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**The Effect of Access Regulation  
on Broadband Deployment**

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# The Effect of Access Regulation on Broadband Deployment \*

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**Abstract.** This paper studies empirically whether mandatory unbundling delayed the deployment of DSL service by BellSouth by exploiting a law change in Kentucky and variation in access prices across markets. I find that deregulation in Kentucky triggered deployment, but I find no evidence that access prices affected deployment pace. An upper bound on the welfare loss due to late deployment in rural markets is \$21 million. The findings are consistent with a positive effect of deregulation on the profitability of upgrades, but can also result from a strategic delay which is part of the bargaining between the firm and the regulator.

**Keywords:** Access regulation; Broadband; Hazard model; Technology adoption

**JEL codes:** L42, L43, L51, L96

## 1. Introduction

The provision of broadband Internet access over telephone lines required incumbent telephone companies to perform costly equipment upgrades. Due to access regulation the telephone carriers could not capture all the profits that such upgrades would yield; the Telecommunication Act of 1996 imposes access rules, which force the upstream telephone companies to lease all the elements of their local network and charge regulated prices. The retailers which lease the lines compete in the downstream market with the incumbent carriers. In the case of broadband, independent Internet Service Providers (ISPs) compete with the Bell companies in the provision of DSL service to consumers.

The access rules have two opposite effects on consumer welfare which are demonstrated in Figure 1. Once a telephone company upgrades the network in a certain market, consumers in that market benefit from access rules that enhance competition between ISPs and therefore increase consumer surplus. On the other hand, the expected competition and regulated access prices may decrease the returns of the incumbent from investment in network upgrades. As a result, the deployment of

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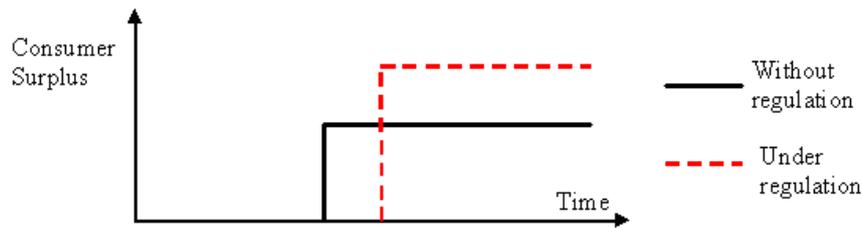


Figure 1. The Economic Tradeoff

the new service may be delayed in some markets, decreasing the surplus of consumers.

As a first step in quantifying this tradeoff I examine how the access rules affected the timing of upgrades in BellSouth Central Offices (COs) using two approaches. First, I study how deregulation in Kentucky, which released BellSouth from the requirement to provide access to downstream retailers changed the frequency of upgrades. Estimating a proportional hazard model allows me to separate between market covariates and changes in deployment pace over time. I find a large positive effect of deregulation on deployments rate. Second, I exploit variation across markets in the difference between the regulated wholesale price and the cost of upgrade. I do not find robust evidence that this margin affects deployment pace.

The increase in investment after deregulation is consistent with a positive effect of deregulation on the profitability of upgrades, but may also be a strategic response of the firm once its request from the regulator is accommodated. Delaying upgrades in profitable markets, puts pressure on the regulator to revise the rules. Thus, the estimates that I get are an upper bound on the effect of deregulation on pace of deployment. I use these estimates to calculate what would have been the deployment time profile without access regulation in rural areas. I find that regulation induced a welfare loss of at most \$21 million to BellSouth customers due to late deployment.

This analysis contributes to the empirical literature that examines the effects of the 1996 Telecommunication Act mandatory unbundling requirement on the market of ordinary telephone service.<sup>1</sup> Contrary to the previous literature in this area which focuses on the effects of the rule on downstream retailers behavior, my paper investigates the effect

<sup>1</sup> Greenstein and Mazzeo (2005), Crandall, Ingraham and Singer (2004) and Quast (2005a) study entry and investment decisions of Competitive Local Exchange Carriers (CLECs). Economides et al (2004) evaluate the effect of CLECs' entry on consumer welfare.

of the Telecommunication Act on the upstream incumbent decisions. I also build on the work that studies the effect of the access rules on broadband deployment. In Appendix A I present the arguments that are discussed in this mostly theoretical literature.<sup>2</sup> The third motivation is to approach empirically policies that trade off between firms' investment incentives and the extent of competition in the market. This question has been studied theoretically in contexts such as collusion in industries with intensive innovation and patent rules. While the theory is very rich, empirical work quantifying this tradeoff is scant.

The next section describes the data and the empirical approach. In section 3 I present the analysis of the law change in Kentucky, on which the welfare analysis in section 4 is based. Section 5 examines the relationship between wholesale prices and upgrades pace. Finally, section 6 concludes.

## 2. Data and Empirical Approach

The dataset combines three sources of information. The first source is the dates in which DSL service was available to consumers in each of 1603 BellSouth's central offices, which serve nine states. The data was downloaded in June 2005 from BellSouth's website.<sup>3</sup> The day in which the service was provided is the dependent variable in the estimated equations. Figure 2 shows a clear pattern: the higher the number of lines that a central office serves the earlier the deployment of DSL. Since we are interested in the effect of regulation on the timing of the incumbent's investment, ideally we would want to observe the date of investment. Using the day in which the service was offered as the dependent variable is based on the assumption that it is a good proxy for the time when the decision to invest was made.

The second source is information from an FCC report from 1999 that includes the total number of lines that each central office serves. These two sources were matched with the demographic characteristics of the city or town from the US 2000 Census. The variables from the census include educational attainment, income, age, as well as population and density of homes. In addition to the three main sources, FCC orders and BellSouth contracts with entrants were used to obtain information about regulation rules, and wholesale prices.

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<sup>2</sup> The only paper that addresses this question empirically is Wallsten (2005). He finds that most state policies that encourage broadband penetration are ineffective. The unit of analysis in his study is a state.

<sup>3</sup> By June 2005 1594 out of the 1603 central offices were upgraded

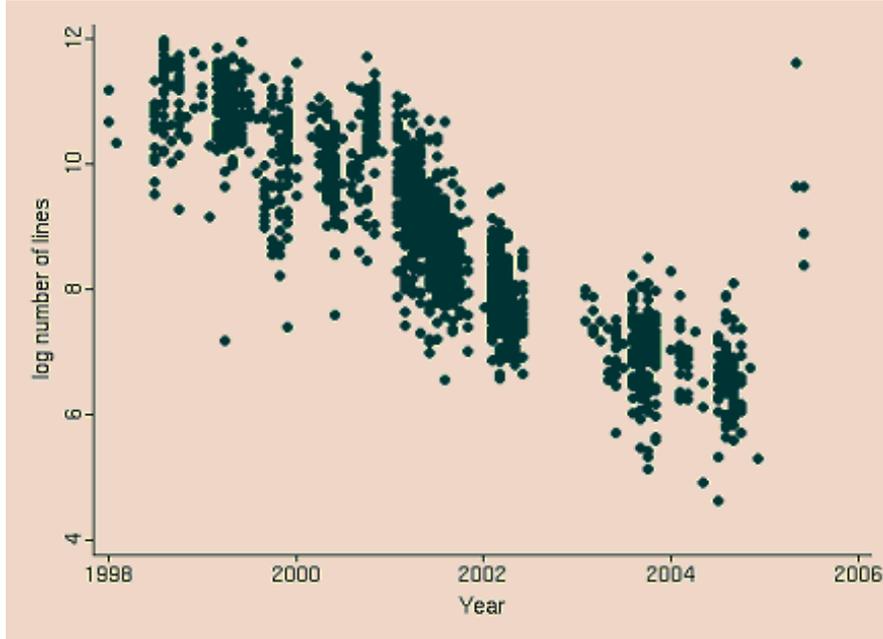


Figure 2. Central office size and time of upgrade

The goal of the empirical analysis is to infer from the central office upgrade dates how deregulation in Kentucky and different access prices across markets affected BellSouth behavior. A hazard model is a reduced form description of the solution to the firm's profit maximization problem. In the underlying model, the optimal day  $t$  for deployment in market  $i$  is the day on which the net present value of the project is maximal:

$$\max_t \pi(X_i, t) = \max_t R(X_i, t, \theta) - C \quad (1)$$

where  $X_i$  are demand characteristics of market  $i$ ,  $R$  is the present value of revenue and  $C$  is the fixed cost of upgrade, which is assumed to be constant across markets and over time. We expect demand characteristics to affect the deployment dates in the following ways. First, assuming that consumers willingness to pay for broadband access increases over time, a large market will become profitable before a market which has fewer consumers. Second, if the firm faces capacity constraints in terms of number of upgrades per time period, the profit maximizing strategy may be to sequence investments by market on the basis of expected revenue.

A hazard model is a suitable framework for quantifying the effect of the law change in Kentucky on the pace of deployments. A simple

regression, in which the upgrade time is the dependent variable, cannot separate between variation across markets and a time trend. A proportional hazard model estimates the effect of market characteristics as well as time trend on the probability of upgrade in each central office. The time trend, also called *baseline hazard*, reflects changes in deployment pace over time which cannot be explained by market covariates.<sup>4</sup> By comparing the baseline hazard in the periods before and after the law change, I investigate in Section 3 the impact of deregulation in Kentucky on the pace of upgrades. I use the baseline hazard in the period after the change to perform the counterfactual and welfare analysis in Section 4.

### 3. Kentucky Law Change

In April 2004, the Kentucky General Assembly voted to deregulate broadband. The goal of this decision was to accelerate broadband rollout in the state's rural areas. Because of its relatively low population density, broadband deployment in Kentucky was considerably slower than other states. In 2005, 25 percent of homes and small business did not have access to broadband service compared to less than 5 percent in the rest of the country. The 2004 decision provides us with an opportunity to examine how exempting BellSouth from following the access rules changed its deployment behavior.

The law change in April 2004 was followed by a surge in upgrades. Between August 2004 to December 2004 BellSouth upgraded 53 central offices in Kentucky and completed the rollout in the 179 COs of the state. The following facts suggest that the upgrades were a direct response to the law change. First, a year after the deregulation, Ellen Jones, the regional director for BellSouth, said the following about the law change in Kentucky: "BellSouth was reluctant to invest more money in broadband equipment in Kentucky when the state could try to control prices or require BellSouth to sell DSL service to competitors at discount prices... We would have expanded anyway, but it would have been at a much slower rate."<sup>5</sup> Second, the breaks in installations that we see in Figure 3 suggest that the reason that these COs were not upgraded earlier is not a constraint on the number of installations that the firm can perform each month.

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<sup>4</sup> Market covariate coefficients are identified from the sequence of upgrades, without using information about the actual dates. This allows a non parametric estimation of the baseline hazard. See Appendix B for a more detailed discussion of the hazard model assumptions.

<sup>5</sup> From "Broadband bound," The Courier Journal, September 25, 2005.

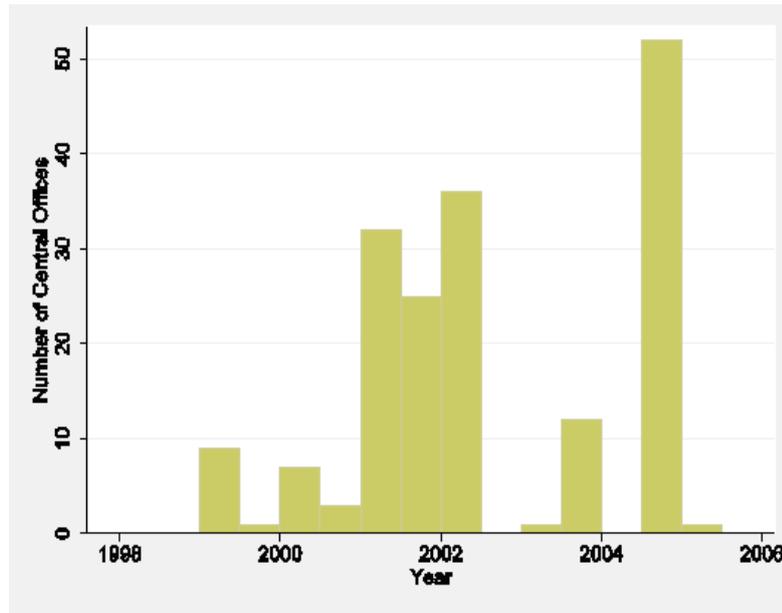


Figure 3. Histogram of Deployment in Kentucky

I separate between the effect of deregulation and market characteristics on deployment behavior using a three-step procedure. First a proportional hazard model is estimated, and the baseline hazard is calculated. Second the baseline hazard is smoothed with a Epanechnikov kernel. Third, the hazard is regressed on a constant and a dummy variable for the post law change period. The regression results, in Table I suggest that deregulation doubled the hazard rate. In Section 4 I use this result to perform welfare analysis.

Two factors may bias the estimated effect: anticipation of the legislation and strategic delay. If BellSouth predicted the change, it would have also accounted for it in the deployment decisions before April 2004. If it was the case that there was partial or full anticipation, the effect that we measure will be biased toward zero, since the expectations about future revenue were already internalized by BellSouth before the rule passed. A second source for bias is strategic delay. The naive interpretation for the break in upgrades between November 2003 and August 2004 is that these markets were not profitable under the old regime. Once the new law passed BellSouth started deploying the new technology in the COs that became profitable under the new regime. However, if we think about the interaction between BellSouth and the regulator as a regulatory bargaining, it may be in BellSouth interest

Table I. OLS Regression

<b>Dependent Variable: Baseline Hazard</b>		
	<b>Coef</b>	<b>t</b>
Deregulation	0.002744	7.14
Constant	0.002485	15.31

not to upgrade profitable markets, in order to increase the pressure on the regulator to revise the rules. If these tactics were operating, it would bias the measured effect upward, as some of the installations after the legislation would have been taken place even without a regulatory change.

When considering these two sources for bias, strategic delay seems more dominant. First, the long break in installations is more consistent with a story in which BellSouth halts upgrades to put pressure on the regulator to change the rules. Also, there is an explicit evidence that the issue was negotiated between BellSouth and the state.<sup>6</sup> Following these arguments I interpret the measured effect as an upper bound on the actual impact of the law change.

#### 4. Welfare Analysis

Given an estimation of the effect of deregulation on the frequency of upgrades we now turn to calculating bounds on the welfare loss due to late deployment. This exercise takes the shift in the baseline hazard as a reduced form representation of the increase in BellSouth expected profit as a result of the law change. Given the new regulatory regime, the firm updates its deployment strategy, and accelerates upgrades. By calculating the fitted value of the median deployment date in each market using both, pre- and post- law change baseline hazards, we find the predicted delay in each market due to regulation. As Figure 4 demonstrates, we can calculate an upper bound on welfare loss by multiplying the predicted delay with an estimate of the average consumer surplus from DSL line per unit of time.

When applying the welfare analysis to other markets which are served by BellSouth we have to consider to what extent they are similar

<sup>6</sup> "...[BellSouth] had promised it would speed up its DSL expansion if freed from government dictates." From "Broadband bound," The Courier Journal, September 25, 2005.

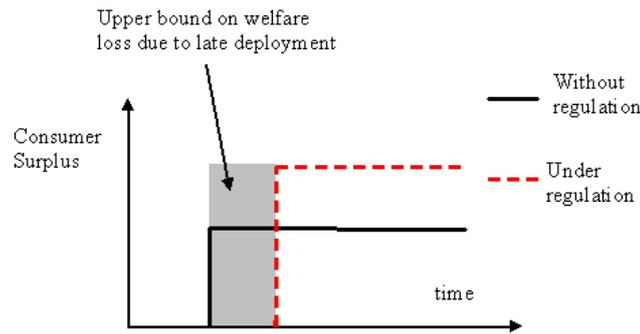


Figure 4. Welfare loss

to the markets in Kentucky which were affected by the law change. Deregulation was enacted after sixty nine percent of Kentucky customers had access to DSL, and it affected deployment in rural areas. Using the measured effect for counterfactuals in urban markets is justified only if we expect regulation to have the same effect on deployment pace in urban and rural areas. To account for the variation in costs and demand across markets, all COs in BellSouth territory were divided into four quartiles according to the total number of lines they serve. As figure 2 and the regression in section 5 demonstrate, number of lines is a very significant variable when predicting upgrade time and frequency. The first quartile includes COs with up to 3375 lines. These mostly rural markets are similar to the markets which were upgraded in Kentucky after the law change. The COs in the other quartiles are typically located in suburban and urban areas.

Welfare analysis requires information about the distribution of consumers' willingness to pay and retail price. Since the available data does not allow us to estimate the demand function, we use results from Goolsbee (2002) for assessing the surplus consumers derive from DSL service.<sup>7</sup> Goolsbee finds that under monopoly pricing, the average surplus of consumers who buy the service in San Francisco is \$48 a month. When incorporating this result in our calculation we have to consider the following factors. First, since 1998, when the survey was carried out, both the level and the distribution of the willingness to pay for broadband has been changed. In addition, San Francisco consumers are more wealthy and considered more technology savvy than consumers in the rest of the country (the median household income in San Francisco

<sup>7</sup> Goolsbee's paper estimates demand using survey data from Forrester's Technographics 1999 program, and compares between two approaches for subsidizing broadband: subsidizing usage and subsidizing investment.

Table II. Bounds on Welfare Loss

Central Office Quartile (ranked by num of lines)	Total Lines	Upper Bound on Welfare loss
Q1	up to 3375	21,200,000
Q2	3376 - 9429	33,822,222
Q3	9430 - 30624	71,022,222
Q4	more than 30624	153,333,333

is 55,221 compared with 32,000-42,000 in the states in BellSouth territory). The last concern is that while in Goolsbee's analysis the retail price is set by a monopoly, in many markets DSL service competes with broadband over Cables, so we expect lower prices.<sup>8</sup> Since these factors affect the \$48 estimation in opposite directions, and I cannot quantify the "net" bias, I will use the Goolsbee estimate as the average surplus of consumers in the welfare calculations.

The results for each quartile, are reported in Table II. They are based on calculating the consumer surplus loss  $W_i$  in each market:

$$W_i = Delay_i * Lines_i * 0.05 * \$48 \quad (2)$$

where  $Delay_i$  is the predicted adoption delay. It equals the difference between the fitted value of deployment under regulation and deregulation.  $Lines_i$  is the number of phone lines in central office  $i$  and 5% is the proportion of telephone lines that provide DSL.<sup>9</sup> The conservative calculation, which applies deregulation only on the rural markets, suggests that access regulation induced a consumer surplus loss of \$21 million due to late deployment. If we replicate the effect for the entire BellSouth market, the total loss is \$279 million.

## 5. Variation in Regulated Access Prices

Next, I explore the variation in the margin between regulated wholesale prices and upgrade cost to further study the relationship between access regulation and deployment pace. According to the Telecommunication Act of 1996 the Public Utility Commission (PUC) of each state fixes the access prices that incumbents can charge for leasing network elements

<sup>8</sup> As a reference, in a duopoly market with linear demand curves and Cournot competition consumer surplus is 16/9 times bigger, than in the monopoly case.

<sup>9</sup> This number is based on information from BellSouth Quarterly earning reports.

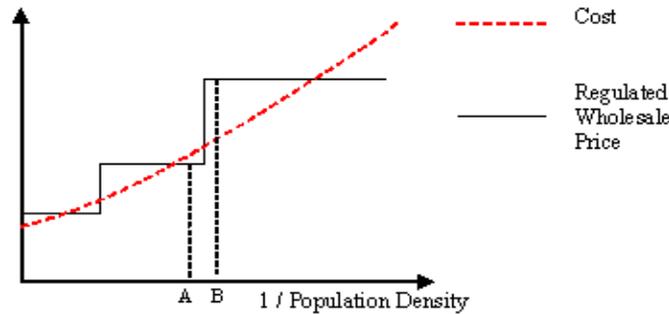


Figure 5. Qualitative Description of Wholesale Prices and Upgrade Costs

to retailers. Since the prices are set independently by each PUC they vary across the nine states that BellSouth serves. Moreover, each PUC classifies each central offices in its state as urban, suburban or rural. For each one of the three zones the PUC sets a different price that reflects the fact that installation and maintenance costs increase when population density decreases.<sup>10</sup>

We expect that conditional on demand characteristics, the difference between wholesale price and the cost of upgrade is positively correlated with early deployment. Everything else equal, BellSouth would prefer to upgrade first markets for which this margin is bigger. It is less likely to face competition in these markets as the costs of operation for potential entrants are higher. Even if competitors enter, the revenue from leasing the lines is higher. To test this prediction we need variation in the margin between wholesale prices and costs. While ideally wholesale prices perfectly reflect the incumbent's costs, in practice there are gaps due to two factors. First, dividing each state to three zones does not allow perfect pricing as demonstrated in Figure 5. In this case for example, we expect BellSouth to upgrade market B before market A. While in terms of cost they are very similar, the wholesale price in market B is significantly higher, and consequently BellSouth faces less competition in the retail market.

The second source for discrepancies between costs and wholesale prices is political power. Quast (2005b) and Rosston et al (2005) find that political affiliation of the governor and state regulators may affect

<sup>10</sup> For example, the wholesale price per month of a "2 wire DSL compatible line" in zones 1, 2 and 3 in Florida in 2001 were \$11.52, \$15.96 and \$30.19, respectively.

wholesale rates. Therefore, there may be variation in prices across states that reflect other factors besides costs.<sup>11</sup>

I exploit these two sources of variation by estimating a hazard model of upgrades with wholesale price as a regressor in addition to demand and cost variables. I use access prices as listed in is the agreement that BellSouth and Covad, the largest independent broadband retailer in the US, signed in October 2001. Prices for earlier periods are not available, therefore the model is estimated with the full sample and also with a sub sample that includes only upgrades that took place after October 2001. Each sample is estimated with and without state fixed effects.<sup>12</sup>

The coefficients, reported in Table III, represent the effect of each variable on the hazard ratio. Variables with a coefficient which is larger than one have a positive effect on the pace of upgrades. Under the hazard model assumptions, a change in the value of a variable affects the probability distribution of the upgrade day (as opposed to changing only the mean in standard regression). In order to give the coefficients a duration interpretation it is useful to use the fact that for Exponential hazard model with hazard ratio  $\lambda$  the median duration (in days) is  $M = \ln 2/\lambda$ .

The regression controls for cost by using the *City houses density* variable and for demand by including income, age and market size variables. As we would expect, the results indicate that a higher median income is associated with an increase in the upgrade hazard. The percentage of families in poverty also has a positive effect on the hazard, which is the opposite of the expected, perhaps resulting from the high proportion of poor people in urbanized areas. The estimates of the age coefficients results are intuitive. They suggest that a high proportion of people age 25-44 is associated with high hazard rate. The coefficient of log the number of lines is the most significant with a strong positive effect on the hazard rate. The number of lines is also included in order to allow a more flexible effect. It has a negative effect on the hazard rate, but the total effect of number of lines is positive and significant. The number of lines is the best proxy in the data for market size.<sup>13</sup>

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<sup>11</sup> Prices may be endogenous if the regulators in states, in which deployment is slow because of factors that we do not observe, try to encourage upgrades by increasing prices. Due to this concern the preferred specification includes state fixed effects.

<sup>12</sup> The matching between the COs and demographics is based on city or town name. This process is sensitive to the spelling of the names, thus 1159 observation were matched.

<sup>13</sup> Other papers that study empirically broadband availability find similar results. Augereau and Greenstein (2001) and Gabel and Kwan (2002) report that high-speed access to the Internet is more likely to be available in urbanized area. Prieger (2003) finds that in rural areas the availability is lower, and education increases availability.

Table III. Proportional Hazard Model with Access Price

	Dependent variable: Deployment Day							
	Full Sample 1113 Obs.				Sub Sample 268 Obs.			
	1		2		3		4	
	<b>Haz.</b> <b>Ratio</b>	<b>z</b>	<b>Haz.</b> <b>Ratio</b>	<b>z</b>	<b>Haz.</b> <b>Ratio</b>	<b>z</b>	<b>Haz.</b> <b>Ratio</b>	<b>z</b>
City population*	1.0028	9.78	1.0025	9.58	0.9676	-2.48	0.9631	-2.88
City houses density*	1.4424	7.31	1.2571	4.89	1.2696	0.85	0.8667	-0.51
Income median hh*	1.0392	5.74	1.0348	5.16	1.0182	0.93	1.022	1.17
Per. families in poverty	1.0141	1.83	1.0177	2.35	1.0156	1.11	1.0231	1.71
Per. age under 18	1.0107	0.92	1.0217	1.93	1.0131	0.58	1.0192	0.9
Per. age 18-24	0.9522	-4.08	0.9459	-4.72	1.005	0.13	1.0065	0.18
Per. age 25-44	1.04	3.91	1.0532	5.37	1.0434	1.99	1.0225	1.05
Per. age 45-64	1.0342	2.01	1.0357	2.14	1.0489	1.44	1.0217	0.67
Per. less 9 years educ	0.9928	-0.96	1.0005	0.07	0.9918	-0.7	0.9982	-0.16
Per. educ. bachelor	0.9931	-1.13	0.9963	-0.62	1.0046	0.26	1.0174	1
Total lines*	0.9882	-4.77	0.9874	-5.27	0.9751	-2.4	0.9809	-1.78
ln(Total lines)	3.2999	18.55	3.056	18.02	2.8588	7.81	2.3917	7.34
Access price	1.0189	2.44	0.9931	-1.23	1.1063	4.43	1.0196	1.79
AL	1.1218	0.89			1.234	0.79		
FL	0.5219	-4.67			0.8024	-0.59		
GA	1.1511	1.12			3.7555	4.64		
KY	0.938	-0.5			0.4032	-3.68		
LA	1.361	2.27			2.0371	2.28		
NC	1.5339	3.18			7.8058	3.84		
SC	0.8689	-0.99			0.4516	-2.4		

\* In thousands

The preferred specification is the one with the full sample and state fixed effects and is reported in column 1 of Table III. The estimation with the sub sample yields coefficients with a sign which is opposite of what we would expect for the *City population* variable. Also the coefficients of the income variable are not significant, while in the full sample they are strongly significant. It may be the case that the sub sample, which includes installations from the late period of deployment, suffers from selection bias and therefore I choose to rely on the full sample. The full sample estimation with state fixed effects is preferred over the one without them (Column 2) since states policies may be

correlated with unobserved variables. Without fixed effects, the access price coefficient may be biased downward, since PUCs in states where the deployment is slow may encourage it by increasing access prices in order to make investment more profitable for BellSouth.

The coefficient of interest is *Access price*. In Column 1 wholesale prices have a positive effect on the upgrade hazard. This implies that within a state, everything else equal, higher access prices induce earlier deployment. An increase of \$1 in the access price makes the deployment hazard 1.0189 times bigger. This means for example that three years after the rollout starts, the probability to remain without the new technology decreases by about 5 percent. The coefficient of access price in the specification without state fixed effects (column 2) is negative, which implies a negative effect on the hazard rate.

The results in this subsection provide some evidence that BellSouth deployed DSL faster in markets in which the regulated access price were higher. However, the effect is small in magnitude and is not robust.

## 6. Conclusions

This paper has investigated the effect of mandatory unbundling on the deployment of DSL technology by BellSouth. The analysis finds clear evidence of a positive effect of deregulation on deployment pace in rural areas. Counterfactual calculation suggests that if the DSL market were deregulated, the surplus of BellSouth consumers in rural areas would have increased by \$21 million. The findings are consistent with a positive effect of deregulation on BellSouth profitability, but can also result from a strategic delay which is part of a bargaining between the firm and the regulator.

This paper contributes to the literature that studies the outcomes of the Telecommunication Act of 1996 by focusing on its effect on incumbent strategies. Also, while many scholars have examined the adverse effect of mandatory unbundling on deployment from a theoretical perspective, this is the first empirical study which investigates the effect of access regulation on the incumbents investment in broadband technology.

In addition, the paper builds on the economic literature, which studies the trade-off between firms' investment and competition. The results suggest that policies that encourage competition in the market may be costly as they may affect firms' investment strategies. Thus, policy makers when setting such rules should balance carefully between the increase in consumer surplus due to competition and the decrease in surplus caused by delayed investment.

## Appendix

### A. Theoretical Background

Two theoretical regulatory questions are in the background of the analysis. The first, which is not investigated empirically in this paper, is under what circumstances in terms of technology, costs, demand and contract availability and enforcement, should access regulation be imposed? Communication services can be provided by either a fully integrated network, or by independent suppliers which provide service in the network different layers. Access regulation separates the layers and allows multiple providers to participate in the vertical chain under terms which are subject to the regulator's control. Noll (1995, 2002) discuss the benefits from integration, such as better efficiency through economies of scale and scope, and its costs; for example, exploiting the integration to extend monopoly power into vertical related markets.

The second theoretical issue is how the regulator should set the wholesale prices, so that the incumbent investment incentives are not distorted? The FCC implementation of the Telecommunication Act sets wholesale prices according to the Total Element Long Run Incremental Costs (TELRIC) scheme. This framework sets the rental rate for each network element equal to the incremental cost of creating and supplying that leased element if the network owner were designing and constructing a completely new, optimally configured network. Pindyck (2005) argues that this approach under-compensates the incumbents because it does not account for the risk that the incumbent bears. According to Pindyck, while the sunk cost of a telephone company is lost if there is no demand for the new service, an entrant gets the option to stay outside if market conditions are bad or to enter if they are favorable. The TELERIC price does not include the value of this option. Thus, Pindyck argues, TELRIC under-compensates the incumbent, and consequently decreases its capital investment. Other analysts believe that this potential under-reimbursement is offset by a corresponding increase in the allowed cost of capital; for higher risk levels the rental rate that the regulator sets is higher. To the extent that BellSouth's upgrades decisions are based on the profitability of each market (as opposed to a strategic considerations) evidence of a negative effect of regulation on deployment is consistent with Pindyck's argument.

## B. Hazard Model Assumptions

A hazard model allows estimating both the effect of the demand covariates and a time trend. Denoting the cumulative probability that DSL is offered at time  $t$  in market  $i$  by  $F_i(t)$  and the density function as  $f_i(t)$ , the hazard function  $\lambda_i(t)$  is defined as the probability that service will be offered at time  $t$  given that it was not offered before:  $\lambda_i(t) = f_i(t) / (1 - F_i(t))$ . The hazard function is specified with a proportional hazard form:  $\lambda_i(t) = \lambda_0(t) \exp(X_i\beta)$ . The proportional hazard model is not based on any assumptions concerning the shape of the underlying survival distribution. By estimating the covariates effect with Cox's partial likelihood estimator we can derive the non parametric baseline hazard. The covariates coefficients  $\beta$  are identified only by the order in which COs with different characteristics are upgraded, without using information about the actual dates. This allows non parametric estimation of the baseline hazard.

This approach requires a few assumptions. First, it makes the proportionality assumption, which means that the ratio of the hazard function for any two observations does not depend on time. In the context of the underlying model discussed above, this means that the relative profitability of two markets is constant over time. In other words, changes in the level of demand over time are equal across markets.

Another limitation is the use of a single value for the covariates in all periods. This implies that the demand variables from the US 2000 Census are a good proxy for the expected revenue during the deployment period 1998-2005. As long as there are no systematic changes in demographic variables over time this assumption holds. The last assumption is that censoring is independent of upgrade hazard. It implies that central offices in which DSL was not deployed have the same upgrade distribution as non-censored observations.

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