies. In addition to economic inefficiencies, regulatory solutions encompassing RoR and cost allocation rules also impose administrative costs on society. A pure price cap model that, in theory, eliminated jurisdictional cost allocation processes and the patchwork of federal and state systems clearly would save administrative costs, in addition to fostering a more efficient path for network evolution.

Fourth, if the price cap model discussed in this chapter were implemented, and network capital and innovation converged to their "golden rule" accumulation paths, the cumulative capital stock and quality effects on productivity would tend to dominate the mechanics of the price cap formula. The price cap would then tend to stabilize and possibly decrease.[7]

## V. SUMMARY

This chapter has presented an analysis of the effects of alternative regulatory forms on an exchange carrier's incentives regarding pricing, investment, and innovational (quality enhancing) activity. The main findings indicate that there are more drawbacks to relying on a rate-of-return or hybrid price cap/rate-of-return model than a pure price cap model in terms of not eliciting the kinds of decisions needed to achieve an efficient evolution of the telecommunications network. Administratively as well as economically it is logical to dispense with the current patchwork system of federal and state regulatory systems and replace it with an integrated, internally consistent price cap framework.[8] Loosely speaking, the stylized version of the exchange carrier model used here might also be viewed as the exchange carrier industry as a whole and the franchised serving area as covering the entire nation. In making this generalization, I am glossing over a number of technical issues concerning consistent aggregation from micro to macro functions. Nevertheless, the general point remains valid. The savings in administrative overhead and the elimination of distortions associated with rate-of-return regulation and cost allocation rules would produce net benefits. The political difficulties of implementing such a system, however, are quite formidable.

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## ENDNOTES

1. The term *basic service* generally implies narrowband. However, in principle it may include a minimal amount of broadband capability, such as access to a gateway.
2. Open Network Architecture refers to an FCC policy initiative designed to make the components of an exchange carrier's network available on a nondiscriminatory basis to all vendors of value-added services. The network components that will be unbundled are still being determined but will include various network access components, switching services, signaling and software services, and so on.
3. Because I will be examining the FONC at each point in time along the optimal path, I will drop the $t$ subscripts from the Lagrange multipliers.
4. In a previous paper I allowed for the allocation of all cost categories between regulated and unregulated sectors and permitted allocation percentages to depend on the mix of services. See Stolleman, "Dynamic Effects of Cost Allocations Between Regulated and Non-Regulated Exchange Carrier Operations," *Proceedings of the Bellcore-Bell Canada Conference on Telecommunications Costing*, San Diego, CA, 1989. These more complex cost allocation rules introduced additional distortions into the firm's decision process by creating incentives to skew the service mix. That analysis also concluded that variable and innovation related costs should be assigned entirely to regulated operations, so that the firm would "see" the true cost consequences of its pricing and investment decisions on the regulated side of its business.
5. Time subscripts on variables such as $Q_{R,t}$ are omitted, and only $Q_R$ is shown to simplify notation.
6. Certain technical, simplifying assumptions were made in order to derive Equations (11) and (12). These relate to symmetry assumptions among the elements in line 3 of Equations (6) and (7).
7. The technically simplifying assumptions in endnote 6 result in a stable price cap when network capital and its average level of productivity (*B*) both grow according to the "golden rule" in a steady state equilibrium, and there are no expected charges in the parameters of the price cap formula (i.e., MIPCA or MQPCA). In principle, regulators should be able to design the price cap formula so as to produce declining price caps in the future; however, care must be taken to provide enough incentive for the investment necessary to sustain a long-run, stable growth path.
8. See Stolleman, "Policy Position: Alternative Regulatory Frameworks," unpublished manuscript, 1989, on file with the *George Mason University Law Review*.