The Internet Upheaval

Raising Questions, Seeking Answers in Communications Policy

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Telecommunications, the Internet, and the Cost of Capital

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This chapter applies a two-period model of investment to examine how consideration of the real options associated with investment decisions might be expected to affect the cost of capital for telecommunications infrastructure firms in light of the tumultuous changes associated with the emergence of the Internet. Because investments in new telecommunications facilities also may provide access to additional growth opportunities (e.g., to enter new information service markets) or strategic flexibility (e.g., enhanced ability to respond to changing traffic demand patterns), these investments may also create valuable options. Therefore application of contemporary investment theory to estimating the cost of capital for telecommunications firms should consider the impact of changes in technology, the regulatory environment, and the structure of the telecommunications infrastructure industry in order to assess the relative magnitude of competing investment options. The Internet and the changes it is bringing to the communications infrastructure industries is reducing the value of the option to delay while increasing the value of the options associated with increased growth opportunities and strategic flexibility.

Introduction

Most investment decisions, especially those associated with long-lived capital, are not fully reversible. Moreover, in the face of uncertainty, it is often possible to delay investments until more information can be obtained. Traditional neoclassical investment theory which assumes investments are perfectly reversible (i.e., capital stocks may be adjusted upward or downward without friction) ignores these effects of uncertainty.

Dixit and Pindyck (1994) illustrate how traditional interpretations of neoclassical capital theory can underestimate the cost of capital for irreversible investments because it fails to account for the value of the call option to invest at a later date that is extinguished once the investment occurs ("delay option").[1] In some of the extreme examples they cite (e.g., perfect irreversibility and no costs associated with delay), a revised estimate of the cost of capital that properly accounts for the option to delay may be twice as large as an estimate based on a traditional net present value (NPV) analysis that ignored the delay option.

Accepted at face value, this result has profound implications for how one estimates the cost of capital for capital-intensive firms, and for the valuation of these firms. In the context of infrastructure firms subject to price regulation (i.e., telecommunications, electric power transmission, natural gas pipelines, etc.), the theory of real options raises important questions for how policymakers ought to estimate the cost of capital used to assure that the firm has the opportunity to earn a fair return on its invested capital and faces appropriate incentives for continued investment. If the cost of capital is set too low, then firms will fail to recover their investment, leaving them with "stranded plant." Conversely, if the cost of capital is set too high, then the regulated firm may be able to extract surplus profits from consumers or competitors.

For the contemporary telecommunications industry in the United States, the need to establish an appropriate cost of capital for local telephone infrastructure owned by the Incumbent Local Exchange Carriers (ILECs, e.g., Bell Atlantic, BellSouth, etc.) became newly important with the passage of the Telecommunications Act of 1996.[2] This Act required the ILECs to unbundle their networks and make the network elements available to competitors at "cost-based rates." Failure to estimate correctly the cost of capital for telecommunications infrastructure would have obvious perverse implications for investment incentives and the prospects for the emergence of effective competition. In the context of U.S. regulatory policy, this chapter traces the debate over the application of real options theory to estimating the cost of capital for telecommunications infrastructure firms to a submission to the FCC by Hausman (1996). In that submission, Hausman argued that because telecommunications investments are largely irreversible, proper consideration of the real options theory and the call option to delay, should lead to substantially higher estimates in the cost of capital than those produced using a traditional neoclassical approach to investment theory. Hausman's argument made use of an example presented in Dixit and Pindyck (1994). The policy debate over this issue has continued.[3]

While the authors disagree with Hausman's original arguments (see Hubbard and Lehr 1996), there is more widespread agreement that the theory of real options has important implications for pricing investments in telecommunications assets. The original debate focuse narrowly on the likely magnitude of any error associated with failure to account for the "delay option." A more general framework is needed to understand how this theory might best be applied in the context of the telecommunications industry. Specifically, while investment today may extinguish the value of the delay option, it also creates options to adjust one's capital flexibly in the future.

This chapter presents a simple two-period model developed by Abel, Dixit, Eberly, and Pindyck (hereafter "ADEP (1996)"), to explore the impact of the options to flexibly adjust capital that are created when investment occurs. It interprets this model in light of the changes in the telecommunications industry implied by and associated with the emergence of the Internet. The chapter further explains these changes are likely to enhance the value of embedded investments in telecommunications infrastructure, thereby leading to a reduction in estimates of the appropriate cost of capital.

The remainder of the chapter describes the basic ADEP (1996) model and discusses some of its limitations in the context of a full understanding of the implications of real options on cost of capital and firm valuation estimates, applies the model to the case of telecommunications firms in light of the emergence of the Internet, and provides conclusions and directions for future research.

1 Real Options and the Valuation of Firms

Abel, Dixit, Eberly, and Pindyck (ADEP 1996) present a two-period model of investment decisions that provides a useful framework for examining the implications of applying real options theory to the question of valuing telecommunications assets. Before introducing the model, it is worthwhile reiterating a point that is sometimes misunderstood by those unfamiliar with the cost of capital literature and the impact of real options theory. Traditional neoclassical capital theory properly incorporates expected changes in the value of capital assets associated with depreciation and changes in the relative price of capital assets. The traditional Jorgensonian user cost of capital, u, is given by (ignoring taxes):[4]

$$u = (r + \delta - \lambda)b \tag{1}$$

where r is the risk-adjusted discount rate, δ is the expected rate of depreciation, λ is the expected rate of change in the relative price of capital goods, and b is the current purchase price for a unit of capital (relative to the price of output).

Naïve applications of this theory that neglect to account properly for expected price declines in the relative price of capital assets (e.g., because of productivity-enhancing innovations embodied in new capital) will systematically underestimate the user cost of capital if capital prices are falling over time (i.e., treating λ as if equal to 0 when in fact $\lambda<0$). In telecommunications, failure to account properly for expected declines in the price of capital goods is likely to have a substantial impact. Biglaiser and Riordan (1998), for example, examine the impact on rate of return and price cap regulation of properly accounting for predictable reductions in capital equipment prices and operating costs.[5]

Abstracting from the effects of predictable depreciation and price declines, this analysis assumes that $\delta=\lambda=0$ in order to focus attention on the impact of uncertainty and factors that may influence how uncertainty affects the valuation of telecommunications firms in light of the growth of the Internet.[6]

2 Two-Period Framework of ADEP (1996)

ADEP (1996) present a simple two-period model of investment under uncertainty that allows easy consideration of when investment is neither fully reversible nor irreversible. In their framework, the firm faces costly expandability (wherein the future purchase price of capital may exceed its current price) and costly reversibility (wherein the future resale price may be less than its current purchase price).[7] Firms make an investment decision in the first period, yielding a certain return. Second-period returns on invested capital are stochastic, affecting both the return on capital invested in the first period and the decision to purchase or sell capital in the second period. The value of a firm, then consists of the value of its assets in place (first-period capital) and the value of options to purchase or sell capital in the second period. These same "real" options will affect the user cost of capital conventionally used to analyze the firm's investment decision.

More formally, the firm's investment can be described as follows: In the first period the firm purchases and installs K_1 units of capital at a unit cost of b. This investment yields a return of $r(K_1)$, where $r(K_1)$ is increasing and concave in capital. The return on capital in the second period is stochastic and is given by R(K,e), where e is stochastic. In particular, $R_K(K,e)$ is continuous and strictly increasing in e (and continuous and strictly decreasing in K). The firm adjusts capital in the second period to a new level, $K_2(e)$, which may be greater than, equal to, or less than K_1.

Initially ignoring any options associated with adjusting the level of capital in the second period, the value of the firm in the first period would be equal to the expected present value of the net cash flow from the first-period investment of K_1, or:

$$V(K_1) = r(K_1) + \gamma \int_{-\infty}^{+\infty} R(K_1, e)\, dF(e) \tag{2}$$

where γ is the firm's discount factor (i.e., one divided by one plus the appropriate risk-adjusted discount rate for the firm).

To explore the firm's investment decision in this case, note that the firm chooses K_1 to maximize $(V(K_1)\text{-}bK_1)$. The firm's desired capital stock may be characterized using either the "marginal q" or "user cost of capital" expressions conventionally used in neoclassical investment models (see, e.g., Hassett and Hubbard 1999). The first-order condition for the capital stock yields the familiar marginal-q expression:

$$V'(K_1) \equiv r'(K_1) + \gamma \int_{-\infty}^{+\infty} R_K(K_1, e)\, dF(e) = b \tag{3}$$

Therefore, the Jorgensonian user cost of capital, u, is given by:[8]

$$u \equiv V'(K_1)(1-\gamma) = b(1-\gamma) \tag{4}$$

That is, abstracting from depreciation, the user cost of first-period capital is the financial opportunity cost of using the capital, approximately, rb.[9]

As the large body of research on real options points out, these conventional valuation and investment expressions abstract from potentially important options associated with decisions about expandability and reversibility.[10] One obvious extension is to focus on the call option associated with delaying an investment which increases the hurdle rate for investment and the extinguishing of which reduces the firm's value as noted above. As noted above and as explained further below, this call option of delay may be less valuable while the put option to resell—or more generally, to put to other use invested capital—may be more valuable for telecommunications infrastructure because of changes associated with the emergence of the Internet. Taken together, these effects would tend to lower the estimated cost of capital and increase firm valuation relative to traditional neoclassical theory.

The ADEP (1996) framework can be used to illustrate these option values straightforwardly. For simplicity, assume that the firm faces a first-period purchase price of capital of b; in the second period, capital may be acquired at a unit cost of b_H or sold at a unit cost of b_L. When $b>b_L$, investment is characterized by *costly reversibility* (the often-used case of complete irreversibility implies that $b_L \leq 0$).[11] When $b_H > b$, investment is characterized by *costly expandability* (as $b_H \to \infty$, no expandability is possible). The conventional neoclassical benchmark implicitly assumes that $b_L = b = b_H$.

When investment is characterized by both costly reversibility and costly expandability, the expected present value of net cash flow accruing to the firm with capital stock K_1 in the first period (assuming $b_H \geq b \geq b_L$) is:

$$
\begin{aligned}
V(K_1) \equiv r(K_1) \; & + \gamma \int_{-\infty}^{+\infty} R(K_1, e)\, dF(e) \\
& + \gamma \int_{-\infty}^{e_L} \{ b_L[K_1 - K_2(e)] - [R(K_1,e) - R(K_2(e),e)] \}\, dF(e) \\
& + \gamma \int_{e_H}^{-\infty} \{ [R(K_2(e),e) - R(K_1,e)] - b_H[K_2(e) - K_1] \} dF(e)
\end{aligned} \tag{5}
$$

where $K_2(e)$ is the firm's capital in the second period, and e_L and e_H are threshold values for the second-period profitability disturbance, e, that warrant resale or purchase of capital in the second period, respectively.[12] The first two terms are just the traditional neoclassical net present value of expected returns. The last two terms are new and include the value of the options to adjust capital. The third term is the expected value of the put option to sell capital while the last term is the expected value of the call option to buy additional capital. For example, the value of the put option is the expected present value of the revenue from selling capital (K_2-K_1) at price bL less the foregone returns that would have been earned had capital not been reduced.

The threshold values of e_L and e_H are determined by the marginal conditions, $R_K(K_1,e_L)=b_L$ and $R_K(K_1,e_H)=b_H$, respectively, that are associated with the first order necessary conditions that emerge from the firm's optimal investment decision in the second period.[13] When e is less than e_L, the marginal productivity of capital is less than the resale price and the firm will sell or redeploy its capital so $K_2(e)<K_1$. When e is greater than e_H, the marginal productivity of capital will exceed its purchase price and the firm will acquire additional capital and $K_2(e)>K_1$. For intermediate values of e between e_L and e_H, the firm will keep its capital constant so $K_2(e)=K_1$. This formulation assumes that the future resale price for older capital will always be less than the future purchase price for new capital (i.e., $b_L<b_H$).[14]

Combining terms in Equation 5 and rearranging terms, we have:

$$V(K_1) = r(K_1) + \gamma \int_{e_L}^{e_H} R(K_1,e)\, dF(e) \tag{6}$$

$$+ \gamma \int_{-\infty}^{e_L} \{R(K_2(e),e) + b_L[K_1 - K_2(e)]\} dF(e)$$

$$+ \gamma \int_{e_H}^{-\infty} \{R(K_2(e),e) - b_H[K_2(e) - K_1]\} dF(e)$$

In contrast to the formulation in Equation 2, the valuation expressed by Equation 6, has three regions of values for the second-period returns. For low values of future profitability ($-\infty < e < e_L$), the firm sells or redeploys capital, netting a cash flow in the second period of $\{R(K_2(e),e)+b_L(K_1\text{-}K_2(e))\}$. For intermediate values of the profitability disturbance ($e_L < e < e_H$), the firm neither acquires nor sells capital, and the second-period cash flow is $R(K_1,e)$. For high values of future profitability ($e_H < e < +\infty$), the firm acquires additional capital and the second-period cash flow is $\{R(K_2(e),e)-b_H(K_2(e)-K_1)\}$.

In this more general case, the investment rule implicit in the expression for marginal q is given by:

$$V'(K_1) \equiv r'(K_1) + \gamma \int_{e_L}^{e_H} R_K(K_1,e)dF(e) + \gamma\left[b_L F(e_L) + b_H(1-F(e_H))\right] = b \tag{7}$$

In contrast to the neoclassical expression in Equation 4, the augmented user cost of capital is given by:

$$u = b(1-\gamma) + \gamma\left[(b-b_L)F(e_L) + \int_{e_L}^{e_H}[b - R_K(K_1,e)]dF(e) - (b_H - b)(1-F(e_H))\right] \tag{8}$$

Equation 8 adds the second term in brackets to the conventional user cost. If the call option of delay is more important than the put option of resale or redeployment, the additional term is positive and the traditional user cost of capital (Equation 4) underestimates the true user cost (Equation 8). Conversely, the put option of resale or redeployment dominates, the additional term is negative and the traditional user cost of capital actually overstates the true user cost.

We can also explicitly incorporate option valuations into the investment threshold ("marginal q") and the valuation ("average q") expressions. Rewriting Equation 7 as:

$$V'(K_1) \equiv NPV'(K_1) + \gamma\left[P'(K_1) - C'(K_1)\right] \tag{9}$$

where "marginal q" is expressed as the sum of three components:

$$NPV'(K_1) \equiv r'(K_1) + \gamma \int_{-\infty}^{+\infty} R_K(K_1,e)\,dF(e) \tag{10}$$

$$P'(K_1) \equiv \int_{-\infty}^{e_L} \left[b_L - R_K(K_1,e)\right] dF(e) \geq 0$$

$$C'(K_1) \equiv \int_{e_H}^{+\infty} \left[R_K(K_1,e) - b_H\right] dF(e) \geq 0$$

The first is the familiar NPV of marginal returns on the first period capital stock, K_1. The second is the value of the marginal put option, $P'(K_1)$, an increment to marginal q. The third is the value of the marginal call option, $C'(K_1)$, a decrement to marginal q. The optimality condition for the choice of the first-period capital stock remains $q(K_1)=b$, so that:

$$NPV'(K_1) = b - \gamma\left[P'(K_1) - C'(K_1)\right] \tag{11}$$

That is, again, the investment threshold is affected by the marginal put and call option values.

Average put and call option values also affect the value of the firm. Note that Equation 5 may be rewritten as follows:

$$V(K_1) = NPV(K_1) + \gamma\left(P(K_1) - C(K_1)\right) \tag{12}$$

where:

$$NPV(K_1) \equiv r(K_1) + \gamma \int_{-\infty}^{+\infty} R(K_1, e)\, dF(e)$$

$$P(K_1) \equiv \int_{-\infty}^{e_L} \left\{\left[R(K_2(e), e) - b_L K_2(e)\right] - \left[R(K_1, e) - b_L K_1\right]\right\} dF(e)$$

$$C(K_1) \equiv \int_{e_H}^{+\infty} \left\{-\left[R(K_2(e), e) - b_H K_2(e)\right] + \left[R(K_1, e) - b_H K_1\right]\right\} dF(e)$$

The first term is the familiar expression for the expected present value of returns on K_1. The second term is the value of the put option to redeploy capital in the second period at a unit price of b_L. Finally, the third term is the value of the call option to acquire capital in the second period at a unit price of b_H.

As with the user cost of capital and marginal q, the values for the embedded put and call options affect the value of the firm. When the put option of resale or redeployment is relatively more important, the true value of the firm exceeds the conventional NPV valuation. In the often-discussed case in which the call option is relatively more important, the true valuation is less than the conventional NPV valuation. The extreme case of perfect irreversibility assumed by Hausman (1996) corresponds to $b_L=0$ (i.e., no resale value, so that the put option may be ignored).

Table 6.1
Effect of Changes in Model Parameters

	Exercise price of option	Value of option	User cost capital u	Value of firm $V(K_1)$
b_H (*i.e.*, exercise price for call or "delay" option or the purchase price for capital in period 2)	Increases Decreases	Decreases Increases	Decreases Increases	Increases Decreases
b_L (*i.e.*, exercise price for put or "resale" option or the resale price for capital in period 2)	Increases Decreases	Increases Decreases	Decreases Increases	Increases Decreases
	Change in distribution	**Value of option**	**User cost capital u**	**Value of firm $V(K_1)$**
$F(e)$ (*i.e.*, distribution for profitability shock)	σ_e^2 increases symmetrically	Put and call option increase	Depends on relative option values	Opposite to u
	σ_e^2 decreases symmetrically	Put and call option decrease	Depends on relative option values	Opposite to u
	Fatter left tail	Put option increases	Decreases	Increases
	Fatter right tail	Call option increases	Increases	Decreases

Note: This table gives summary statistics and detailed variable definitions.

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3 More General Dynamic

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The underlying parameters of the model affect the option values, the user cost of first-period investment, and the value of the firm in intuitive ways.[15] Imagine that b_H and b_L may both move in the same or opposite directions and may move different amounts relative to b, which is both the current and expected price per unit of capital. For example, an increase in b_L, which may be associated with an increase in potential uses for the investment, increases the value of the put option, reduces the user cost, and increases the firm value. A decrease in b_L, implying greater irreversibility of the investment, by contrast, increases the first-period user cost of capital and reduces the value of the firm. Shifting to expandability, an increase in b_H reduces the value of the call option (i.e., delay) and the user cost of capital, and increases the value of the firm. A decrease in b_H, implying that the cost of acquiring capital in the future falls, increases the user cost of capital and reduces the value of the firm assets in place.

It is also possible to consider the impact of changes in the distribution of profitability shocks, F(e). For example, a reduction in σ_e^2 would reduce the value of both options while a symmetric increase in σ_e^2 would increase the value of both options. This latter effect could occur if the something happened to cause F(e) to have fatter tails. If F(e) changes asymmetrically so that the lefthand tail is fatter, then the put option (resale) becomes more valuable; while a shift that makes the righthand tail fatter increases the value of the call option (purchase new capital). These effects are summarized in table 6.1.

3 More General Dynamic Framework

The foregoing analysis helps explain the roles that option values associated with expandability and reversibility play in investment decisions and valuation. While the analysis is somewhat limited by the two-period structure, many of the intuitive results carry over to the more general dynamic formulations of the investment and valuation problems. In general, the expectation that the purchase and sale price of capital will increase and decrease, respectively, in the future influences current investment decisions and valuations (e.g., see Dixit and Pindyck 1998). Option valuation techniques can be used to calibrate the magnitude of these effects.

One can also use this intuition to describe the consequences of "first-mover advantage" for investment and valuation. When first-mover advantages are important, expected first-period profitability rises for the first mover, reducing the initial user cost of capital (as in Equation 8 for the two-period case) and increasing initial value (as in Equation 12 for the two-period case for the first mover). Subsequent entrants face lower profitability and, for a given cost of expandability, a higher first period cost of capital.

More generally, these effects follow the broad outline of the two-period example. When costs of additional capacity are expected to rise rapidly because of entry or expansion by other firms, current investment thresholds are reduced (through reduction of the call option value), and the value of the firm rises. When resale prices are expected to fall in the future, the value of the put option declines, increasing the user cost and reducing the valuation.

The context of telecommunications and Internet firms is particularly interesting in this regard. On the one hand, the important first-mover advantage (e.g., arising from positive network externalities) for such firms implies a high cost of expandability. On the other hand, the usefulness of current investments for a wide range of future technologies and products implies that one can think of declines in resale or redeployment values as being modest, or even negligible. For example, newly available technologies are increasing the marginal value of conduit and first-stage investments. That is, the cost of putting wire in the ground has not fallen as dramatically as the cost of technologies that may be used to expand the capacity of the installed wire (e.g., xDSL or DWDM). Such technologies make expansion of the existing capital less expensive.

In the context of the model presented earlier, the first-mover advantages reduce the call option value in Equation 6; the high flexibility in redeploying capital increases the put option value in Equation 6. Both effects act to reduce the required return on equity and increase valuations relative to those obtained using traditional NPV methods. The Internet illustrates both effects well—making network infrastructure investment more reversible, while making the risk of not having adequate capacity greater if capacity is costly to obtain. The option to use capacity installed initially is more valuable, and the value to redeployment or selling capacity if not used for its originally installed purpose also rises.

4 Real Options and the Cost of Capital for Telecommunications and Internet Firms

The telecommunications industry has been subject to several important forces for a number of years. Rapid innovation has resulted in substantial productivity gains which translates into rapid economic depreciation and continuing declines in the price for capital (i.e., $\lambda < 0$ in reality). In addition, the capabilities of the technology have expanded substantially, allowing providers to offer a wider range of services. The technologies have also become more modular, permitting capacity to be added in smaller increments, thereby reducing economic entry barriers. In light of these changes, policy-makers have begun to remove regulatory entry barriers. The Telecommunications Act of 1996 represented an important step in this direction. Its chief goal was to eliminate both economic and regulatory entry barriers to competition in local telephone services that in most markets remains a de facto monopoly.

The Internet accentuates these trends. Because the Internet is based on open standards that facilitate the flexible interconnection of heterogeneous equipment (i.e., assure interoperability), it helps lower the costs of constructing and maintaining a network.[16] In terms of the example we presented, the future price of capital, b_H, is reduced, which increases the value of the delay call option.

Internet technology also makes networks more flexible. Because the Internet shifts network intelligence to the edges of the network, it makes it easier to upgrade the technology or offer new services. With traditional telecommunications networks based on hierarchical systems, the introduction of new services requires modifications to network components both within the core of the network and at the periphery, which increases both the coordination and the direct costs of making a change.[17] In contrast, with a relatively dumb network core based on simple and stable communications protocols such as the Internet protocols, innovation in services and network equipment are decoupled and can proceed more rapidly.[18] These make Internet networks inherently more flexible than traditional telecommunications networks. New technologies can be integrated more easily and new services can be supported more easily than on traditional circuit-switched telecommunications networks. In terms of our earlier model, this aspect of Internet technology increases b_L (increasing the put option—enhancing reversibility) and decreases b_H (reducing the costs of expandability and increasing the value of the call option) on Internet networks relative to traditional telecommunications networks.

The Internet is helping to fuel industry convergence in several important respects. First, Internet protocols can be used to support multiple applications on what have been historically single purpose communications infrastructure. For example, cable television networks can be used to provide telephone service (Internet telephony);[19] while telephone networks can be used to provide data and video services (e.g., Internet access and soon Internet broadcasting). Although there have been other technologies for supporting mixed multimedia services over alternative local access infrastructure (e.g., ATM for supporting multimedia over telephone networks, or voice-over-data technologies for carrying telephone calls over cable television networks), the wide adoption of the Internet protocols and their flexibility make them an ideal spanning layer to provide technology-blind connectivity across multiple physical network platforms and to allow physical infrastructure to provide application-blind transport to a multiplicity of traffic types. This development allows investors in transport infrastructure to decouple their decision to invest in underlying transport from a forecast of the demand for a specific application. The universe of potential applications that can be supported on the physical infrastructure is expanded. In terms of this model, convergence in this sense increases b_L and initial firm value because the range of end-user service markets that can be served by physical infrastructure is increased. For example, with the growth of the Internet and interest in broadband access, and with the development of xDSL technologies to support broadband services over copper local loop plant, the value of the underlying copper infrastructure is increased (i.e., b_L is increased).

Second, the growth of the Internet has helped blur industry boundaries. The markets for computer and network equipment are merging as traditional distinctions between data and telecommunications disappear. The resulting increased competition helps lower equipment costs, especially for the electronic network components used to switch traffic. Meanwhile, the costs of installing outside plant have not fallen as rapidly. It is still quite costly to dig up streets and install new wires, especially in built-up urban areas. This may have the effect of increasing b_H (increased call option) and increasing b_L (increased put option).

Third, the growth of the Internet is facilitating the convergence of media so that consumers will be able to take advantage of mixed interactive video, voice, and data services. Although these services are still not widespread, it is anticipated that service providers will want to supply and consumers will want to buy integrated mixed-media services. This will substantially increase the demand for bandwidth required in the backbone and the periphery of the network. Furthermore, because data traffic is inherently more heterogeneous (i.e., more bursty with a higher peak to average bandwidth), this will further enhance the need for network capacity.[20] Anticipation of this substantial growth in demand for capacity for all electronic communications services again enhances the value of existing infrastructure, especially for local loop plant (b_L increased).

Finally, the growth of electronic commerce over the Internet is further enhancing the need for and demand for reliable broadband communication services. All of these forces further increase the mission-critical nature of electronic communication networks and make end-users less price sensitive in aggregate. As data communications and the Internet become more entrenched and impact more aspects of day-to-day business functions, the risk of not controlling one's network facilities may encourage self-provisioning of networks. See table 6.2.

The overall effect of these trends is likely to make all levels within the communications infrastructure value-chain more competitive and to accelerate the pace of innovation. This effect will increase overall uncertainty for firms that compete in cyberspace. In terms of the model presented earlier, σ_e^2 will increase, increasing the value of both the put and call options, with a possibly ambiguous effect on the cost of capital and the value of most Internet firms. For example, increased competition upstream or downstream will tend to increase the put option and decrease the call option, making a firm in a protected niche more valuable. Because at this stage in the industry's development, no one is precisely sure where protected niches might be, this may have the effect of increasing the put option for capital at all levels (a fatter left tail to the profitability shock distribution). That is, if every firm thinks that in the future it will need to have an electronic-commerce presence on the Web to survive (i.e., failure means loss of quasi-rents as well as extinquishing of future profit options), this could increase the value of assets necessary

Table 6.2
Telecommunication and Internet Trend Effects

	Example	Effect on Options for infrastructure owners	User cost capital u	Value of firm $V(K_t)$
Technology	xDSL, DWDM	Call option value decreased, put option value increased	Decrease	Increase
	More modular	Call option value decreased	Decrease	Increase
	More flexible	Put option value increased	Decrease	Increase
	Accelerated innovation, increased uncertainty	Put and call options more valuable	Uncertain	Uncertain
Industry structure changes: convergence, deregulation, increased competition	Demand growth	Call option value decreased, put option value increased	Decrease	Increase
	Horizontal Competition increased (firm uncertainty increased)	Call option increased	Increase	Decrease
	Vertical competition increased (upstream and downstream bargaining power reduced)	Call option decreased, put option increased	Decrease	Increase
Internet: Growth of e-commerce	Mission-critical value of infrastructure	Call option value decreased, put option increased	Decrease	Increase

User cost capital u	Value of firm $V(K_1)$
Decrease	Increase
Decrease	Increase
Decrease	Increase
Uncertain	Uncertain
Decrease	Increase
Increase	Decrease
Decrease	Increase
Decrease	Increase

to sustaining a Web presence (e.g., in addition to basic network infrastructure, all of the application support such as security, billing, Web design, etc.). In addition, because of first-mover effects, whichever firm is lucky enough to establish itself in what turns out to be a very valuable protected niche may earn extremely high returns. Formally, one may think of this as increasing the expected value of the upper tail of the profitability shock distribution (i.e., higher probability of a very high return while keeping the total probability that e exceeds e_H unchanged). The opportunity to capture the first-mover advantage in such a case is analogous to holding a lottery ticket that promises a small chance to win a very big prize; while the risk of hold-up discussed above is like having a very large penalty associated with not having bought any lottery ticket. When coupled together, these effects may help account for the extremely high valuations for some Internet firms in 1999. For example, Amazon.com may be on its way to establishing itself as "the retailer on the Net" (first-mover advantage). However, to the extent that no bookseller or publisher can afford to ignore having a Web presence, this increases the value of Amazon's competition as well. A similar effect may help explain the value of Web portals such as Yahoo.com.

While investment to meet these needs is occurring at all levels within the telecommunications network, local access facilities remain an important potential bottleneck. The trends that are increasing the value of Internet firms may be especially important for owners of local access infrastructure (i.e., b_L increases). The increased technological flexibility and market flexibility that allows infrastructure that was originally installed to handle only telephone service to support video, data, and voice services increases its value. This would tend to decrease the user cost of capital for owner's of local access infrastructure, or, equivalently, increase the value of such firms.

Technologies such as xDSL that increase the capabilities of existing infrastructure (i.e., allow copper loops to support broadband service) may be thought of as increasing b_L; while technologies such as DWDM that substantially lower the costs of incremental investment[21] may be thought of as conveying a first-mover advantage on firms that deploy cable that is DWDM-upgradable. As noted above, this reduces the call option and increases the value of capital in the first stage.

5 Conclusions and Extensions

This chapter applied the simple two-period investment model of Abel, Dixit, Eberly and Pindyck (ADEP 1996) to explore the implications of incorporating real options into estimates of the cost of capital and the value of firms in the telecommunications and Internet industries. The theory of real options helps highlight important errors that may arise in the face of uncertain investment that is costly to adjust *ex post*. Prior research in this area in the context of telecommunications firms (e.g., Hausman 1996, or Hubbard and Lehr 1996) focused solely on the relative value of the option to delay investment (the call option) that is extinguished when a partially or completely irreversible investment is made. Failure to account for this delay option leads to underestimates of the cost of capital and overestimates of firm value. This approach neglects the valuable resale (put) option that is created by the investment. That is, while it may be possible to delay investment today in order to learn whether investment is really desirable, delay may force the firm to miss an industry bandwagon or forgo a first-mover advantage. Investing early may increase future flexibility. Whether the cost of capital should be higher (and firm value lower) or the reverse depends on which of the options is more important.

The analysis showed how the Internet is likely to have affected the value of the real options associated with the capital assets of telecommunications infrastructure providers and Internet firms in general. To be more definitive in assessing this fast changing arena, further work is being pursued both in developing a more robust dynamic theoretical model and, more important, attempting to empirically validate the still intuitive assessments of the impact of the Internet.

Two extensions of the framework considered here appear particularly promising. First, the integration of option values in the user cost of capital and firm valuation suggests that one may want to explore the extent to which familiar methods for estimating required rates of return for telecommunications firms incorporate these options elements. Second, the potential importance of first-mover advantage in telecommunications and Internet markets points up the potential relevance of a dynamic extension of the model presented here.

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$$\frac{V(K_1) - r(K_1)}{\int_{-\infty}^{+\infty} R(K_1, e)\, dF(e)} = \gamma *$$

$$\text{where: } \gamma^* = \gamma \left[1 + \frac{P(K_1) - C(K_1)}{\int_{-\infty}^{+\infty} R(K_1, e)\, dF(e)} \right]$$

The DCF approach would produc
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Previous analysis of the real option component of the required rate of return for telecommunications firms has focused on the consequences of the call option of delay associated with irreversible investment for the required rate of return (see, e.g., Hausman 1996; Biglaiser and Riordan 1998; and Salinger 1998). These examples generally emphasize complete irreversibility, so that the "put option" of sale or redeployment of technological investments does not affect the user cost of capital or the value of the firm. At the same time, costs of delay are not usually considered.

One might ask, as in the context of the telecommunications industry, how option values complicate the estimate of required rates of return in traditional discounted cash flow analyses. If one has financial data for firms in the individual line of business (e.g., in the regulatory setting, local exchange access and telephony services as opposed to telecommunications holding companies), and marginal and average investment projects are similar, the traditional DCF approach would produce a reasonable estimate of the return on equity. Note for example, that Equation 5 can be re-expressed as follows:

$$\frac{V(K_1)-r(K_1)}{\int_{-\infty}^{+\infty} R(K_1,e)\,dF(e)}=\gamma^* \tag{13}$$

$$\textit{where: } \gamma^*=\gamma\left[1+\frac{P(K_1)-C(K_1)}{\int_{-\infty}^{+\infty} R(K_1,e)\,dF(e)}\right]$$

The DCF approach would produce an estimate of γ^*. Higher values of the call option reduces the estimate of γ^* (i.e., increasing the estimated required rate of return). In addition, a high value of the call option relative to the put option reduces the firm's value and leads to a higher estimated return on equity than in a traditional DCF analysis of the required rate of return. Higher values of the put option increases the estimate of γ^*; the higher resulting valuation of the firm is associated with a lower DCF estimate of the return on equity.

Second, extension of the framework to a dynamic setting to study effects of first-mover advantage on firm value is likely to be fruitful. Loosely speaking, such an extension would incorporate heterogeneity in the distribution of future returns depending upon order of entry. As noted, the presence of a significant first-mover advantage reduces the option value of delay for a potential first mover.

Notes

1. See also Trigeorgis (1996), who emphasizes the options created by new investment.

2. See Federal Communications Commission (1996) or Hubbard and Lehr (1998) for further discussion of Telecommunications Act of 1996.

3. A conference organized by James Alleman and the Columbia Institute of Tele-Information on October 2, 1998 further examined opposing views on this issue (Alleman and Noam 1999).

4. The original derivation of the user cost of capital by Jorgenson (1963) assumed that $\lambda=0$.

5. In an appendix, they present a preliminary examination of the impact of considering uncertainty (real options), but focus on the option to delay so that this will increase the user cost of capital.

6. Taken literally, the two-period example we use abstracts from any trends in the purchase price of capital goods. While this abstraction is relatively innocuous in this setting, it would be problematic in a more dynamic extension, in which the assumption that $b_H > b$ would imply that $\lambda > 0$. In principle, one can think of there being a trend in purchase prices (see Hubbard and Lehr, 1996; or Biglaiser and Riordan 1998, for examples in the telecommunications setting), which could be positive or negative. As we noted earlier, a negative trend would, all else being equal, increase the current user cost of capital, while a positive trend would decrease the current user cost. Around this trend, however, option values arise as long as the firm faces decisions about expandability and reversibility.

7. For descriptions of general models of costly reversibility, see Pindyck (1991), Dixit and Pindyck (1994), and Hubbard (1994).

8. Remember, we are ignoring depreciation ($\delta=0$) and assuming that the price of capital is expected to be constant over time (i.e., expected price of capital in second period is b, so $\lambda = 0$). In this case, the user cost of capital (Equation 1) reduces to rb.

9. $(1-\gamma) = r/(1+r) \approx r$ for small r. In this simple two-period model, the user cost of capital is exactly γrb; however, in a continuous model, this is only approximate.

10. That is, traditional naïve investment theory assumes that future capital is fully adjustable up or down at a price b. For a discussion of the impact of including real options see the general references cited earlier, as well as Kulatilaka (1995), Kulatilaka and Trigeorgis (1994), Myers and Majd (1990), and Salinger (1998).

11. The sale price b_L may be less than zero in the event of costly disposability (e.g., hazardous waste from a nuclear power plant).

12. The profitability disturbance, e, is distributed with cumulative probability distribution F(e) with $-\infty \leq e \leq +\infty$ and with E(e)=0 and variance σ_e^2.

13. These results follow naturally from solving the first-order necessary conditions associated with the firm's optimal investment decision in the second period:

$$\max_{K_2.}\left\{\left[R(K_2)+b_L(K_1-K_2)\right], R(K_1), \left[R(K_2)-b_H(K_2-K_1)\right]\right\}$$

where terms represent payoffs to firm if it sells capital, keeps capital the same, or increases capital in the second period.

14. This seems a reasonable assumption in most cases in light of technical progress and transaction costs (i.e., bid/asked spread). In the ADEP (1996) framework, capital is homogeneous. As we discuss more below, in local telecommunications infrastructure, this assumption may be less appropriate because existing facilities may have advantageous placement with respect to conduit, especially in densely populated urban environments where such conduit is a scarce asset.

15. It is also possible that the shock e is an industry disturbance, raising both b_L and b_H. In this case, as long as there is an important idiosyncratic component to e, the marginal q is defined by:

$$V'(K_1) \equiv r'(K_1)+\gamma\int_{-\infty}^{e_L} b_L(e)dF(e)+\gamma\int_{e_L}^{e_H} r(K_1(e))dF(e)+\gamma\int_{e_H}^{+\infty} b_H(e)dF(e)=b$$

as in ADEP (1996). For example, good news for the industry might shift both b_L and b_H to the right: b_L because of more liquid secondary markets for vintage capital; and b_H owing to an upward sloping supply curve for new capital.

16. Reliance on modular technologies based on open standards increases competition at all levels within the value chain and allows deeper, more liquid markets to emerge for complementary products and services (e.g., support services, replacement equipment, etc.).

17. For example, to change our touch-tone phone system would require changes both in customer premise equipment and backbone switching and signaling equipment. The magnitude of the challenge of coordinating this change is one reason we continue to live with the limitations of Dual Tone Multi-Frequency (DTMF) keypads as a telephone interface.

18. See Kavassalis and Lehr (2000) for a more complete explication of these ideas.

19. In this regard, consider AT&T's attempts to acquire the cable television firms TCI and MediaOne to facilitate AT&T's entry into local access and telephone services.

20. Furthermore, the delay in delivering viable quality-of-service technologies encourages over-provisioning to assure service quality (i.e., decrease packet-loss and end-to-end delay).

21. That is, DWDM makes it possible to substantially increase the capacity of installed fiber for a relatively small marginal cost, making capital more easily adjustable.

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