Dynamic Analysis of the Long-Distance Telecom Bubble

Rintaro Kurebayashi[1]
Kurebayashi: NEC Corporation
1131, Hinode, Abiko City, Chiba 270-1198, Japan.
rintaro@mvb.biglobe.ne.jp

Nathaniel Osgood, PhD[1]
Department of Computer Science, University of Saskatchewan
110 Science Place, Saskatoon, SK S7N 5C9 Canada
306-966-6102 (Office), 306-966-4884 (Fax)
osgood@cs.usask.ca

Sharon Gillett
CTPID, Communications Futures Program, MIT.
Email: sharoneg@mit.edu

ABSTRACT

It is well known that the long distance telecom service providers suffered heavy damage in the aftermath of the telecom bubble. What is it about the telecom industry that drove participants to fall victim of the bubble dynamics despite historical understanding of the destructive consequences of past bubbles? Was the bubble simply the result of a "perfect storm", or was it an inevitable reflection of industry dynamics? To what degree did the bubble arise from irrational exuberance and misperception of demand growth, and to what degree did it simply reflect pathological emergent behavior arising from individually rational actors? The answer to such questions are interesting historically, but may also help provide insights for regulators and enterprises. The objective of the analysis described in this paper is firstly to use system dynamics to characterize the telecom bubble phenomena, secondly to analyze and understand the mechanism of the telecom bubble, and thirdly to utilize the model to make preliminary recommendations that may help to lower the risk of similar phenomena in the future. The model provided insight into the impact of factors such as technological advancement, misinformation concerning demand growth, competition among network service providers, and the impact of demand forecasting techniques.

1 Introduction

It is well known that the long distance telecom service providers suffered heavy damage in the aftermath of the telecom bubble. The bubble was marked by overshoot and collapse of installation of transmission capacity and was marked during its boom phase by rapid entry of new competitors, technological advancement in both telecommunications technology and internet

[1] The first two authors acknowledge equal authorship.

[5] Williams spun off its telecommunication sector in 2001 and the new company was named as WilTel Communications.

applications, and corporate expansion borne of exuberant and ill-founded demand forecasts. Its bust was characterized by a capacity glut, bitter price competition for new customers, and corporate defaults.

The telecom bubble and its burst had pronounced effects on telecom system integrators, equipment manufacturers, and component manufacturers through the US telecom value chain. The telecom bubble in turn affected many companies and markets all over the world.

Studies have analyzed many factors influencing the telecom bubble. Despite these studies, it appears that no consensus has been reached on how the bubble could have been avoided, on identifying the underlying key factors for the bubble, and in deriving lessons from the bubble.

The telecom bubble emerged from many causes including overly optimistic demand forecast (which induced a mismatch with real demand) and excessive fiber installation amplified by factors such as the high cost of construction and competitive pressures [1] . However, historically, bubbles have occurred many times in different industries [2] . Such booms include the canal boom in the early nineteenth century, the railroad booms and busts in the late nineteenth century, and similar effects in industries such as electricity transmission and Interstate highways. All of these industries share certain characteristics: all are politically and economically important, and are affected by financial instability and/or government regulation. The boom-and-bust phenomenon experienced by telecom had similar characteristics and temporal progression to other industries which have experienced bubbles. What is it about the telecom industry that drove participants to fall victim of the bubble dynamics despite historical understanding of the destructive consequences of past bubbles? Was the bubble simply the result of a confluence of historic of historic factors that produced the “perfect storm”, or was it an inevitable reflection of industry dynamics? To what degree did the bubble arise from irrational exuberance and misperception of demand growth, and to what degree did it represent the consequence of individual rational actors? The answer to such questions are interesting historically, but may also help provide insights for regulators and enterprises.

The paper uses a system dynamics simulation model to provide insight into the impact of factors such as technological advancement, misinformation concerning demand growth, competition among telecom backbone network service providers, and the impact of distinct demand forecasting techniques. The objective of the dynamics analysis described below is firstly to characterize the telecom bubble phenomena, secondly to analyze and understand the mechanism of the telecom bubble, and thirdly to utilize the tools to make preliminary recommendations that may help to lower the risk of similar phenomena in the future.

In the next section, we sketch a few pieces of an integrated model that attempts to capture many of the essential phenomena that shaped to the telecom bubble. By bringing together a wide variety of types of data related to these effects and integrating them into a cohesive picture of the bubble and its causes, the model is designed to help us gain insight into the degree of impact different factors had on the bubble.

2 The Mode

2.1 Model scope

The model presented in this paper focuses on the US long-distance telecom service industry during the telecom bubble era. Specifically, the model seeks to represent the dynamics of the US telecom service industry between 1995 (when the Internet started to emerge and affect the industry) and the end of 2003. The current model characterizes the industry at an aggregated level, and does not attempt to disaggregate the behavior associated with different companies.

The model is divided into five sectors: Capacity planning, capacity expansion process, demand, price setting, and operations cost. The four sectors most important for the current analysis – those for capacity planning, expansion, demand and price setting – will be briefly described in the section below. The relationships between some of the most important variables in these sectors are shown in Figure 1. Due to space constraints, only the briefest of descriptions can be given of the model operation; interested readers are referred to [23] , which provides significant additional detail on the model design and operation.

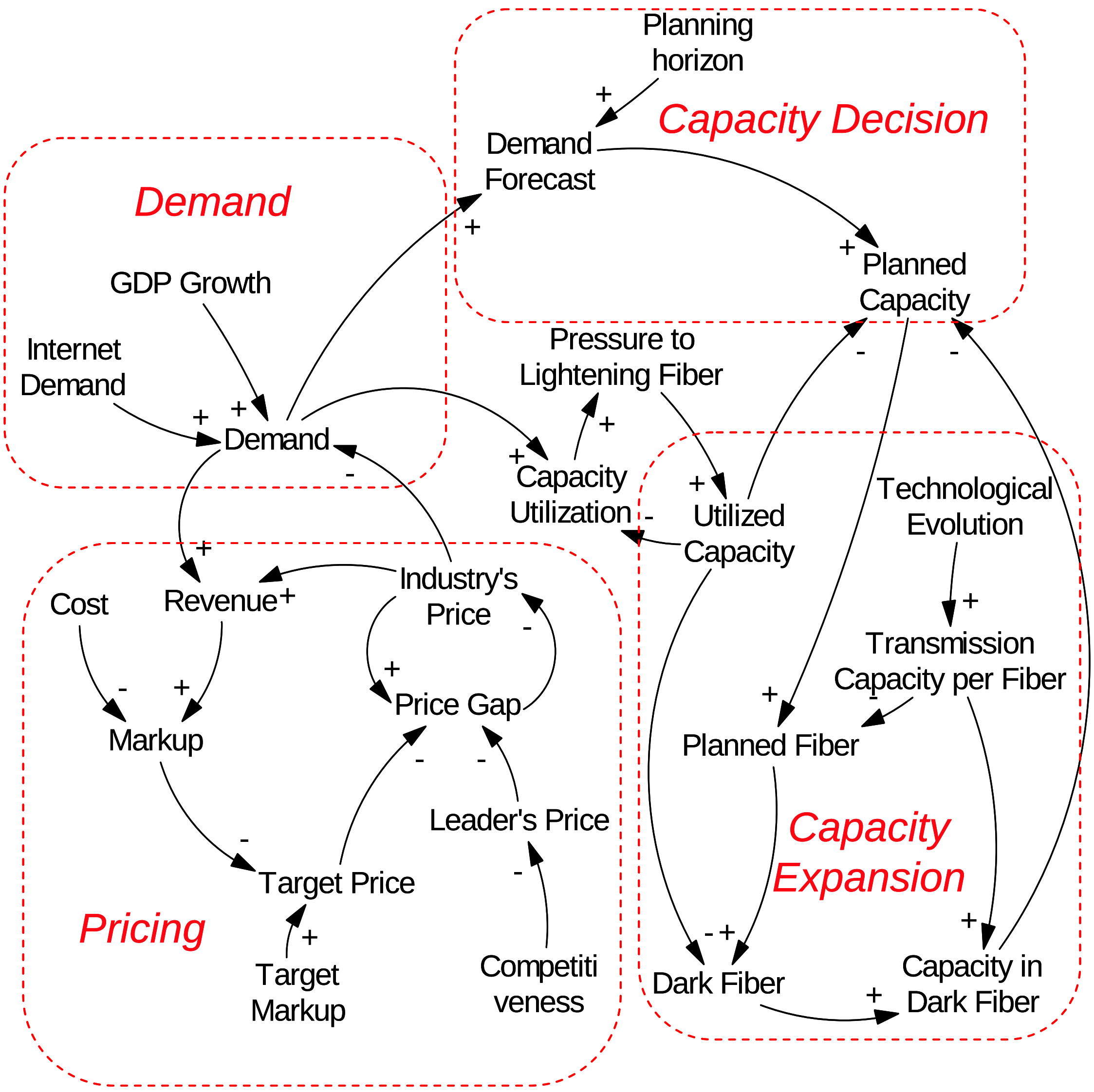

Figure 1: Overall Model Structure

2.2 Technology

2.2.1 Technology background

The evolution of optical fiber telecommunication technologies strongly influenced the dynamics of the telecom market; this impact was particularly pronounced in the telecom bubble era. The advent of optical fiber – which has enormous transmission bandwidth compared to copper transmission lines – ignited a rapid capacity expansion in the long distance telecommunication industry. Technologies such as optical amplifiers, Wavelength Division Multiplexing (WDM), Optical Add Drop Multiplexing (OADM) and gain-equalizing techniques allowed the capacity available in one fiber transmission line to increase explosively. While each technology in isolation underwent incremental innovation in this period, the resultant synchronized incremental innovation generated the explosive expansion of transmission capacity. Furthermore, the telecom boom and the competition and easy financing it possible stimulated R&D for telecom companies, further accelerating the pace of technological advancement and the growth rate of transmission capacity.

As a result of the above, following years of relatively modest growth, the expansion rate of transmission capacity literally "exploded" after 1998. Figure 2-2 shows the historically observed capacity over time. The expansion rate seems to have been beyond that anticipated by telecom service providers, since historically capacity had increased 10 times for every four years before the telecom bubble, a much lower rate than obtained in the bubble, during which capacity doubled every 9 months [14] This rapid expansion occurred concurrent with the Internet boom, which began in the middle of the 1990s and was partly fueled by the influx of R&D investment during the boom.

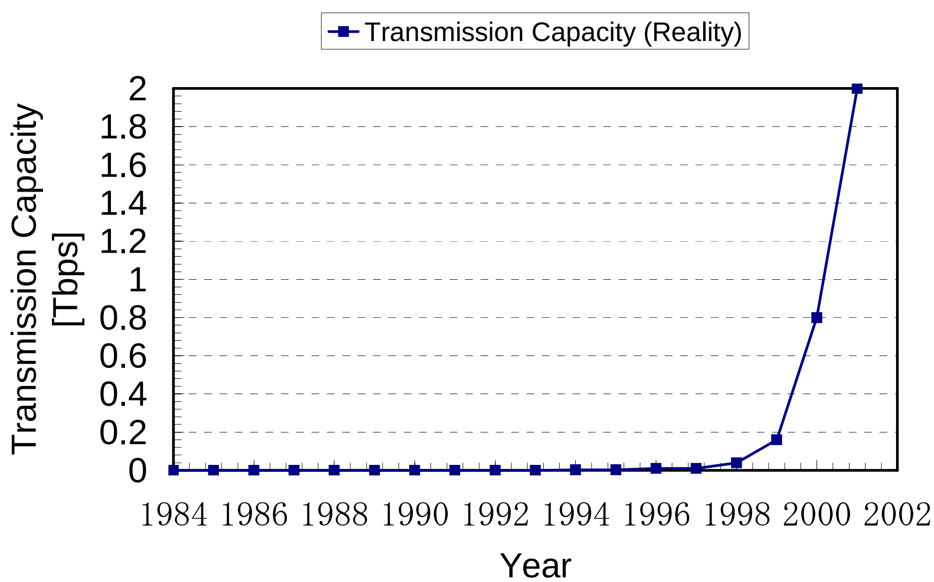

Figure 2-2 Commercially available per-fiber transmission capacity

As noted above, fiber network installation is a lengthy process. In the telecom bubble, transmission capacity inevitably expanded dramatically in the midst of any capacity expansion project. Technologies such as WDM allowed telecom service providers to utilize the latest technology to increase capacity of existing lines, including those newly installed. As a result, the capacity actually made available following a project frequently far exceeded the one originally planned, thereby enhancing the gap between the growth of bandwidth availability on the one hand and of Internet bandwidth demand on the other.

Although the funding available for capacity-related R&D was influenced by the evolution of the telecommunications sector, for the sake of simplicity the capacity available per fiber is represented exogenously within the current system dynamics model. The associated time series is shown in Figure 2-2.

2.3 Capacity planning and expansion

Within the system dynamics model, capacity buildout is carried on the basis of many factors, including forecasted future demand, a desired level of capacity utilization, and the time required for buildout. This section briefly sketches some of the issues involved within the demand forecasting needed. Interested readers interested are referred to [23] for additional detail.

2.3.1 Demand Forecasting

Within the model, future demand is generally forecasted on the basis of estimated current demand. The current demand can in turn be estimated either directly by measurement of capacity utilization or indirectly by the demand information of other companies. In the early stage of the bubble, many of the new entrants would not have had access to the real demand growth across the whole of their market since they lacked sufficient statistical data from their own operations and because of the lack of reliable external sources of information on market demand growth.

The model presented in this paper captures two types of demand forecasting by companies: demand forecasting based on extrapolating the aggregate traffic volume including both voice and data communication, and forecasting on the basis of separately extrapolations of the traffic volume of voice communication on the one hand and data communication (primary driven by the Internet) on the other.

The former type of forecasting was predominantly used by incumbents at the beginning of the telecom bubble, reflecting the fact that such companies had recourse to large amounts of historical data and industry-specific knowledge.

The latter form of forecasting would seem to be an appropriate logical description to describe the behavior of new entrants at the beginning of the bubble such as Qwest, Level 3 and Williams (Current: WilTel)[5], who saw opportunities in long distance telecom service industry in the upcoming Internet era. Such new entrants primarily based their capacity expansion plans around forecasts of growth of data demand. This growth was driven less by characteristics of the long distance telecom service itself and more by the Internet diffusion and technological advancement (e.g. application development) triggered by the emergence of World Wide Web. In light of this reliance on external demand estimates by new entrants, the model treats the demand for data communication as an exogenous factor [20] to simplify the model – although it is in reality influenced by endogenous factors such as the available capacity.

We further assumed that in the course of the telecom bubble, an increasing fraction of capacity expansion plans were dictated by forecasts of internet growth rather than by empirical measurements of network use. This reflects the rapid rise of the networks owned by new entrants and the fact that competitive and shareholder pressures led an increasing number of incumbents to begin basing capacity decisions on internet demand.

While the source of demand growth estimates in the model differ between new entrants and established players, the model applies to both groups the same general logic for deriving desired capacity from the demand growth estimates. Regardless of its source, the estimated growth rate is used to forecast the demand at the end of the planning horizon of the telecom service providers. The demand forecasts for data demand for those forecasting demand in each of the two growth techniques were then added, with each weighted by the estimated fraction of the telecom service providers using each decision rule. Because the model is formulated at an aggregate level, a further multiplicative factor was used to account for the fact that the total market share the telecom service providers collectively aim to obtain tends to exceed 100% of the available market segment. This phenomenon is particularly pronounced when new entrants compete to obtain opportunities in the emerging market. The projected demand is then used to estimate the capacity which will be needed after the planning horizon.

Because real-world capacity expansion is determined differently (and often somewhat subjectively) by each firm, the model cannot fully capture all nuances of corporate behavior. Nonetheless, the model does capture some general features of the planning process that bear on strategy choice.

2.3.2 Demand Misinformation

The telecom boom was marked by widespread circulation of poorly grounded forecasts of internet growth. It seems highly likely that these overly exuberant internet demand forecasts were employed for capacity planning, particularly in companies which lacked sufficient capacity utilization trend data from their own networks. This demand explosion led corporate planners and Wall Street analysts to make some major miscalculations. For example, US Department of Commerce reported in 1998 that the traffic on the Internet doubles every three months, implying a continuing annual growth rate of 1,600%. This accorded with and contributed to the widely held view in the years around 1997 and 1998 that the Internet traffic was doubling every three months [16] , although in reality capacity growth rate at that time had subsided to 100% per year, as demonstrated at the time by Odlyzko [15] .

Accurate statistics on the growth of the traffic on the Internet were not widely circulated for the years around 1999 and 2000, and –based partly on the testimony from players (e.g. [17]) – many people seemed to believe that the demand for the Internet was continuing to grow with extremely high rates such as 1,000% per year. However, Coffman and Odlyzko[18] cast doubt on such statements and concluded that the Internet traffic was likely to continue at a much lower (not to say small) rate than perceived by many in the industry based on long-term historical data and various resources obtained in the period of the late 1990s. Among other factors, these lower growth rates reflected the importance of the local bottleneck on long-distance demand. This prediction has been borne out by later analysis through at least 2002.

Reflecting these considerations, the default model parameterization represents the increasing proliferation of misinformation in planning decisions over time during the mid-1990s; within alternative scenarios (some of which are described in Section 3.1), we examine the impact of varying the assumptions about the source and reliability of demand forecasts used in planning.

2.3.3 Capacity planning

The capacity required for a new project for fiber installation is usually assessed using current capacity utilization and the expected demand growth. In theory, the amount of new fiber is determined by these two factors together with the time horizon and expected capacity per fiber. Such forecasting is very difficult the context of rapid Internet growth and volatile technological evolution. In addition, the actual amount of fiber installed is usually greater than that implied by these factors due to the desire to spread high construction costs over as many fibers as possible.

Fiber usually requires a long time to install. The length of time required depends critically on the size and topology of the expansion, but in general requires at least a year. While construction time is considerable, securing right-of-ways is a major challenge throughout the project. For example, it took about four years (from 1997 to 2001) for Level 3 to build up its own US network, an interval which included negotiation to get permission of right-of-way, according to its financial statements[4] [11] [12] . Williams also needed three to four years to finish building up their own network throughout the US [10] . This installation time had a major impact on the telecom bubble, because it required long-range forecasting in a highly uncertain and dynamic situation.

2.3.4 Stock and flow structure of capacity expansion

This section briefly overviews the model's characterization of capacity expansion process. A project to install optical fiber cable starts as a capacity expansion plan is formulated. The desired fiber is determined by the desired capacity which is based on the demand forecast, capacity per fiber, and a multiplicative factor accounting for the effect of construction cost. This final item is used to capture the phenomena (noted above) that service companies responsible for installing the fiber cable tend to increase the amount of the cable installed in recognition of the fact that the fixed cost of construction (e.g. the excavation and fill associated with cable laying) is much larger than the incremental cost of laying a particular fiber cable.

As was noted elsewhere, the installation and activation of cable may take place at very different times. Installed fiber is frequently not fully utilized until many months after an installation finishes. The lighting of fiber proceeds incrementally; a typical rule of thumb is said to be that utilization on a lit fiber pair has to reach 65% usage[6] before lighting the next fiber pair is planned [13] . It generally takes more than 6 months from installation to the point when the new fiber can be lit since the system with the new fiber must be tested with the latest amplifiers and switches. On the other hand, once new fiber is lit, it is relatively quick to add capacity up to a point because adding new channels requires only the addition of modules to the terminal equipment.

The installed cable in the model thus resides in a dark fiber stock until the point at which it is activated by the installation and activation of terminal equipment, amplifiers, and switches. The model treats the decision to activate installed cable as being triggered when the capacity utilization in lit fiber reaches a certain level. The model disaggregates the process of lighting fiber and adding channels in order to capture the behavior of capacity expansion using technologies (such as WDM) in which the timing of lighting fiber can be different from that of adding channels. Typically the time to add channels is much smaller than that required to activate fibers since many tests are conducted before installing equipment for the activation.

2.4 Pricing

Although the model described in this paper is an aggregate model and did not represent the competitive behavior of individual companies, it does require a representation of price competition, which played an important role in telecom boom industry dynamics.

In the late 1990s, revenue was being squeezed by aggressive price cutting in telecommunications services. The drop in prices was a reflection of two primary phenomena. The first was competition – companies who cannot obtain enough capacity utilization to maximize their profits tend to reduce their price to obtain customers to better match demand with supply. The second

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[6] The usage seems to be based on the peak traffic although details are not explained.

factor was the progressively lower costs arising from technological progress, and particularly the fact that operating cost per capacity was reduced with the rise of per-fiber transmission capacity. Aggressive pricing was reinforced by the fact that many companies expected future benefits only after an industry shake-out [6]

The drop in prices was further magnified by a growth in the number of competitors. This growth in the company count reflected both a rise in the number of entrants (arguably reflecting lower entry barriers due to the Telecom Act of 1996) and a greater difficulty for those seeking to exit the market. The wholesale business stimulated competition because the barrier for entry [5] was lowered and many new companies started constructing optical fiber networks throughout the US, seeking to make money by leasing their dark fiber or capacity to resellers. This growth in market competitors also extended to toll resellers. Figure 2-3 depicts the number of companies related to toll services; as can be seen, the number of toll resellers increases rapidly after 1999. At the same time, market exit was complicated by the fact that telecom service providers (facility-based carriers) usually obtain money only after investing large amount of money for the installation of optical fiber networks.

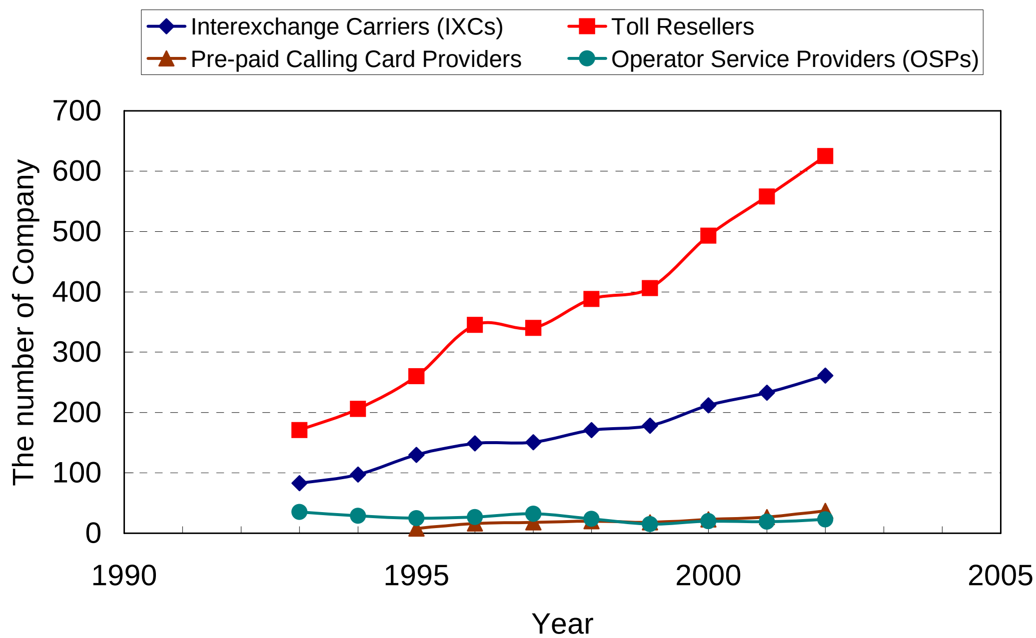

Figure 2-3 Number of companies in long distance telecom service industry, absent wholesalers.

Within this pricing submodel, two factors were used to determine a leading price. First, the model captured the price setting based on the prevailing price in the industry. Secondly, the model represented the setting of price based on a desired profit margin. Before we discuss each of these approaches to price setting – and the means used to choose between them – we first provide an overview of how competitiveness is represented in the model.

The system dynamics model uses Herfindahl-Hirschman Indices (HHIs) to capture telecom marketplace competitiveness in an exogenous fashion. HHIs were introduced for describing telecom market competition by Hogendorn [2] . HHIs used in the current model are defined as the sum of the square of each firm's percentage of market share. For example, if ten firms have 10% market share, HHIs become $(10\%)^2$ x 10 firms = 1,000. The maximum value of HHIs is 10,000 when one company dominates the whole market. For the particular model at hand, we use the fraction of route miles owned by a company as a measure of its market share. The model incorporates a descriptive exogenous time series of HHIs to characterize competition in the telecom service provider market place.

The HHIs described by route miles each firm owns is shown in Figure 2-4.

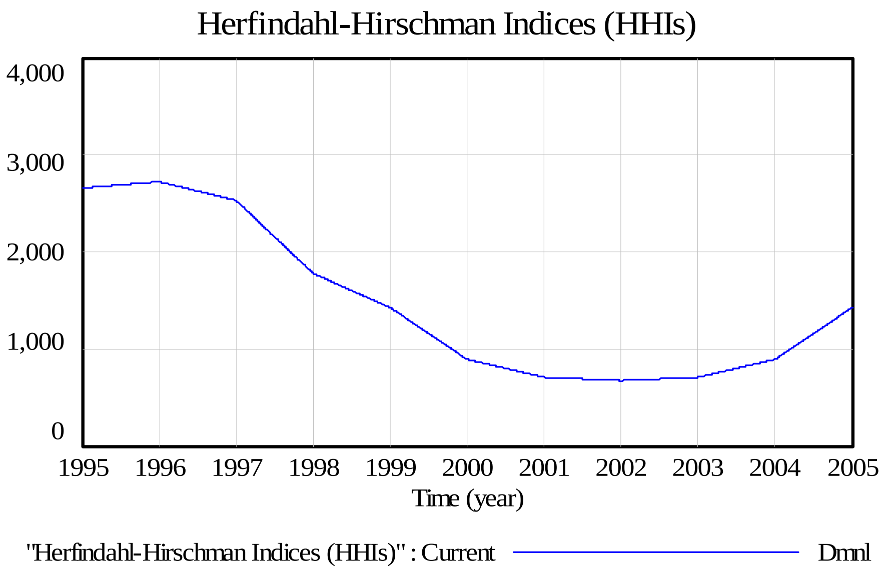

Figure 2-4 HHI of total route miles

The data on the telecom HHI time series extended only until the end of 2001 (2002 in the graph). Therefore, HHIs after 2003 were approximated with the simple understanding that companies were consolidated following the telecom bubble.

There are two primary mechanisms by which price competition is captured in the model. The first factor being considered is the establishment of price margin by means of prevailing price. The prevailing price of the industry is treated as declining over time, where the speed of this decrease in the leading price depends on the competitiveness as measured by HHIs. The other determinant of the price captured in the model is the "rational" pricing method in which pricing is driven by the profit margin being sought by a firm. In this formulation, a target profit margin is set based on a fixed coefficient times revenue and operational expenses. The price decreases based on the reduction of operating cost, which is in turn a function of technological evolution.

The industry leading price is determined by the minimum of leading price by competition and target price by profit basis. Therefore, leading price always decreases at least at the rate of leading price change by competition. This follows the concept of a kinked demand curve [1] , which reflects a situation in which rivals match price cuts but do not respond to price increases by competitors.

The average price of the industry is treated as approaching the leading price with some delay. The delay partly reflects the fact that it takes time for the leading price to diffuse throughout the US market when the leading price may initially be localized only in specific regions. Moreover, firms tend to respond to the leading price when they recognize that the price advantage is actually a threat to them. Therefore, the parameter expressing the period for the adoption to the leading price is set to one year, which is much longer than the period over which firms can change the price by changing their internal processes.

2.5 Summary

In this section, we have very briefly surveyed four important pieces of the system dynamics model for the long distance telecom industry. The following section uses the model introduced here to analyze some of the drivers underlying the telecom bubble.

3 Analyses of the long distance telecom industry

Although full data for model calibration is lacking, the model briefly described in the previous section faithfully captures many aspects of historical behavior in its "baseline" simulation (the simulation using default model parameters). By running alternative scenarios (embodying different assumptions about policies or external conditions), we can use the model to try to better understand the basis for several key behaviors which affected the bubble. In this section, we will analyze the long distance telecom industry by addressing the following questions.

- What would have happened if the internet demand forecast had been correct?
- What would have happened if technological progress had not been so rapid?
- What would have happened if there were no new entrants?
- What conditions would have been necessary to avoid the bubble? Misguided though it was, were the contributing factors behind the bubble based on reasonable assumptions and behavior?

3.1 Misinformation concerning internet growth rates

As noted in Section 2.3.2 and documented by Odlyzko [20] and others, there was widespread dissemination of misinformation on internet growth rates during the peak periods of the telecom bubble. Poorly researched data on internet growth made its way into capacity planning decisions in that period. As we have seen, new entrants laid massive amounts of cable anticipating a explosive growth in internet demand within the period of a few years. As testified by Ebber's misstatements of capacity expansion plans, even incumbents with access to extensive data on capacity utilization increasingly fell prey to – and helped to promulgate – the giddy expectations of internet demand growth. Companies pursuing more measured expansion plans discovered that their plans sometimes became points of concern for investors who interpreted slower growth not as prudence but as indications of lack of competitiveness and loss of market share.

In order to better understand the impact of poor-quality demand estimates, we compared the base case (in which a time-varying fraction of companies estimate demand growth using poor-quality data) with a scenario in which those companies have access to highly accurate and up-to-date information on demand. The scenario assumes that the companies forecasting by internet demand projects forecast future internet demand using these more accurate and timely data rather than the inaccurate estimates that circulated publicly. While this scenario ignores the delay and sampling error associated with realistic demand reports, this scenario helps give some sense as to the level of impact that misinformation may have had on capacity expansion plans.

Figure 3-1 contrasts the assumptions of demand growth for the base case and the alternative scenario. Based on results by Odlyzko [20] , we assume that the misestimation for demand growth were significantly overstated for the later years of the telecom boom.

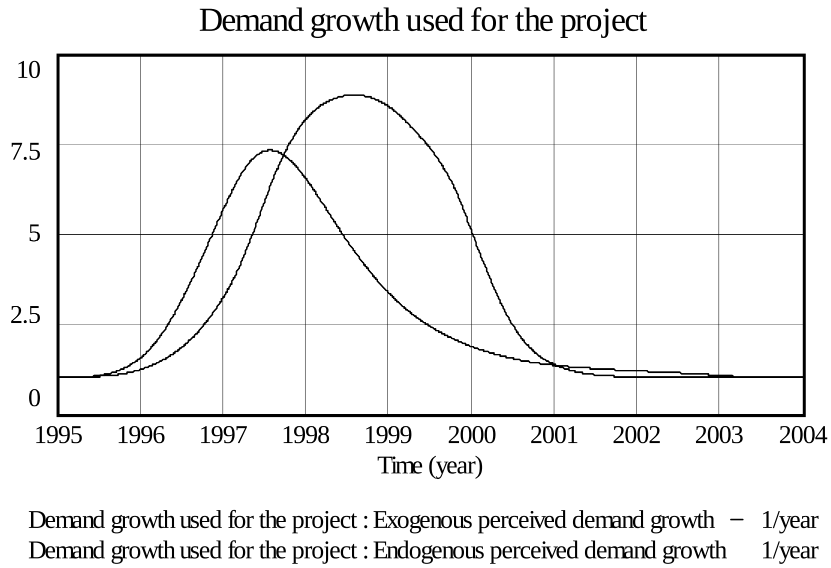

Figure 3-1: Demand Growth Assumptions for Understanding Impact of Inaccuracy on Capacity Planning. In our assumptions, demand growth was overestimated particularly acutely during the period 1998-2001.

Figure 3-2 shows the impact of the more accurate demand forecasts on the amount of cable service providers projected to be required to meet demand growth expectations. As we can see, the model suggests that inaccurate data led to severe overestimation of the amount of cable required to meet demand need. Figure 3-3 contrast the model's estimate of base case (historic) cable installation rate with the installation rate that would be required under the more accurate demand forecasts. The figure suggests that the dissemination of inaccurate information concerning demand growth significantly deepened and prolonged the extent of cable overinvestment. In addition, the graph suggests that that the misestimation also deepened the extent and accelerated the rapidity of the collapse in cable demand following the burst of the bubble. The fact that the model suggests that misinformation about demand growth both amplified boom the boom and let to – a more rapid collapse suggests that such misinformation may have been responsible for severe damage to the cable manufacturers.

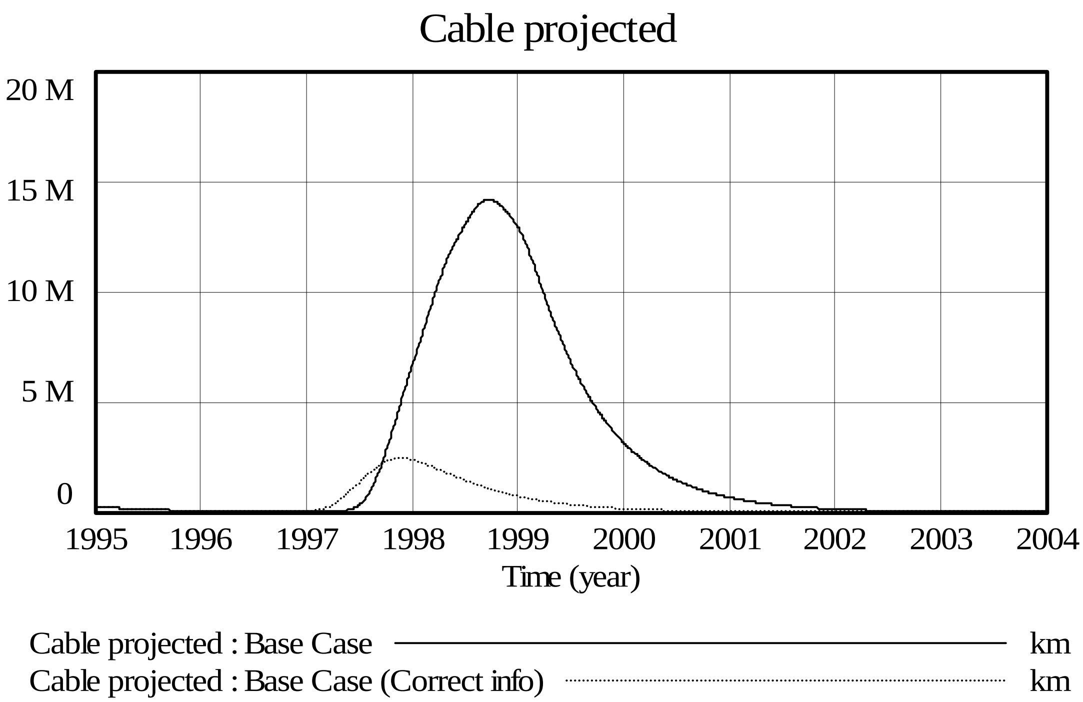

Figure 3-2: Impact of Misestimation on Projected Amount of Cable Required.

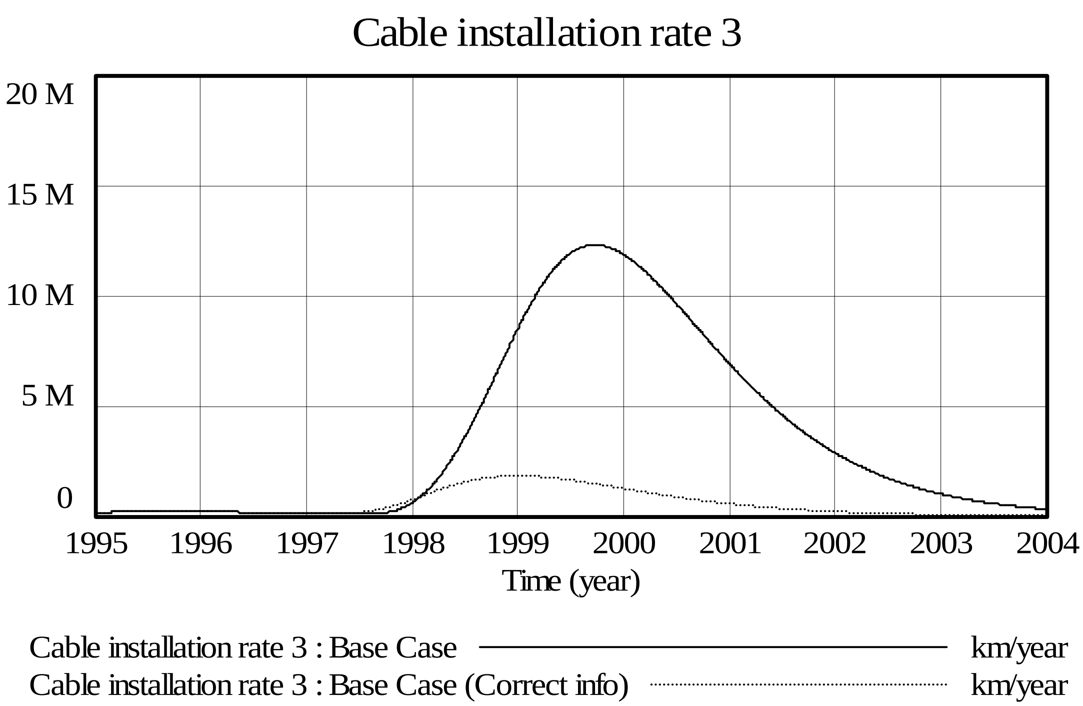

Figure 3-3: Installation Rate for New Cable Under Historic and More Accurate Growth Data

Figure 3-4 contrasts the model's projection of the amount of dark fiber laid for the case of accurate and inaccurate reports of demand growth. As we can see, the model suggests that the proliferation of inaccurate demand reports led to several-fold increase in the quantity of dark fiber laid – an overexpansion the consequences of which the fiber manufacturers are living with to this day in the form of lower demand.

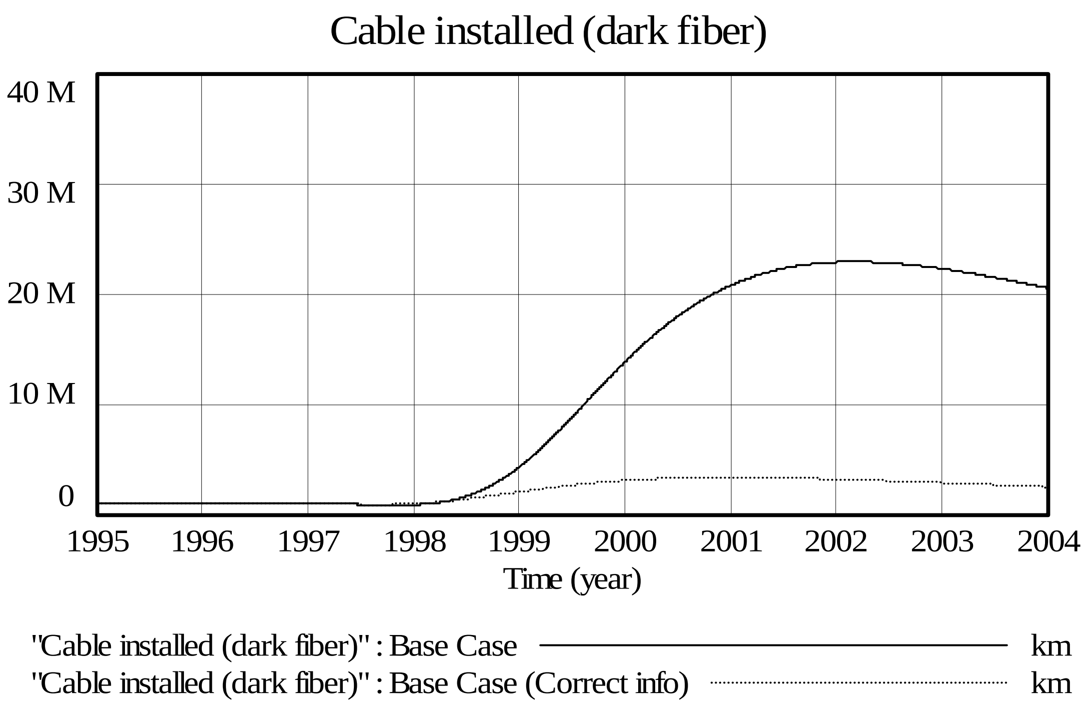

Figure 3-4: Impact of Demand Misestimates on Quantity of Dark Fiber Installed.

In all, the model suggests that demand misestimation caused high levels of distortion, significantly worsened the telecom bubble and was likely to have been particularly deleterious in its effects on cable manufacturers.

3.2 The impact of the demand forecast misestimation

As already explained above, misestimation of the demand forecast, amplified by a long planning horizon, presumably had substantial impact on over-investment in the optical fiber network. The system dynamics model suggests three possible changes to reduce the impact of this misestimation: Making the planning period shorter, making the period for estimating the demand growth longer, or forecasting based on measured demand. To confirm the effect of these three cases, we compared simulations of each scenario in turn with the baseline, keeping all other parameters constant. In one simulation the planning period in the bubble was shortened from 4 years to 3 years to examine the effect of shortening the planning horizon. In another scenario, the period for perceiving the demand growth was changed from one to three years. Finally, in a third scenario, we treated all firms as if they used the more reliable scheme of forecasting traffic demand by extrapolation of empirically observed network usage rather than via reliance on internet growth predictions.

The dynamics of the amount of cable for each of these scenarios are shown in Figure 3-5. The peak associated with overdeployment is substantially reduced in all cases compared to the base case. As a result, the peak observed in the dynamics of the amount of dark fiber (shown in Figure 3-6) is also much smaller in the three cases. In contrast to base case (in which the amount of cable expands rapidly during the years 1998-2001), the amount of fiber in most alternative scenarios declines from its mid-1990s levels. This decline may reflect the much smaller quantity of fiber that requires deployment, due to the rapid technological advances that permitted each fiber to support a much greater bandwidth.

Given the alternative scenarios above, the question then arises: Why didn't this more gradual expansion happen during the historical telecom bubble? There are rational reasons for a departure from each the alternative assumptions above.

First, it is not economical for the telecom service providers to shorten the planning horizon for each company's perspective since construction cost dominates the total expense for installing a new optical network. Therefore, in a competitive situation, the providers try to reduce their own costs by making the planning horizon as long as possible, thereby allowing them to amortize the costs of a given fiber-laying construction project over the many years of benefit. This rational decision by each firm amplified the impact of the telecom bubble. Furthermore, they recognized the risk associated with the long planning horizon because of the easy availability of financing during in the telecom bubble.

Second, it may not be realistic to make the period for perceiving the demand growth long in the context of rapidly changing market conditions and a context in which companies can quickly obtain estimates (accurate or otherwise) of demand growth. As a result, many providers – including new entrants – started to construct their new fiber network in a very short period of time and sought to stay abreast of the latest trends in demand change.

Third, the pressure to keep service quality high enough to retain customers and to respond to changing market conditions (e.g. the evolution of new internet technologies) makes it difficult to construct the fiber network purely on the basis of measurement-based demand forecasts. As a matter of fact, the providers could not anticipate the rapid growth of transmission capacity per fiber by WDM technology in the early stage of the telecom bubble as is explained in greater detail elsewhere. If transmission capacity per fiber grows with the same pace as the long term historical growth rate, the capacity utilization continuously increases as shown in Figure 3-8. The capacity utilization is the averaged data including rural areas and off-peak time periods. Given the need for the infrastructure to handle peak demands, the capacity utilization of 20% seems to be high enough for the providers – lacking knowledge of the coming technological breakthroughs in WDM and related technologies – to install new fiber network. Therefore, basing decisions on projected data demand growth does not seem to be irrational taken by itself.

It would appear that a set of individually rational decisions by each service provider – combined with technology trends treated here as exogenous – precipitated the telecom bubble. Furthermore, it seems that the pressure to grow in the emerging business and the availability of easy financing made it difficult for the providers to stop investing in the fiber network. One thing the providers could have done – and something that might have been very valuable – would have been to closely scrutinize the data underlying demand projections and to seek out alternative projections. Such caution was particular important in an emerging business fraught with many uncertainties and which often impacted by a small number of key driving forces.

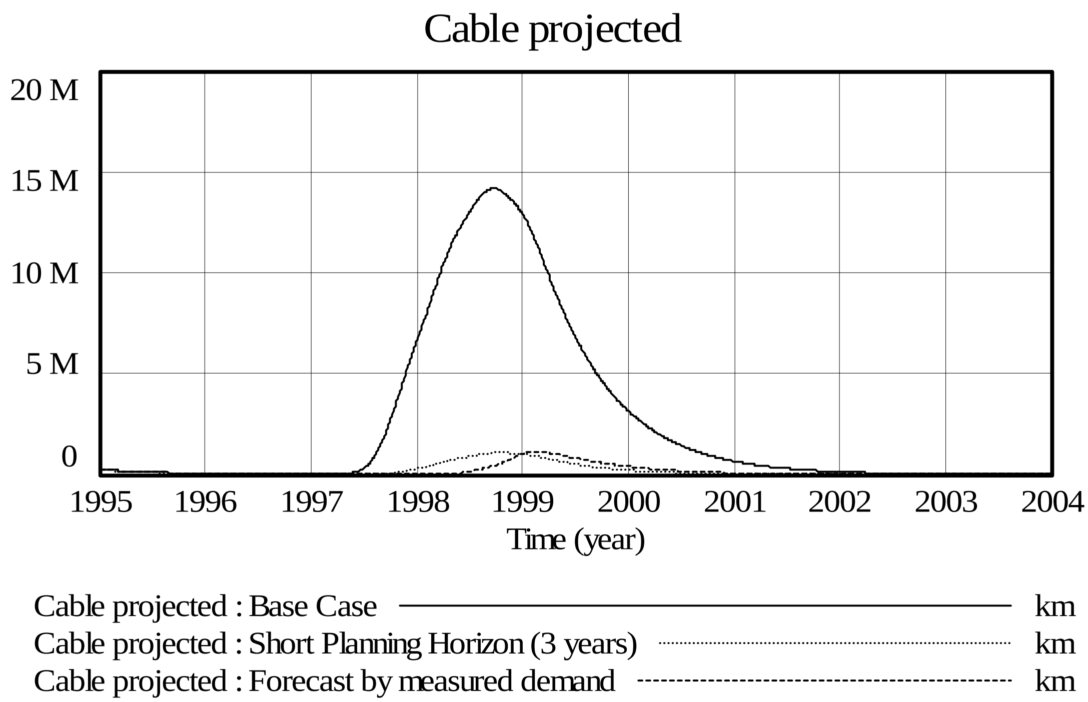

Figure 3-5 Dynamics of cable for the new project in three cases (base case, forecast by measured demand, long demand information delay, short planning horizon)

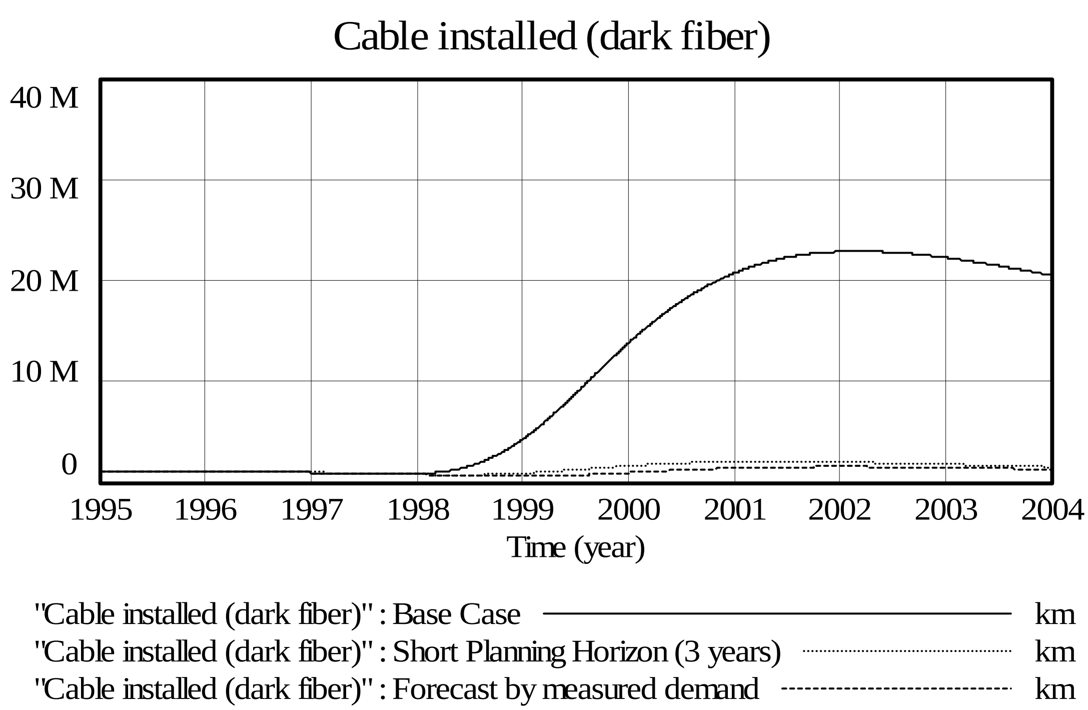

Figure 3-6 Dynamics of dark fiber in three cases (base case, forecast by measured demand, long demand information delay, short planning horizon)

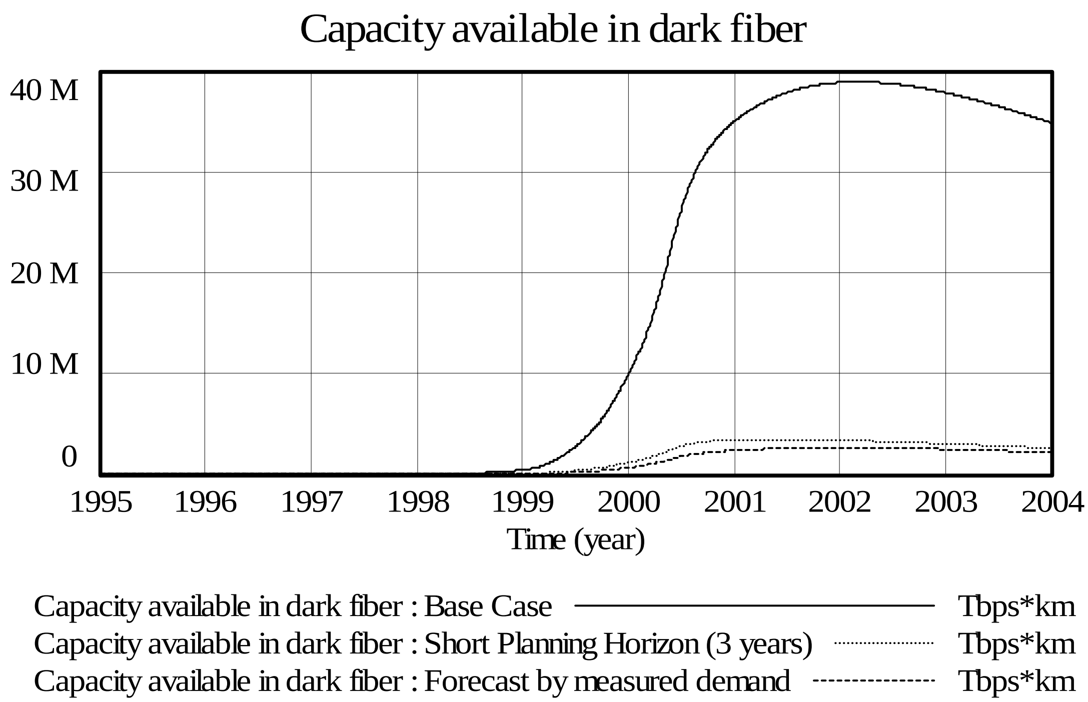

Figure 3-7 Capacity available in the dark fiber (base case, forecast by measured demand, long demand information delay, short planning horizon)

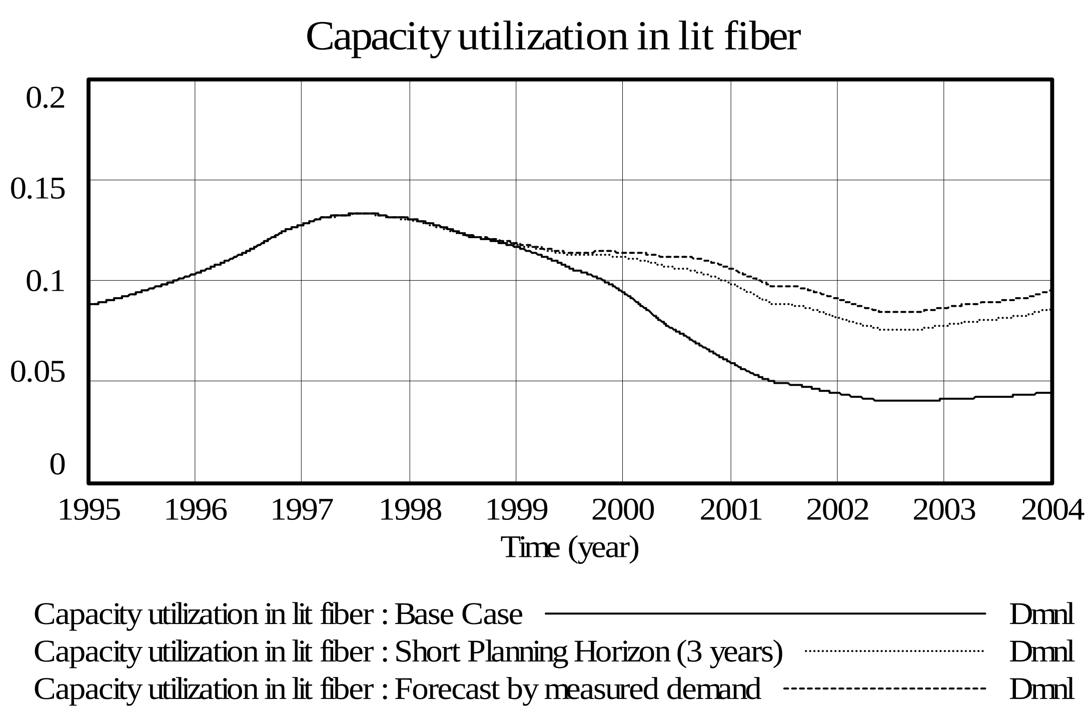

Figure 3-8 Capacity utilization in the lit fiber for five cases

3.3 Over-capacity by technology and construction cost effect

Arguments have been raised that overly rapid evolution of transmission capacity per fiber was the one of the key contributing factors behind the bubble. It is believed that telecom service providers experienced major damage because of heavy investment installing what proved to be a much higher quantity of fiber than they actually needed. Although cable companies benefited handsomely in the early stages of the telecom bubble, following the burst of the bubble they also suffered high losses since an excess of "dark" (unused) deployed fiber led to a crash in demand for new fibers. To observe the influence of the rapid capacity expansion per fiber by WDM technology, we parameterized the model so as to exhibit a steady pace of transmission capacity expansion (10 times for every 4 years).

The amount of fiber for the new scenarios is shown in Figure 3-9. As one can easily imagine, the amount of cable (as measured in km of laid cable) for the new project would be larger in the case that no rapid growth of transmission capacity per fiber is assumed than in the base case where rapid growth is actually included, since the quantity of fiber is determined by the total additional capacity required divided by the capacity per fiber. This result suggests that far from worsening industry volatility, the rapid technological evolution seen during the telecom bubble had the effect of mitigate the turbulence associated with the sudden demand increase and collapse in the fiber industry.

By contrast to Figure 3-9– which depicts the *quantity* of cable installed as dark fiber in each of the scenarios being considered – Figure 3-10 shows the *capacity* available in dark fiber under each of the scenarios being considered. Whereas the *amount* of dark fiber is larger in the scenario in which transmission capacity per fiber does not expand rapidly than in the case it explosively expands, when the *capacity* is considered, the reverse is true. As intuition would suggestion, the capacity of the dark fiber remains small when technology advances slowly, while it expands much more rapidly in the base case of rapid technological evolution.

We can thus say that the model suggests that while rapid technological innovation certainly contributed in a pronounced way to the overshoot of *capacity* and (and therefore precipitated the subsequent collapse in orders to the cable manufacturers), this evolution actually helped to cushion these manufacturers from a an even more pronounced swing in cable purchasing. When it comes to the "bullwhip" effect experienced by the cable manufacturers, the fact that a fast technological advance lowered the initial need for a rapid rise in orders in the early stage of the boom appears to have more than compensated for its contribution to a sudden drop-off in orders in the late stages of the boom.

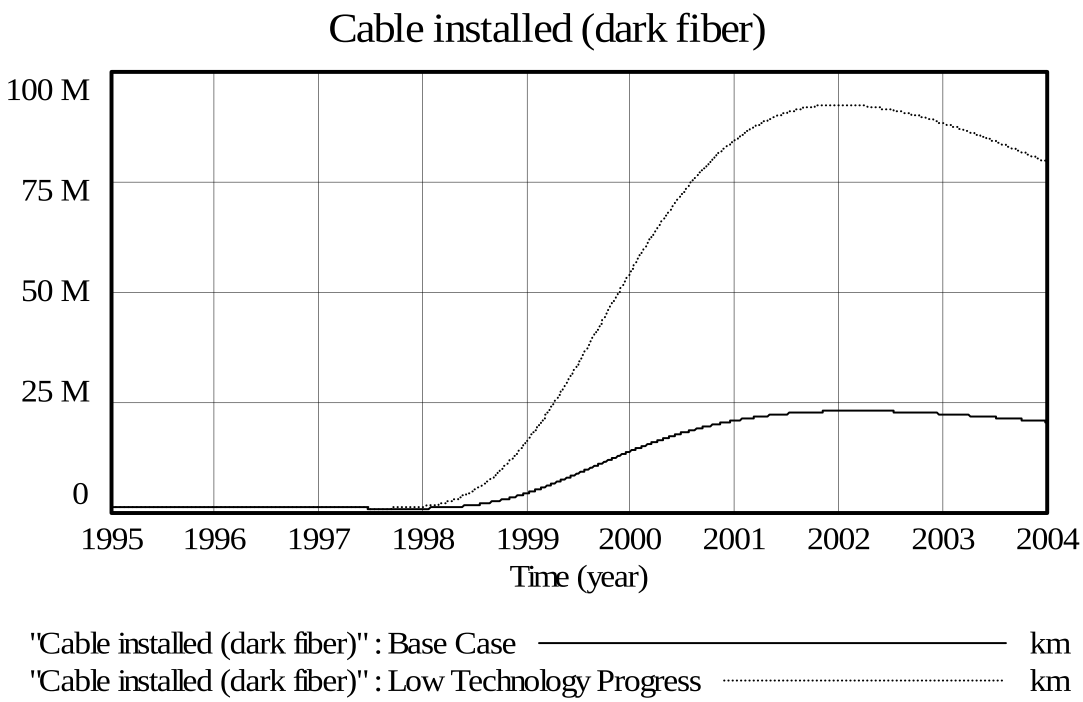

Figure 3-9 The impact of the rate of technology advancement on the total amount of dark fiber laid. As would be expected, a smaller technology advancement rate requires laying more physical fiber to meet perceived capacity needs.

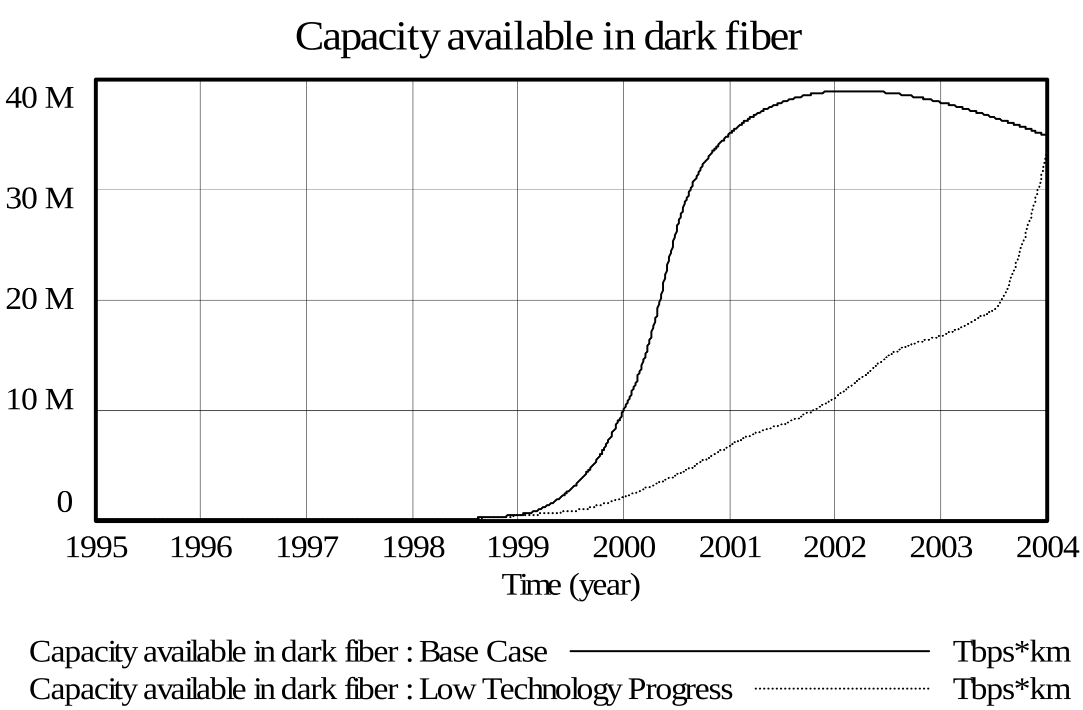

Figure 3-10 The impact of the rate of technology advancement on the *capacity* available in

the dark fiber

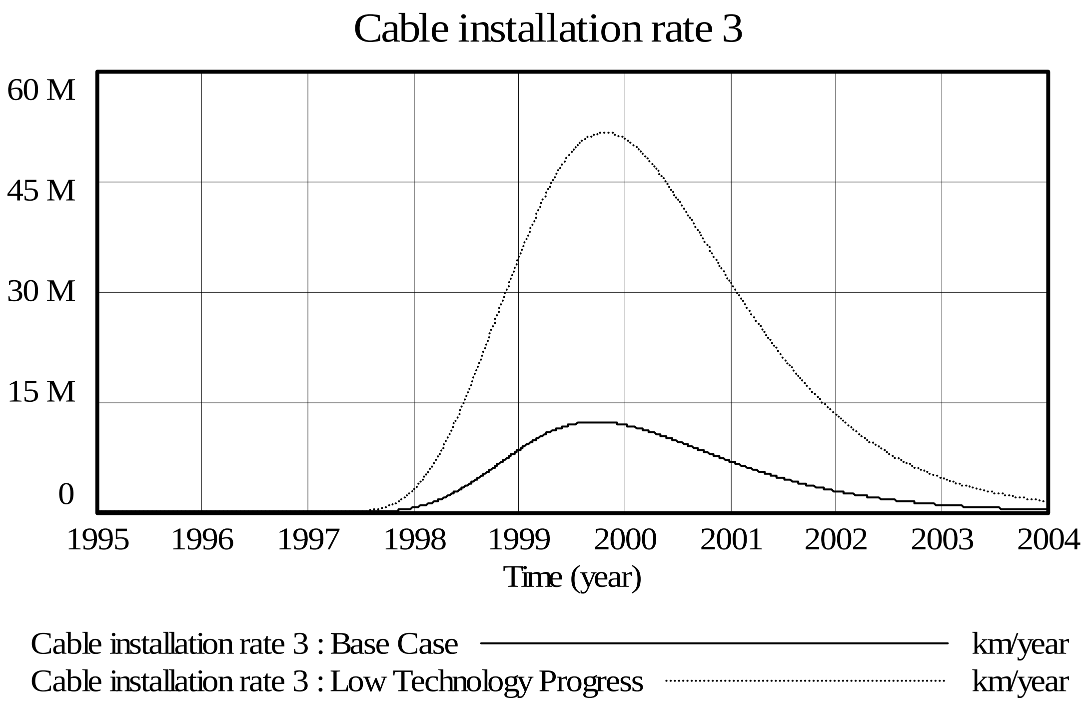

Figure 3-11: Impact of Rate of Technology Advancement on the Cable Installation Rate.

3.4 The role of construction cost

Some observers have argued that the high cost of construction relative to the fibers being laid had a large impact on the fiber glut. To investigate the sensitivity of the results to this parameter, we decreased the model parameter specifying the relative cost of construction by a factor of 3. The results of this experiment are shown in Figure 3-12 and Figure 3-13. The experiments suggest that the tendency to install large numbers of fibers in a given project in order to amortize the high costs of construction did indeed have a pronounced impact on the overshoot-and-collapse phenomenon. The masked some of the tendency of technology advance to mitigation of the fiber deployment in the actual telecom bubble. While high capital investment costs (such as may be imposed by the market or regulatory agencies) are often assumed to throttle an industry's rate of growth, the results of this scenario suggest that at least in some cases, certain forms of such costs can increase the risk of overinvestment by causing companies to elongate their planning horizons in an uncertain environment.

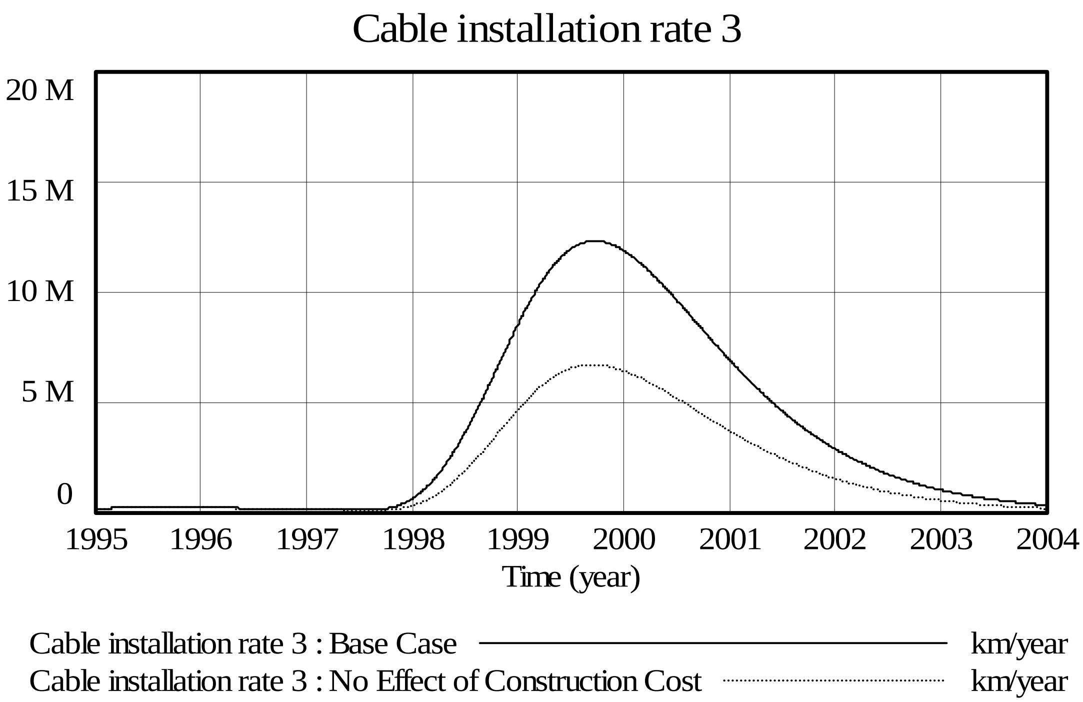

Figure 3-12 Impact of Lower Construction Cost on the Rate of Installing New Fiber

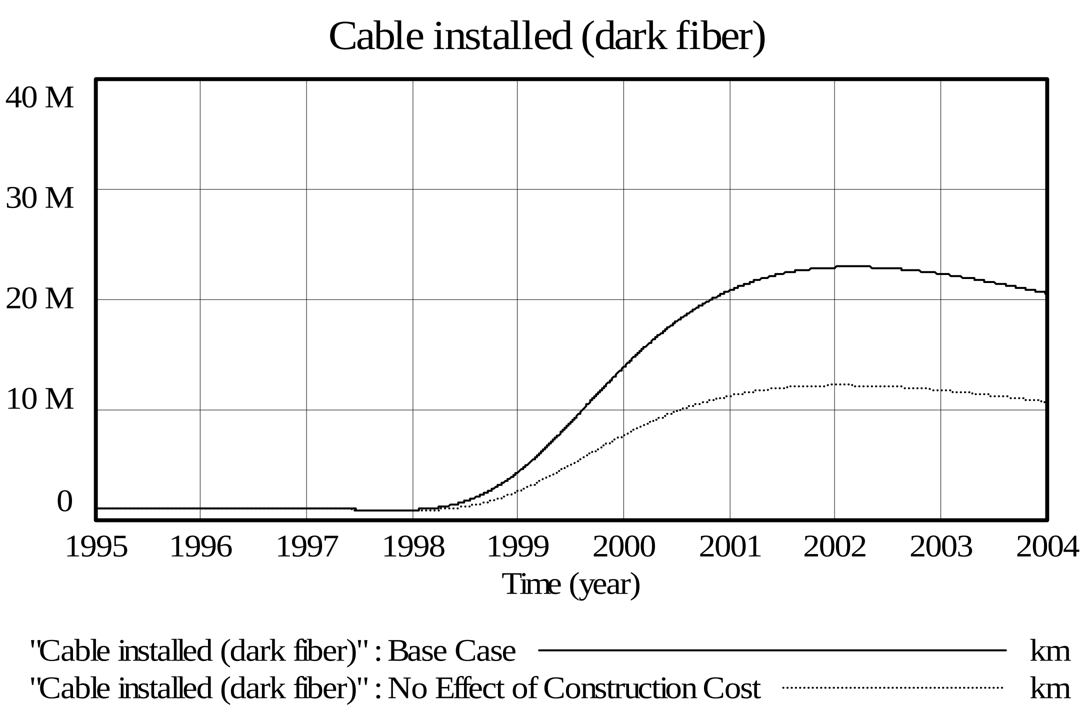

Figure 3-13: Impact of Lower Construction Cost on Dark Fiber Installation

3.5 The Impact of competition

Section 2.3 introduced the use of HHIs to capture competition effects. HHIs decreased over the course of the telecom bubble since new competitors such as Level 3 appeared and facility-based telecom service providers sold their own channels or fiber to their competitors. As previously explained, this increase in competition led to accelerating price reductions as HHIs decreased. In this section, we compare these historical dynamics with a hypothetical case in which both the number of competitors and their market shares – and thus the HHIs – remain constant throughout the period of study. Examining the dynamics of this counterfactual situation may help us to understand how the HHIs affected the telecom bubble.

Industry average price and revenue are shown for the base case and hypothetical scenarios in Figure 3-14 and Figure 3-15, respectively. Aggressive price reduction is not observed in the case of constant HHIs; the resulting price difference from the historical situation is large and continuously expands after 2000. Revenue shown in Figure 3-15 reflects this tendency, and revenue continuously grows in the case of constant HHIs. The results clearly suggest that competition factors induced a fierce price war and suggest this as the key reason behind the aggregate decrease in market revenue in the late stage of telecom bubble.

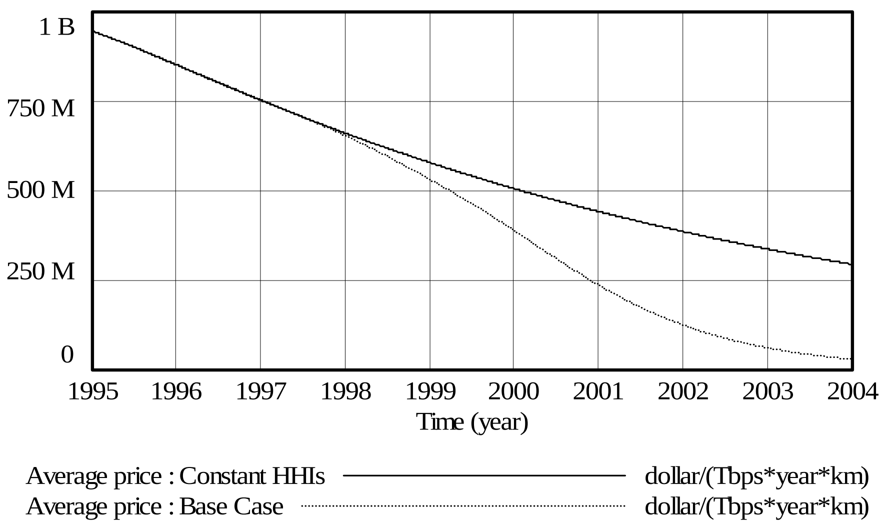

Figure 3-14 Average price (Real case and constant HHIs)

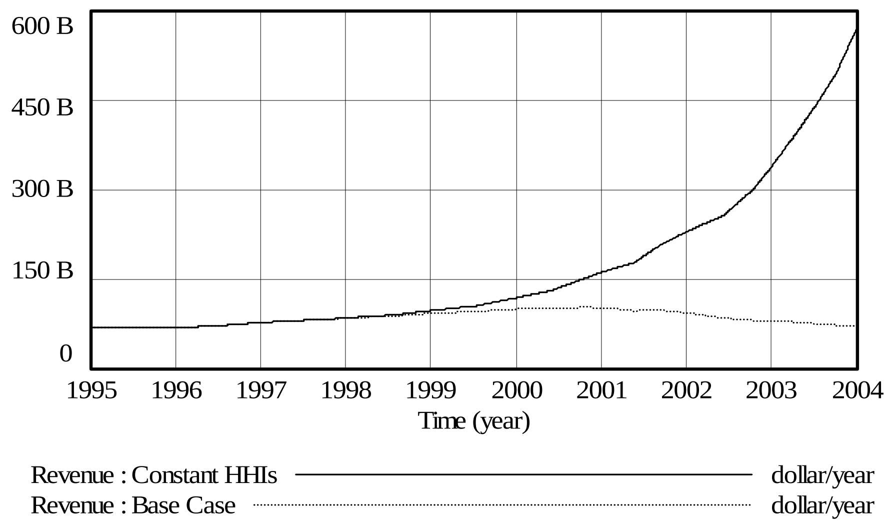

Figure 3-15 Revenue (Real case and constant HHIs)

The price and revenue dynamics seen above is determined by two factors, the competition factor and the cost reduction factor – themselves shown in Figure 3-16 and Figure 3-17. Figure 3-16 traces the price dynamics of the historical case in which a fierce price war occurred. Leading price by competition is smaller than the target price by profit basis throughout the years simulated. This means that price is determined by price setting based on the prevailing price rather than by the price setting based on target profit margin. By contrast, the price dynamics in the case of constant HHIs – shown in Figure 3-17 – shows that the although leading price remains determined based on prevailing price (rather than by target margin), leading price is not so different from – and converges on – the price setting based on the target margin. In this case, price reduction does not harm the telecom service providers and "healthy" competition occurs.

In the system dynamics model, we assumed that operating expense is simply in proportion to the cost to deploy a network. Therefore, the precise estimates associated with this result might not be quantitatively correct. However, circumstantially it seems to be correct that price setting was based on the prevalent price since the simulation result matched well with the real historical data, as shown in Figure 3-16.

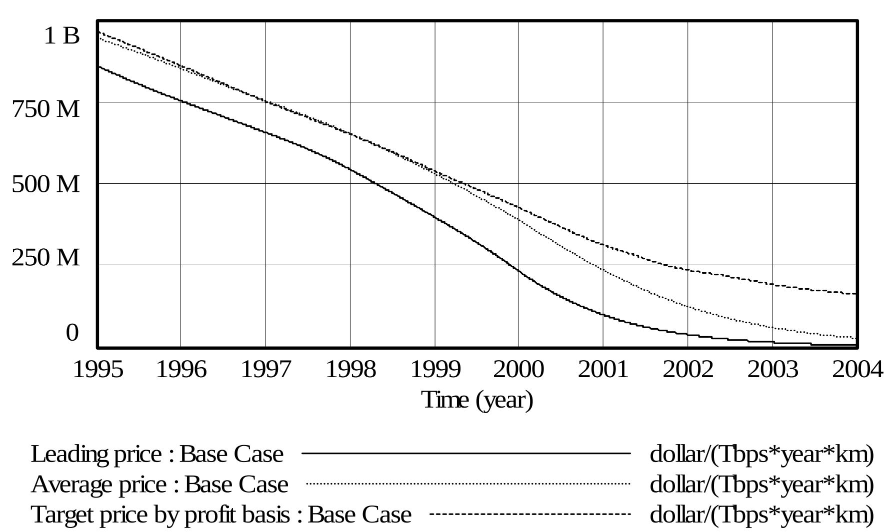

Figure 3-16 Price reduction by each decision rules (Real case)

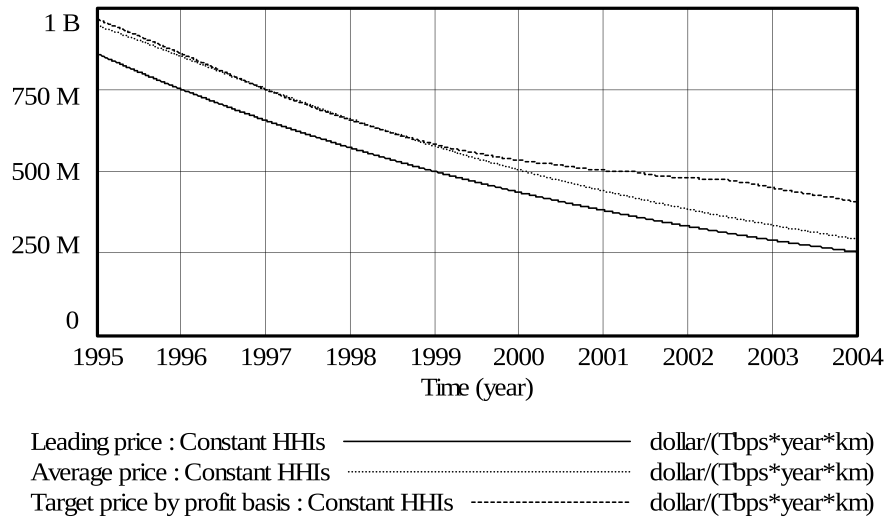

Figure 3-17 Price reduction by each decision rules (constant HHIs)

4 Conclusions

The previous section explored the numerical results of the telecom bubble dynamics using the system dynamics model to analyze real and hypothetical cases. The model captures well the amount of dark fiber in the late stage of the telecom bubble and the dynamics of revenue. The analysis suggests the following findings:

- Installation of excessive capacity can be lessened by forecasting demand in an aggregated fashion based on statistics for both voice and data communication demand. The demand forecast based on projections of Internet growth – notoriously difficult to estimate during the telecom bubble – tended to be misleading, and often grossly so. The acceptance of such poor estimation without close examination of their source and reliability contributed in a major way to bubble phenomenon. Careful cross-checking with other sources could have greatly reduced the errors associated with forecasting total demand.
- Excessive installation may also be avoided by setting a short planning horizon. While this policy increases flexibility and permits a more incremental rollout of capacity, this policy may not make economic sense for the individual companies since it risks an escalation of installation cost due to the fact that construction costs tend to dominate the fiber cable costs.
- The fact that internet demand growth was so widely discussed and speculated about itself amplified the tendency towards over-installation of capacity. Widespread anticipation of high levels of growth stimulated heavy levels of financial investment among individuals and institutions, and attracted a variety of new industry entrants.
- Capacity expansion in each fiber transmission line by the rapid development of WDM technology does not reduce the tendency to over-install capacity – but may have cushioned the impact of the bubble on upstream cable manufacturers by substantially lessening the *quantity* of fiber ordered.
- The aggregate analysis of competition based on HHIs suggests that fierce competition in

> the telecom bubble led to aggressive price decreases and reductions in the revenue of the industry in the late stage of the telecom bubble. Because of the long time delay between the launching of a capacity-expansion project and the time at which the capacity was installed, the business and technological climate and user demand can change dramatically over the course of a project. As a result, even the most nimble of companies may be faced with the necessity of completing projects that are no longer regarded as being needed.

Nobody knows the future. Therefore, we must rely on forecasts and expectations for decision making in many business situations. These forecasts might derive from the mental model of the decision makers based on their experience, or the characteristics of historical data related to their decision. Prior to the telecom bubble, telecom service providers could forecast the demand relatively using well-established statistical relationships, such as that between GDP growth and telecom service demand.

By contrast, emerging industries contain a lot of uncertainty, due many causes including complex non-equilibrium dynamics, because of the lack of reliable historical precedent, and because of uncertainty about factors such as demand and technology. As noted by Sterman [1] , behavior and expectations do adapt through learning – but only slowly. Whenever a new industry appears, many people view it as an opportunity and enter the industry seeking fortune. Often excess entry induces fierce competition, leaving only few companies to survive, as suggested by Utterback. Moreover, it is almost impossible to forecast correctly in the emerging industry, particularly for new entrants with limited experience in the new industry. As already noted above, telecom service providers made a fateful mistake by expecting Internet growth to continue its extraordinary growth rate in the mid-1990s, and the mistake was amplified by many factors, including their long planning horizon and the desire to minimize construction cost.

Nevertheless, as suggested in the previous section, from the point of view of the telecom service providers, it would appear that the decision making was not so irrational in the environment faced in the early bubble. However, there seem to be three important mistakes the service providers did make in the telecom bubble.

First, incumbent such as AT&T and MCI WorldCom did not share their data demand growth with the public – and in certain cases released wrong information – to the public as Odlyzko suggested in his paper in 2000 [18] . As a result, new entrants were not well informed about the real data demand growth, leading them to install far too much capacity into fiber network. While it may seem naïve for companies to share information on demand growth, a more accurate perception of demand growth for the broader industry could have helped greatly reduce the economic loss by the incumbents due to unhealthy competition and the precipitous industry shakedown once the bubble burst.

A second mistake occurred when the facility-based telecom service providers sold or rented their own network to resellers. Such a business strategy is effective in the short term since there was huge demand by the resellers. However, the medium-term consequences of this strategy were highly negative – the increase in the number of industry players induced greater competition, and aggressive price reduction ultimately reduced the revenue of the providers. If the number of competitors had not increased, the providers may well have been able to implicitly communicate with each other through pricing policy, potentially avoiding the excessive price war which was the only avenue to differentiation in the commoditized historical market.

The third mistake lay in the negligence of the market participants in failing to more closely examine the pedigree of and cross-check the data predictions released by industry analysis and other participants. The model results clearly suggest that even given conservative assumptions, the extraordinary overestimates of internet growth rates circulating during the period of 1998 and

1999 were likely to have greatly worsened capacity overinvestment. While the model suggests that the internet bubble would likely still have occurred in the presence of perfect demand information, it would have been far less costly.

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