DO SWITCHING COSTS MAKE MARKETS MORE OR LESS COMPETITIVE?: THE CASE OF 800-NUMBER PORTABILITY*

Abstract

Do switching costs reduce or intensify price competition in markets where firms charge the same price to old and new consumers? The answer is theoretically ambiguous because a firm prefers to charge a higher price to previous purchasers who are "locked-in" and a lower price to unattached consumers who offer higher future profitability.

800-number portability provides empirical evidence to determine whether switching costs reduce or intensify price competition under a single price regime. Before portability, a customer had to change toll-free numbers in order to change service providers. In May 1993, 800-numbers became portable, under a regulatory regime that precluded price discrimination between old and new consumers.

I test how AT&T and MCI adjusted their toll-free services prices in response to portability. I find that the firms reduced prices with portability, implying that the switching costs arising from non-portability made the market less competitive. Thus, despite rapid growth in toll-free services, the firms' incentives to charge a higher price to "locked-in" consumers exceeded their incentive to capture new consumers.

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Firms offering products with significant switching costs generally prefer to charge a higher price to existing customers who are "locked-in" and a lower price to unattached consumers who offer higher future profitability. However, transactions costs, regulatory constraints or the ability of customers to arbitrage price differences may prevent firms from charging different prices to new and existing customers. Nonetheless, the previous empirical switching costs literature has primarily examined firms engaged in differential pricing. In this paper I take advantage of a unique situation in which switching costs changed to determine its effect on prices in a single-price regime. To inform my estimation, I extend previous theoretical models to develop an estimable empirical model. Models in which firms charge a single price have been limited to two-period models or models in which switching costs are assumed to be high enough that no customers switch in equilibrium. I develop an infinite-horizon model that allows for actual switching in equilibrium.

In the model, an increase in switching costs may lead to either an increase or a decrease in equilibrium prices. The net effect depends on the relative number of old and new consumers and the importance of "lock-in" relative to the incentives for attracting new consumers. I test the effect of switching costs on competition in the high-growth, toll-free services market. To justify the applicability of the theoretical model, I provide evidence of significant switching in this market and show that characteristics of prices are consistent with the model's implications. Since rapidly growing markets have a greater proportion of new consumers, there is a higher probability that switching costs will lead to increased price competition. In spite of this rapid growth, I find that switching costs led to lower competition for toll-free services.

Originally, users of 800-, or toll-free, service could not switch providers without changing their telephone number. The introduction of portability on May 1, 1993 reduced switching costs at the same time as regulatory restrictions required firms to charge the same price to new and existing consumers. Controlling for other factors, declines in price resulting from portability is evidence that switching costs make markets less competitive, while increases in price would be opposing evidence.

Portability lowered prices for both types of toll-free services I examine, implying that higher switching costs under non-portability made the market less competitive. First, I use contracts for AT&T virtual private network (VPN) services, a bundle of long-distance services offered to large users. Estimating the policy function implied by the theoretical model and taking advantage of the fact that the data provides actual marginal cost, I find that VPN contracts constrained by non-portability had significantly higher prices than those unconstrained by non-portability after controlling for cost. I use contracts that contained no toll-free services as a control group (the other services were always portable) and find that the prices on these contracts were not significantly affected by portability. Second, I use prices for stand-alone (unbundled) services offered by both MCI and AT&T. Again estimating the policy function and controlling for cost, I find that prices for toll-free services dropped after portability in a manner consistent with higher prices due to switching costs. Moreover, portability had no significant effect on prices for toll services (which were always portable).

The magnitude of the effect on the average VPN and stand-alone toll-free users is approximately the same once I adjust for the fact that toll-free services comprise only a portion of VPN contracts. I estimate that portability lowered toll-free prices by approximately fourteen percent for the average consumer. For larger VPN users, the effect is much greater, consistent with large users being more "locked-in." I offer evidence that these effects are not due to confounding events, including AT&T's loss of monopoly power over vanity numbers and changes in regulation. The results indicate that AT&T's and MCI's incentive to charge higher prices to existing consumers subject to the high switching costs of non-portability exceeded their incentive to "capture" new users by charging lower prices. Given the rapid growth in 800 services during this period (AT&T's toll-free minutes grew over fourteen percent per year), switching costs are likely to increase prices in single-price markets with lower growth rates.

Because it is difficult to measure switching costs, tests of single-price switching costs models are few.[1] Sharpe (1997) tests the Klemperer (1987a) result that prices are more competitive the greater the consumer turnover in a market. Sharpe finds that the degree of migration into or out of a local market has a positive effect on bank deposit interest rates paid to depositors. This does not address the overall effect of switching costs on prices, the question of this paper. Kim, Kliger and Vale (2001) employ an Euler equation approach to estimate switching costs and probabilities from aggregated data in a panel data set of Norwegian banks. Their paper provides a methodology for inferring switching costs levels from price and aggregate share movements rather than using a change in switching costs to infer its effect on prices as I do. Knittel (1997) finds that higher fees charged for switching long-distance providers is associated with greater margins for the long-distance providers. However, the empirical setting does not offer a natural control group, the role played by toll services in this paper, which makes it difficult to control for other changes. This is important given the variation in switching costs occurs over time.

In the next section I provide background on the toll-free services industry. Section 2 develops a theoretical model of switching costs. In Section 3, I describe VPNs and the data. Section 4 describes the econometric tests and empirical results, and I conclude in Section 5.

1. Toll-Free Services and Portability

After the divestiture of AT&T in 1984, other inter-exchange carriers (IXCs) were legally allowed to provide 800- or toll-free service.[2] However, the District Court charged with overseeing AT&T's breakup ruled that AT&T retained patent rights over the database technology that enabled local exchange carriers (LECs) to switch toll-free calls to different

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[1] Three other studies look at contexts in which firms can price discriminate between old and new consumers (dual-price models). Borenstein (1991) finds that gasoline stations price discriminated against consumers of leaded gasoline to exploit the increased switching costs imposed on these consumers as the stations phased it out in favor of unleaded gasoline. Calem and Mester (1995) test for switching costs in the credit card industry. Elzinga and Mills (1998), using transaction-level data on wholesale cigarettes, show that customers exhibiting characteristics associated with high switching costs are less likely to switch to a new entrant during a price war.

[2] The service is often called 800-service because all toll-free numbers originally began with the numbers "800." Toll-free numbers now also begin with "888," "877" and "866."

IXCs.[3] In 1986, the Federal Communications Commission (FCC) decided, as an interim measure, that toll-free calls would be routed based on the next three digits after 800 (800-NXX-YYYY), referred to as NXX screening. The FCC assigned each IXC one or more NXX prefixes for use in 800-service, and the LECs routed all calls beginning with "800-NXX" to the IXC assigned that NXX code. Although NXX screening allowed entry, the method imposed substantial switching costs on toll-free users. Because of the dependence on NXX, a user who wanted to switch carriers for its toll-free service had to switch numbers. Because firms usually publish 800-numbers widely, imprinting them on stationery, advertisements and business cards, the cost of changing numbers is significant.[4]

The FCC required the LECs to install a new switching system on May 1, 1993, a byproduct of which was that it allowed them to assign and route any 800-call to any IXC.[5] Users were now able to switch providers without changing their phone number. Switching costs did not drop to zero after portability – there were still costs of renegotiating a contract, running a redundant parallel system during the transition and relationship-specific costs. Nonetheless, switching costs were much lower than under non-portability. Most popular articles published prior to portability speculated that portability would lower prices for toll-free services.[6] This view has prevailed in academic articles published since portability. Both Ward (1993) and MacAvoy (1995) cite portability as a reason to expect more competition for 800-services. Despite these references, no academic studies have rigorously analyzed the effect of portability on price competition.

Since comprehensive data on switching by toll-free customers is not available, I gathered evidence of whether non-portability precluded switching altogether. I identified all firms with

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[3] The difficulty in switching toll-free calls was that the recipient of the calls pays so that the LEC could not simply route the call to the initiator's chosen long-distance provider.

[4] For statements in the popular press describing these switching costs, see: "Carriers Plot Strategies at Dawn of War Over 800 Users" (*Network World*, November 9, 1992), "Firm Predicts Savings With Tariff 12 Net" (*Network World*, February 12, 1990), "Net Users Remaining Loyal After AT&T's Recent Outage" (*Network World*, January 29, 1990), *Telecommunications Market Sourcebook* (Frost & Sullivan, 1995).

[5] As I explain below, portability was not the primary intent of the new switching technology.

[6] See "Portability Sparks Price Wars" (*Catalog Age*, May 1993), "Airlines + Price Wars = Big 800 Traffic" (*800-900 Review*, Strategic Telemedia, May 1, 1992), "Portability Adds Fuel to 800 Fire" (Karen Burka, *Catalog Age*, October, 1992).

sales over five million dollars in successive editions of *The Directory of Mail Order Catalogs* and traced the ownership of their 800-numbers over time based on NXX codes. I focused on only the largest mail-order firms since they were most affected by non-portability. As Table 1 shows, a significant percentage of customers of the later entrants (MCI and Sprint) switched from AT&T, although the sample size is admittedly small. The fact that no users switched to AT&T is reasonable given the small sample size and the fact that fewer consumers would switch to a long-established incumbent.

I cannot perform this analysis post-portability because NXX codes no longer map to specific carriers and no comprehensive toll-free directories are available. I have to rely on (potentially biased) reports of significant switching made by the IXCs themselves.[7] This evidence of switching pre- and post-portability dictates a theoretical model that allows for equilibrium switching.

Switching costs can lower prices in a dynamic setting only if the number of new consumers is sufficiently large relative to the number of old consumers. The data indicate that toll-free minutes grew almost nine-fold from 1985 to 1999. This measure does not reveal whether new or old consumers generated this growth, but the growth rate is sufficiently high that decreased competitiveness resulting from switching costs is plausible.

2. Theoretical Model

The primary purpose of the theoretical model is to provide a basis for empirical estimation, a policy equation that I can estimate. Given this, I focus only on results relevant for my empirical application rather than comprehensive analysis. The secondary purpose is to show, in a model that accurately reflects the empirical setting, that when firms are constrained to charge a single

[7] AT&T claimed that 10,000 users representing over $140 million in revenue switched their numbers to its service, while MCI claimed 6,550 users representing over $170 million and Sprint "several thousand" customers. ("Winds of Change Sweeping Over Cooped-Up 800 World," *Network World*, May 3, 1993). AT&T also claimed that it had retained 505 out of 531 users of and MCI claimed it had gained $500 million in new commitments (not annualized) for VPN services since portability. ("AT&T & MCI Report 'Fresh Look' Results," *Internet Week*, August 9, 1993).

price to all consumers, an increase in switching costs can either increase or lower prices. Previous theoretical work suggests that the *presence* of switching costs has an ambiguous effect on price competition when firms charge the same price to all consumers.[8] The results are only suggestive because they are derived from two-period models that suffer from an "end-of-the-world" effect or models that assume switching costs are so high that no consumers switch in equilibrium. Klemperer (1995) provides a review of many of the switching costs models.

Two-period models, such as Klemperer (1987a), do not fully capture the dynamic effect of switching costs on prices. In the first period, the firms face demand only from unattached consumers. The second period contains both new and old consumers, but an "end-of-the-world" effect distorts the firm's pricing. Because new consumers in the second period are never valuable as repeat consumers, the firm has no incentive to price lower to capture them. Previous infinite-horizon models (Beggs and Klemperer (1992)), on the other hand, assume switching costs are high enough that consumers never switch. In this case, the level of switching costs does not affect prices because all consumers are "locked-in" over the range of switching costs. Since toll-free customers switched both before and after portability, a model of complete "lock-in" is refuted. In the following model, some consumers switch in equilibrium so that I can study changes in the level of switching costs.

The model extends Klemperer's (1987a) two-period model into an infinite-horizon, overlapping-generations model and employs a solution technique similar to that in Beggs and Klemperer (1992). The latter authors consider, as I do, two differentiated product firms facing new and old consumers in each period of an infinite-horizon model. However, unlike their model, I do not assume full "lock-in."

I consider two infinitely lived firms, which I will refer to as AT&T and MCI since they provided most of the toll-free services during the period of my study and constitute the data. I assume the

[8] There are also switching costs models that consider third-degree price discrimination (see Chen (1997), Nilssen (1992) and Taylor (1999)) and endogenous creation of switching costs (see Caminal and Matutes (1990)).

firms' 800-services are horizontally differentiated. AT&T and MCI's physical infrastructures were nearly identical because they both used the LECs' switching network for local access and their long-distance backbones were similar; however, their billing and support services differed. I model this differentiation by locating the firms at the extremes of a unit Hotelling (1929) line. I assume the firms are symmetric except in their initial market shares. The model can accommodate (at the cost of more complicated exposition) vertical quality differences between the firms as long as consumers are homogeneous in their taste for quality. I comment later on the effect this would have on the theoretical results and how I allow for this possibility in my estimation.

Although users of 800-services are primarily firms, I will refer to them as consumers to distinguish them from the telecommunications providers (firms). Consumers incur differentiation costs linear in their distance from the firm. Without loss of generality, I normalize the differentiation costs to one. Thus, if a consumer located at position x on the line purchases from AT&T it obtains utility of $r - P_A - x$ where r is the value provided by the product to the consumer located on the firm and P_A is the price charged by AT&T. Similarly, if the same consumer purchases from MCI it obtains utility of $r - P_M - (1 - x)$ where P_M is the price charged by MCI. Consumers incur differentiation costs in every period that they purchase.

There are overlapping generations of consumers whose length of life is stochastic.[9] Between each period, a fraction ρ of consumers exit the market ("die") with probability independent of age so that the expected remaining lifetime of each consumer is $1/\rho$. A density, λ, of new consumers enters the market uniformly distributed along the unit interval. They join a stock, L, of consumers who remain in the market from the prior period. The fit between an IXC's service and a consumer's needs is uncertain in that the consumer's relative evaluation of the firms may change after using a product each period. Ex ante, consumers expect a certain level of service but after trying the product may change their expectations. For example, a consumer dissatisfied

[9] Assuming certain lifetimes leads to the unappealing result that a market containing firms with asymmetric market shares will exhibit oscillatory prices and shares. This result is inconsistent with my empirical setting.

with service at MCI, may find AT&T more attractive ex-post. Equivalently, a consumer's business needs may change over time in unanticipated ways. To formalize this, a fraction, μ, of consumers are randomly relocated to a new position on the line between each period of their life. This reassignment occurs with equal probability for all consumers (regardless of whether they have previously moved) and is uniform along the line. The remaining fraction, $1-\mu$, maintain their position. This reassignment feature is the main aspect of Klemperer (1987a) that I adopt and drives the switching in the model.

In each period, each firm first chooses a single price (consistent with regulatory constraints explained later) to maximize its discounted lifetime profits taking the actions of the other firm as given. The firms cannot commit to future prices and their marginal cost is c in each period. Consumers then make purchase decisions to maximize the net present value of expected lifetime utility. In the first period of their lives, consumers have the option of purchasing from either firm and consider the ramifications their decision will have on their future decisions.[10] In the second period of their lives, consumers have the choice of purchasing from the same firm they purchased from when young or switching to the other firm at cost s (in addition to differentiation costs).

After the second period of their lives, consumers no longer incur switching costs if they switch firms. This keeps the model tractable[11] while closely approximating the empirical application; the removal of switching costs corresponds to the introduction of portability. Because of long-term contracts, consumers had at most one purchase decision before portability was implemented and switching costs fell. For brevity, I will refer to consumers in the first period of their life as "new," those in the second period of their life as "junior" and older consumers as "old."

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[10] I choose r such that all consumers want to purchase.

[11] If consumers incurred switching costs after the second period, the consumers' value function would not be quadratic. Consumers' future utility depends on the position of the marginal consumers in all future periods. The expected value of this utility more than one period in the future yields a polynomial in the state variable greater than order two.

I solve for the unique Markov-perfect equilibrium in which firm A's market share of old consumers, σ_A, is the state variable and the equilibrium price functions are linear. Since $\sigma_A = 1 - \sigma_B$, the state-space is one-dimensional. I consider a steady state in consumer densities: $\lambda = L\rho/(1-\rho)$. Panel A of Figure 1 shows the state of the market at the end of a period. The method of solution is constructive. I first posit the firms' value (profit) and policy (price) functions and then solve the consumers' problem to derive the demand function for each firm. Using the demand function, I then solve the firms' profit maximization problems by optimizing the Bellman equations. The resulting equations allow me to solve for the unknown constants in the firms' pricing and profit functions. In solving the model I will focus on AT&T since the MCI results are symmetric.

Suppose that AT&T's value and price functions are (d, e, k, l and m are unknown constants):

(1) $\pi_A(\sigma_A) = k + l\sigma_A + m\sigma_A^2$

(2) $P_A(\sigma_A) = d + e\sigma_A$.

There are six cohorts of demand to consider in each period as displayed in Panel B of Figure 1: junior consumers who purchased from AT&T when young and whose positions were reassigned with density $\mu\rho L\sigma_A$, junior consumers who purchased from MCI when young and whose positions were reassigned with density $\mu\rho L\sigma_B = \mu\rho L(1-\sigma_A)$, junior consumers whose positions remained the same and purchased from AT&T when young with density $(1-\mu)\rho L$ over the interval $[0, \sigma_A]$, junior consumers whose positions remained the same and purchased from MCI when young with density $(1-\mu)\rho L$ over the interval $[\sigma_A, 1]$, old consumers with density $(1-\rho)L$ and new consumers with density $L\rho/(1-\rho)$.

I now calculate AT&T's demand from each cohort (the demands are displayed in Panel C of Figure 1). Since old consumers incur no switching costs, the purchase decisions of both new and junior consumers do not affect their purchase decisions when they are old. Thus, new consumers need only consider the current and next periods while junior and old consumers can make purchase decisions period-by-period. The marginal new consumer is indifferent between buying from AT&T and MCI including the effect of her decision on her future utility. In Appendix 1, I show that this implies a position for the marginal new consumer of:

(3) $z_A^N = a_1 + a_2\sigma_A + b(P_M - P_A)$ and demand of $\rho L z_A^N / (1-\rho)$.

where a_1, a_2 and b are defined in Appendix 1. The marginal junior consumer who purchased from AT&T when young and was reassigned is indifferent between purchasing from AT&T again and switching to MCI, implying a position of:

(4) $z_A^R = \dfrac{P_M - P_A + 1 + s}{2}$ and demand of $\mu\rho L\sigma_A z_A^R$.

The marginal junior consumer who purchased from MCI when young and was reassigned is indifferent between switching to AT&T and buying from MCI again, yielding a position of:

(5) $z_M^R = \dfrac{P_M - P_A + 1 - s}{2}$ and demand of $\mu\rho L(1-\sigma_A)z_M^R$.

It is optimal for all consumers not relocated to purchase from the same firm again (full "lock-in") so that demand is $(1-\mu)\rho L\sigma_A$ from those who purchased from AT&T when young and 0 from those who purchased from MCI when young. The marginal old consumer faces the standard one-period purchase choice implying a position of:

(6) $z_A^O = \dfrac{P_M - P_A + 1}{2}$ and demand of $(1-\rho)Lz_A^O$.

AT&T's market share next period as a function of current market share is:

(7) $f_A(\sigma_A) = \rho z_A^N + (1-\rho)\rho\left[\mu\left(\sigma_A z_A^R + (1-\sigma_A) z_M^R\right) + (1-\mu)\sigma_A\right] + (1-\rho)^2 z_A^O$

Substituting the proposed pricing function (2) into (3) through (6) and then these four equations into (7), I obtain:

(8) $f(\sigma_A) = \eta + \theta\sigma_A$ where η and θ are defined in Appendix 1.

Using (1), (2), the demand equations derived above and the definition of a value function, I get:

(9) $\pi_A(\sigma_A) = (d + e\sigma_A - c)L\left[\frac{\rho}{(1-\rho)} z_A^N + \rho\left(\mu\left(\sigma_A z_A^R + (1-\sigma_A) z_M^R\right) + (1-\mu)\sigma_A\right) + \right.$

$\left. (1-\rho) z_A^O\right] + \delta_F \pi_A\left(f(\sigma_A L)\right)$

where δ_F is the firm discount factor. AT&T chooses its price to maximize its value function taking MCI's choice as given:

(10) $\max_{P_A} \; (P_A - c)L\left[\frac{\rho}{(1-\rho)} z_A^N(P_A) + \rho\left(\mu\left(\sigma_A z_A^R(P_A) + (1-\sigma_A) z_M^R(P_A)\right) + (1-\mu)\sigma_A\right) + \right.$

$\left. (1-\rho) z_A^O(P_A)\right] + \delta_F \pi_A\left(f_A(P_A L)\right)$

where the demand functions are before the equilibrium prices are substituted out. In Appendix 2, I explain how I solve this dynamic problem analytically for the stable equilibrium ($|\theta| < 1$). The solution has an easily interpretable form only when $\mu = 0$, which is an uninteresting case for current purposes since the switching costs parameter does not influence market prices. Instead, I numerically calculate markups obtained from all combinations of $\delta_C, \delta_F \in \{0.1, 0.3, \ldots, 0.9\}$,

$\rho, \mu \in \{0.1,0.2,...0.9\}$, $s \in \{0.0,0.1,...,1.0\}$ and $\sigma_A \in \{0.1,0.5,0.9\}$ when consumer densities are in a steady state with $L = 1$.[12]

I focus on three results from the model that are relevant for my empirical tests. I relate these implications to my data in Sections 3 and 4. Figure 2 provides examples of parameter values for which price is an increasing function of s and others for which it is a decreasing function. This leads to the main result:

> *Result 1: In a steady state, a decrease in switching costs can make markets either more or less competitive.*

When switching costs decrease, four main forces are at work on equilibrium prices. It is simplest to consider those forces from AT&T's perspective (after explaining each force, I relate its effect to AT&T's profit equation (10) in parentheses). First, lower switching costs increase the demand elasticity of those switching from AT&T to MCI, providing an incentive to price lower. That is, the lower switching costs increase demand by those switching from AT&T to MCI (a decrease in s decreases z_A^R). Second, lower "lock-in" decreases the demand elasticity of consumers switching from MCI, providing an incentive to price higher. That is, lower switching costs increase demand by those switching from MCI to AT&T (a decrease in s increases z_M^R).

Third, demand from new consumers is less elastic with lower switching costs if AT&T is the high-share firm, providing an incentive to price higher. With a decrease in switching costs, the high-share firm will decrease its next-period price disproportionately (relative to the low-share firm). Consumers now have less to fear from being "locked-in" to the high-share firm, which would otherwise take advantage of the high switching costs (a decrease in s decreases a_1 and increases a_2 so that a decrease in s decreases z_A^N for firms with shares below 0.5 and increases z_A^N for firms with shares above 0.5). Fourth, new consumers anticipate being less "locked-in"

[12] Because the pricing equation is linear in c, markups are independent of c. Output from these calculations is available from the author upon request.

once they purchase from a firm and are therefore more tempted by a price cut today, providing an incentive to price lower (a decrease in s increases parameter b, which increases z_A^N's sensitivity to P_A).

Of course, AT&T's value function depends on future discounted as well as current profits. However, because each of these four forces has the same directional effect on AT&T's future market share, f_A, as it does on current profits and AT&T's future profits are increasing in its future market share these are reinforcing effects. Two of these effects act to increase and two act to decrease price. To summarize, a decrease in switching costs has two effects on old customer demand and two effects on new customer demand. From AT&T's perspective, fewer old customers are "locked-in," decreasing demand from its own installed base but increasing demand from those switching from MCI. Since AT&T was the high-share firm during the time period of my study, the former effect is more important than the latter. Elasticity of new customer demand decreases because consumers are less "locked-in" when old but increases because consumers are more responsive to a price cut knowing that this will be more permanent with lower switching costs. Whether prices are higher or lower depends on firms' market shares, proportion of new consumers and consumers' level of patience.

Klemperer (1987a) exhibits these four forces but the first two occur only in the second period, while the last two appear only in the first period. The model in Klemperer (1987b) differs from mine because it assumes homogeneous products, consumer heterogeneity in switching costs and no switching in equilibrium. The results also differ from other infinite-horizon models. Beggs and Klemperer (1992) find that prices are higher than in a market without switching costs. This result differs from mine because of the full "lock-in" assumption of their model.[13]

[13] To (1996) extends the Beggs and Klemperer model to focus on switching costs' effect on market shares but maintains the full "lock-in" assumption. Bils (1989) models the effect of product uncertainty on a monopolist's prices over the business cycle. While analytically similar to a switching costs model, it is not directly comparable to mine because switching costs are not parameterized. Farrell and Shapiro (1988) and Padilla (1995) also consider infinite-horizon switching costs models but their model is more difficult to relate to current purposes since they consider an equilibrium in which firms alternate selling to new and old consumers.

In the model, those consumers who switch bear switching costs. Those costs are shared between those who switch and AT&T based on the relative demand and supply relationship elasticities. The switching costs are borne by a fraction of consumers, $\rho\mu\left(1 - z_A^R + z_M^R\right)$, ex-post even though ex-ante all consumers face a positive probability of bearing these costs. In Appendix 2, I show that the firm's equilibrium pricing function is linear in share. Price is increasing in market share (because $e > 0$) and profits (because $k, l, m > 0$) for all parameter values solved. It is this pricing function that I use in the empirical estimation:

> *Result 2: In a steady-state, the equilibrium pricing function is a linear function of marginal cost and the firm's market share:* $P_i(\sigma_i) = \alpha + c + \beta\sigma_i \;\; i = A, M$ *. The firm's price and profits are increasing in market share for all parameters solved.*

The firm with a larger share will price higher because it has a larger base of "locked-in" consumers. Since I want to allow for the possibility that AT&T and MCI offer products of different vertical quality levels, it is useful to see what effect this has on the pricing equation. Since the base level of utility from a product does not depend on the firm's market share it only affects the intercept in the pricing equation:

> *Result 3: If AT&T offers a higher quality product* $(r_A > r_M)$*, then only the intercept in the pricing function is affected (*$\alpha_A > \alpha_M$*) Similarly, if MCI offers a higher quality product then* $\alpha_M > \alpha_A$*.*

3. Toll-Free Services Data

I estimate the effect of portability on prices for toll-free service filed in FCC tariffs.[14] The timing of the portability decision and implementation were exogenous with respect to firms' pricing decisions. Portability required implementation of a new switching technology, Signaling System 7 (SS7), which had much more far-reaching effects than toll-free number portability. The timing

[14] Since the FCC does not index tariffs in any meaningful way, I obtain them from CCMI, a division of UCG, which provides pricing information and analysis to telecommunications users. I am grateful to George David and Bill Goddard for helping me obtain these data.

of SS7 implementation was driven by investment decisions of the LECs who were responsible for its implementation. These investment decisions were independent of the IXCs who had been separate firms since the breakup of AT&T in 1984. Moreover, if AT&T attempted to influence the portability decision (via SS7 implementation decisions) it could lower toll-free prices before May 1993, leaving an impression to the FCC that the potential gain from portability is minimal. This would bias the results downward and therefore my estimates would be a conservative estimate of the true effect.

I focus on the interstate market for toll-free service because of its relative importance. The interstate market is a single national market and includes all calls originating and terminating in different states.[15] Under the Communications Act of 1934 (Communications Act), the FCC regulates the interstate telecommunications market, including the market for 800-services. The "filed-rate" doctrine of the Communications Act requires all rate-related information to be filed in a tariff.[16] In order to understand how I constructed the data sets and why I chose VPN service as the primary data source, it is necessary to understand the tariff process.

IXCs file two types of tariffs. The first type, baseline tariffs, contains rates for stand-alone services (no bundling). These tariffs contain volume discounts but do not require the user to pre-commit to a usage level or length of service. The prevailing rates are in effect until the carrier files a change to the rate. The second type, contract-based tariffs, provides discounts off the rates specified in the baseline tariffs for users who pre-commit to usage levels, bundles of services and contract duration.[17] AT&T offered two types of contract-based tariffs: Tariff 12 options for VPN

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[15] The court overseeing AT&T's divestiture defined three types of markets for 800-services: intra-LATA, intrastate (inter-LATA) and interstate (regardless of whether within the same LATA). The United States is divided into 161 geographic LATAs (local access and transportation areas). Intra-LATA revenues represented less than five percent of total toll-free revenues in 1995 according to *Telecommunications Market Sourcebook*, Frost & Sullivan (1995) and Strategic Telemedia (1996).

[16] The penalty for not filing is $6,000 per offense and $300 per day. A stronger deterrent for IXCs is their loss of reputation with the FCC.

[17] A contract-based tariff is available to any "similarly-situated" customer in the ninety days after its effective date. The FCC required IXCs to file both types of tariffs fourteen days before their effective date throughout the period of the study (except for corrections to a tariff which could be filed three days before).

services and Contract Tariffs for bundles of stand-alone services. AT&T issued the first Tariff 12 option in March 1987 and the first Contract Tariff in February 1992.

The Communications Act prohibits "unfair" price discrimination, which has been interpreted as requiring IXCs to charge the same price to "similarly-situated" customers. Although the definition of "reasonable" differences between customers has been the subject of debate between the FCC, carriers and courts, the FCC has generally allowed IXCs to tailor prices only by time of day, type of service, volume purchased, contract length and mix of services. For the class of switching costs models that I wish to test, it is only necessary that carriers charged the same price to old and new consumers, which the FCC does not allow. I confirm the FCC's accomplishing this in the data when I discuss the results.

I estimate the effect of portability on prices of two toll-free service offerings: those bundled in VPN contracts and stand-alone, or unbundled, services.

Virtual Private Network Services Data

The primary data are AT&T VPN service contained in Tariff 12 options (distinct contracts) filed between February 1990 and October 1994. This period provides three years of data prior to portability and over one year after. VPN contracts are most relevant for testing the effects of portability because the largest users of toll-free service, and therefore those most affected by portability, employed VPNs. VPN contracts are also convenient for two reasons. First, the fact that AT&T wrote a significant number of VPN contracts before and after portability provides time-series variation for identification. Second, some VPN contracts included toll-free services while others did not. I use the latter as a control group (other services were always portable). AT&T, MCI and Sprint, comprised ninety-one percent of 800-services revenues at the time of portability. Unfortunately, MCI did not begin filing contract-based tariffs for VPN service until 1992 and Sprint until 1995. I therefore focus on AT&T in the VPN analysis.

In a VPN, an IXC creates a virtual network for large businesses. The user specifies telephone numbers within the network and commits to usage volumes in exchange for discounts on calls made to and from these numbers. VPNs contain up to five types of voice services, data services and, sometimes, international voice and data services. Three of the voice services are toll services and two are toll-free services. The categories are determined by whether the call utilizes dedicated ("on-net") or switched ("off-net") services. Switched calls utilize the LECs' switching network, while dedicated calls do not. IXCs pay a regulated per-minute access fee to the LECs for switched service. For dedicated calls, IXCs lease dedicated lines from the LECs by the month (at a regulated fee) with zero marginal cost for usage. Toll calls fall in three categories depending on whether both, one or neither end of the call is "on-net." Toll-free calls fall into two categories depending on whether the call terminates "on-net" or "off-net".[18] Data service is provided over dedicated lines so that its costs do not vary with usage.

An observation, i, is an original or revised contract with effective date t. AT&T often revises an existing contract instead of issuing a new one. I explain the average voice price of each contract. Since voice services are bundled within contracts they are potentially subject to cross-subsidization with non-voice services, but estimating prices at the contract level requires significant assumptions about the mix of services within each contract.[19]

AT&T filed 233 active contracts during the period of the study. Twelve of these contracts were subject to different regulations, one did not contain any domestic services and another was for a different type of VPN service, providing 219 observations. Of these 219 contracts, 86 are original filings and 133 are revisions. Figure 3 shows the distribution of issuance dates for the contracts in the data set and distinguishes between revised and original contracts. There are no original contracts in the early part of the data set because I had access to tariff files beginning in February 1992, by which time these older contracts had already been revised. The spike in

[18] Calls to a user's toll-free number originate "off-net" by definition.

[19] As a check I estimated the policy equation using prices at the contract level. The results are similar to, although noisier than, those obtained for average voice price. Estimation with the stand-alone rates also acts as a check since they are not subject to cross-subsidization.

contract revisions in the latter half of 1993 is due to “fresh look.” The FCC’s “fresh-look” decision, issued on September 30, 1991, stated that any Tariff 12 option active at the time of portability could be canceled at the customer’s discretion. Consequently, AT&T renegotiated many contracts during this period. The spike in original contracts in the third quarter of 1993 through the first quarter of 1994 is presumably due to increased demand from lower post-portability prices.

Multiple users can, and generally do, sign up for a single Tariff 12 contract. I do not observe the user(s) who subscribe to a particular contract because the FCC does not require disclosure of subscriber information. However, comparing usage patterns of Tariff 12 contracts to those of Contract Tariffs, an alternative to Tariff 12 that became popular beginning in 1994, provides strong evidence that multiple users subscribe. In contrast to the 231 Tariff 12 contracts issued or revised in the seven years of the data set, AT&T issued over twelve thousand Contract Tariffs in the seven-year period between 1994 and 2001. Prior to 1994, Contract Tariff users would have had to subscribe to one of the Tariff 12 contracts or pay the significantly higher baseline tariff rates for stand-alone services.

Contracts vary in size, duration and mix of services. $revenue_i$ is AT&T’s monthly revenue from the contract based on the minimum revenue commitment. Contract duration $\left(duration_i\right)$ is the minimum time commitment allowed under the contract. The average contract length was 3.7 years and ranged from three to nine years. Each contract specifies up to six different prices: up to five per-minute prices for each type of voice service $\left(p^t_{A,i,j} \;\; j=1,2,..,5\right)$ and a fixed monthly fee $\left(F_i\right)$. Thus, voice service prices are usage-dependent while data service charges are independent of volume.[20] In the absence of cross-subsidization, the fixed monthly fee is the price for the voice and data infrastructure (dedicated lines), which is invariant to usage. Each contract provides good, but not perfect, information about the proportion $\left(w_{i,j} \;\; j=1,2,..,5\right)$ of the voice services consumed as explained in Appendix 3. I calculate the average voice price as

[20] Contracts may also include international data and voice services. I explain how I treat this below.

$\overline{P^t_{A,i}} = \sum_{j=1}^{5} w_j p^t_{A,i,j}$. Appendix 3 contains more details on this and all other variables collected and Table 2 provides summary statistics.

Because VPNs utilize the public local telecommunications network and the FCC regulates the rates for accessing this network, I can directly observe the marginal cost of voice calls and therefore the contribution margin of each contract's voice usage to the fixed costs of AT&T's long-distance network. Voice usage marginal costs are per-minute $\left(c^t_j \;\; j = 1,2,...,5\right)$ and the average voice marginal cost is $\overline{c^t} = \sum_{j=1}^{5} w_j c^t_j$.

As Table 2 shows, "off-net" prices and marginal costs are greater than "on-net." Prices for toll-free service are above those for toll service, while marginal costs for toll-free service differ only slightly from those for toll service due to the small database query charges and a slight difference in operating costs (see Appendix 3). As a result, margins are greater for toll-free than for toll services.

I constructed two other variables thought to affect IXCs' costs of providing VPN service. Voice network dispersion $\left(vdisp_i\right)$ measures the geographic dispersion of the voice network, which affects the monthly billing and support costs. A dummy variable, $isched_i$, indicates whether the contract includes international voice services, whose margins may vary from those for domestic services. Thirteen percent of contracts included international service. Although the contracts also specify compensation for network outages and charges for altering network size, these vary little across contracts. Since Tariff 12 contracts potentially apply to more than one customer, implementation details for a specific customer are contained in a separate, non-public document. However, as noted earlier, this document cannot contain any rate-related items. Finally, I set a variable $revis_i$ to 1 if the contract is revised and zero otherwise. Fifty-eight percent of the contracts were revisions.

To provide a proxy for the effect of portability I created a dummy variable, $dport^t$, which I set to 1 if portability was implemented at time t and 0 otherwise. To distinguish between contracts issued after portability was decided but before it was implemented, I created a dummy variable, $ddecid^t$, which I set to 1 if portability had been decided but not yet implemented when the contract was issued.[21] Forty-seven percent of the contracts were written after portability and 28% were written after portability was decided but before it was implemented. For each observation I also collected a measure of AT&T's toll-free market share at the time the contract was written, $\sigma_A^{t-duration_i}$. This declined from a high of 80 percent in the first quarter of 1990 to 67 percent in the fourth quarter of 1994.

Stand-Alone Toll-Free Services Data

I employ a secondary source of data for stand-alone toll and toll-free services over dedicated lines. I use the toll services as a control group since it was always portable and had virtually identical marginal cost. I find the best available rate (including all discounts) for large users (those spending approximately $3 million annually) from the fourth quarter of 1988 through the first quarter of 1999. The best rate for AT&T is taken from baseline tariffs through the third quarter of 1992 and for MCI through the third quarter of 1993. These tariffs specify a unique price for a given volume at each point in time. After this, better rates are available in contract-based tariffs. I use the median rate from a sample of AT&T and MCI contract tariffs of three-year duration. Unfortunately, similar data are unavailable for Sprint because it did not begin filing its contract tariffs until June 1995. The marginal costs for stand-alone services are the same as those for "on-to-off" services in VPN contracts. Table 3 provides summary statistics for these data.

Figure 4 plots the margins and market shares for AT&T and MCI's stand-alone services over the sample period and demonstrates that competition for toll-free services was less fierce under non-

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[21] The decision to implement portability was made on August 2, 1991. Portability was discussed as a possibility before this but whether and when portability would happen was extremely uncertain prior to this.

portability. The toll-free prices are higher than toll prices prior to portability; a gap that closes once portability is implemented. I estimate this effect more precisely in the next section. This data is consistent with Result 2 of the theoretical model. AT&T's margins are higher than MCI's, consistent with AT&T's higher market share. The two firms' margins also converge over time consistent with the convergence of their market shares. Finally, both firms' market shares change gradually consistent with persistence due to switching costs.

4. Estimation and Results

In this section I offer two types of empirical evidence on portability's effects. First, I estimate the policy equation implied by the theoretical model on the average voice price for AT&T VPN contracts. Second, I estimate the policy function on prices for stand-alone services.

The results from both data sets are consistent with the hypothesis that switching costs resulting from non-portability made the toll-free services market less competitive. The policy function estimation reveals that portability is associated with a decrease of 4.4 percent in the average voice price in the VPN contracts. I use contracts that included no toll-free service (other services were always portable) as a control group and find that the prices for these contracts were unaffected by portability. Moreover, prior to portability prices on these contracts were 4.7 percent lower than those with toll-free service, roughly the drop in price that contracts with toll-free service experienced with the introduction of portability.

Portability also had a significant negative effect on stand-alone toll-free prices for both AT&T and MCI but no significant effect on toll services (which were always portable). The effect is greater (around 14 percent for both firms) than for VPN service. The fact that MCI's prices declined after portability provides evidence that lower prices post-portability were not due to a decline in the relative quality of AT&T's toll-free services (the elimination of its monopoly on favorite vanity NXX numbers). That the effect is greater for stand-alone services than for VPN services is reasonable given that toll-free services comprised only 31 percent, on average, of the VPN contracts. This implies that the price of a hypothetical VPN contract with only toll-free service would decrease by approximately 14 percent due to portability – the same magnitude as for stand-alone toll-free service prices.[22] From a policy perspective, the technology for implementing portability was available in 1987 but the court overseeing AT&T's breakup ruled that the technology belonged to AT&T, delaying portability and these lower prices by six years.

Policy Function Estimation – VPN Rates

I estimate the policy function generated from the theoretical model (given in Result 2), controlling for other factors that might affect prices. Although this does not allow me to assess counterfactuals, it provides an estimate of the direction and significance of portability's effect. I estimate the policy function for the average voice price:

$$(12)\quad p^{t}_{A,i} = \alpha + \beta_1 c^{t} + \beta_2 \sigma^{t-duration_i}_{A,i} + \beta_3 dport^{t} + \beta_4 \log(revenue_i) + \beta_5 duration_i + \beta_6 vdisp_i + \beta_5 isched_i + \varepsilon_i$$

Two assumptions are inherent in this specification. First, it assumes that pricing is determined by a choice between carriers rather than an average cost condition based on free-entry. Given the large sunk costs incurred by AT&T, MCI and Sprint in building their networks, this assumption is reasonable. In fact, "entry" into the long-distance market since the time of the study has been by resellers of these three firms' capacity; no other carrier has since built a nationwide long-distance network. Second, price does not depend on quantity of output. This is reasonable given that long-distance transmission is a constant returns-to-scale technology when operating below capacity. In all my results I compute robust standard errors, allowing for heteroskedasticity and autocorrelation.[23]

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[22] Note that the stand-alone prices in my dataset pertain to a $3 million annual user, which is approximately the same amount that the average VPN user in my dataset spends on toll-free service ($16.4 million annually with 31% on toll-free service).

[23] Since my dependent variable is left truncated at marginal cost I re-estimated all results using a Tobit model. These results are all virtually identical because there are no predicted prices below actual marginal cost.

IXCs earn positive contribution margins on toll-free services because they must cover the fixed costs of their networks and possibly because they earn positive economic profits. The IXCs therefore have an incentive to raise or lower prices on toll-free services as switching costs change depending on whether it is more important to harvest or grow its customer base. The effect of portability on prices is identified in two ways. First, contracts varied in whether they included toll-free usage and therefore whether they were affected by non-portability.

Second, contracts varied in whether they originated before SS7 (and therefore portability) was decided or after SS7 (and therefore portability) was implemented. For a contract originating prior to the portability decision, existing AT&T subscribers (whose pre-existing contracts were expiring) were subject to switching costs from non-portability if they did not renew with AT&T. New users availing themselves of this contract and existing users expected to be "locked-in" to AT&T upon its expiration. After implementation, on the other hand, existing AT&T subscribers (whose pre-existing contracts were expiring) were not subject to switching costs from non-portability if they switched from AT&T and both old and new users signing these contracts knew they would not be "locked-in" when the contract expired.[24] If AT&T and users expected portability to be implemented prior to the decision to implement SS7 on August 2, 1991 then I would be misinterpreting my results. Although portability was discussed since the implementation of NXX screening in 1986, based on press accounts it was not considered a reality until the August 1991 decision.[25]

Table 4 contains estimates of the policy equation for the average voice price in the VPN contracts. Overall, portability is associated with 4.4 percent lower average prices. The other coefficients generally have the expected signs. Price is increasing in marginal cost and

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[24] There were also contracts written between the time portability was decided (August 2, 1991) and implemented (May 1, 1993). For these contracts, existing AT&T users were still "locked-in" but may have negotiated lower prices to sign longer contracts and new users may have done the same. I allow for this possibility, as I describe below, by distinguishing these contracts from those before portability was decided.

[25] This is evidenced by the fact that before the August 2, 1991 story announcing the SS7 decision, the *Wall Street Journal* had not published an article related to 800-number portability since 1985 when it reported that the court overseeing AT&T's breakup would not allow other IXCs to use AT&T's original technology, which would have allowed portability.

decreasing in contract revenue. Contracts with more disperse voice networks deliver higher prices but neither duration nor presence of international service significantly affects prices. AT&T's market share does not have a significant effect, likely because there is relatively little variation in this variable over time (see Figure 4). This lack of variation is consistent with the theoretical model, which predicts gradual declines in shares over time due to "lock-in."

I re-estimate the policy function and include a dummy for the contracts that contained no toll-free service and also interact it with the portability dummy. The results shown in Column 2 of Table 4 show that, prior to portability, contracts with toll-free service sold at a premium relative to those without. The premium vanishes after portability so that both had roughly the same prices (portability reduces prices of contracts with toll-free service by 0.00586, and contracts without toll-free service were lower prior to portability by 0.00507). Moreover, portability had no effect on contracts without toll-free service.

The last three columns of Table 4 are robustness checks of the results. Base Model II removes all insignificant variables from Base Model I to preserve degrees of freedom. The revenue and duration variables raise endogeneity issues. Since I lack instruments for duration, I run the model on a restricted sample of options of five-year duration only. Column 4 shows the results. The effect of portability is even greater for these longer-than-average contracts. It is also interesting to examine whether AT&T altered the duration of contracts in response to portability. Figure 5 compares the distribution of durations pre- and post-portability. The distributions are very similar, and a Chi-Square test for equality of distributions yields a test statistic of 5.03 and a significance level of 89 percent so that the null hypothesis of the same distributions cannot be rejected. This is reasonable given that it is much more costly for the parties to alter the duration of contracts (given future uncertainty about local access costs) than to change prices.

If AT&T were able to price discriminate between old and new users, I would be misinterpreting the results. Although the FCC requires AT&T to make Tariff 12 contracts available to "similarly-situated" customers, AT&T could still price discriminate if it tailored the contracts specifically enough that only new or existing users qualified for a particular contract. AT&T's

ability to do this is limited by the “filed-rate” doctrine. Since all rate-related items must be filed with the FCC, they are publicly available and used as information in subsequent negotiations. Because a contradicting tariff takes legal precedence over a private contract, “under-the-table” agreements are difficult to enforce. Moreover, resellers of 800-services can arbitrage away any price differences across tariffs.

If AT&T were able to tailor Tariff 12 contracts sufficiently to price discriminate between old and new users, prices in new contracts should differ significantly from those in revisions to existing contracts. New contracts would target new users while revisions would target incumbent users. To test for such price discrimination, I estimated the model with a sub-sample consisting of only revised contracts. The results are shown in the fifth column of Table 4 and are not significantly different from those in Base Model II. A Chow test yields a test statistic of 0.1082, which is significant at the 99 percent level. Therefore, I am unable to reject the hypothesis that the parameters are the same for the two subsets.

I address the potential endogeneity of contract revenue in two ways. First, I determine the direction of the endogeneity bias. Under the reasonable assumption that average voice price has a negative effect on contract revenue, endogeneity will bias the coefficients on the other independent variables (including the portability dummy) down in absolute value. Properly controlling for the endogeneity should therefore increase the effect of the portability dummy relative to the results.

Second, I estimate the pricing equation on a restricted sample of options of size between $3 and $9 million per month. Column 2 of Table 5 shows the results of estimating the policy equation on this subsample. The results confirm those from the full sample and the portability effects are greater. These greater effects are consistent with the hypothesized direction of the endogeneity bias now controlled for or could be due to the fact that the users in this subsample are larger on average than those in the full sample and therefore benefit more from portability.[26] Portability is associated with 10% lower prices for contracts with toll-free service and has no significant effect on those without toll-free service. Also, prices on contracts with toll-free service are 9.1% higher prior to portability than those without toll-free service, roughly the drop in price due to portability.

Since there was a lag between the time that the FCC decided to implement SS7 (August 2, 1991) and its implementation (May 1, 1993), firms may have begun to alter their prices between these times. Old users renewing their contracts or new users initiating service with AT&T during this period knew that they would not be "locked-in" when their contracts expired. In Column 3 of Table 5, I rerun Base Model I but distinguish contracts issued between the SS7 decision and implementation by a dummy variable. The results again confirm that portability, or lower switching costs, lowered prices and that part of this effect occurred prior to its implementation (but after the decision). Prices dropped 3.4% after portability was decided and another 7.8% after portability was implemented on contracts with toll-free service. Contracts without toll-free service were unaffected by portability and were 4.9% lower than those on contracts with toll-free service prior to the portability decision.

Policy Function Estimation –Stand-Alone Rates

For stand-alone services data the effect of portability is identified by whether the price pertains to pre- or post-portability. The policy function I estimate is:

(15) $p_{jk}^{t} = \alpha_{jk} + \beta_{1,jk} c_{k}^{t} + \beta_{2,jk} \sigma_{j}^{t-1} + \beta_{3,jk} dport^{t} + \varepsilon_{j,k} \quad j = ATT, MCI \quad k = Toll, Toll - Free$

Table 6 displays the results. Portability has a significantly negative effect on toll-free services prices for both firms but no significant effect on toll prices consistent with switching costs

[26] The mean size in the subsample is $4.80 million per month versus $1.35 for the full sample. The range of sizes was chosen to provide the maximum number of observations and variation in contracts that did and did not include toll-free service while providing the narrowest range of sizes.

softening competition.[27] That portability had a negative effect on MCI's prices is also evidence that the negative effect on AT&T's prices did not result from its loss of monopoly on the most popular NXX vanity numbers. Since AT&T had offered toll-free service the longest time and had a much larger market share, it reasonably may have had more popular NXX codes (e.g. those corresponding to "THE" or "USA.") The fact that only five percent of the toll-free numbers in the 1991 sample described in Table 1 contained vanity numbers in the NXX code is additional evidence that this was not the primary effect of portability.

The FCC subjected AT&T to price regulation on its stand-alone toll-free services until the portability date, but there is significant evidence that these regulations did not constrain AT&T's pricing.[28, 29] The design of the regulation gave AT&T more freedom than it appeared. From March 1989 to May 1993 the FCC imposed price-cap regulation on AT&T's stand-alone toll-free services. The regulation was applied by baskets, and toll-free services were part of Basket 2. AT&T could change its prices within each basket by five percent in either direction of a price cap index set annually by the FCC. The FCC subdivided Basket 2 into four categories. AT&T could change rates for services within some categories by more than five percent as long as the weighted average across all four categories stayed within the allowed range.[30] The FCC initially set the price cap index at AT&T's existing rates and then adjusted it annually for inflation and reduced it by a 2.5 percent "productivity offset" and a 0.5 percent "consumer productivity dividend." AT&T could also submit tariffs that deviated from the price bands subject to FCC approval. Hall (1993) offers evidence that AT&T's weighted price was well below the price cap index for Basket 2 services during price cap regulation. Lastly, if price regulation had

[27] The other variables are generally of the expected sign. Increases in marginal cost increase prices for both firms and the effect of previous market share is positive and significant for AT&T. The effect of market share is negative for MCI (but only significant for toll-free services). This is due to the run-up in prices just prior to portability (see Figure 4).

[28] A consultant I talked to who had worked for AT&T as a salesperson prior to portability claimed that AT&T was not at all constrained by price caps in filing their tariffs and the FCC rarely challenged tariffs.

[29] The Tariff 12 contracts used in the VPN analysis were not subject to price regulations. They were subject only to tariff review, and the guidelines for this review did not change during the period of the study.

[30] Basket 2 included service categories: 1) Readyline 800 (inbound WATS switched), 2) AT&T 800 (classic inbound WATS), 3) Megacom 800 (inbound WATS dedicated) and 4) other 800.

constrained AT&T's pricing, AT&T should have increased its price after portability not decrease it as I find.

5. Conclusion

In this paper I have tested the effect of switching costs in a market in which firms could not price discriminate between new and existing users. I find that firms in the market reduced their prices in response to a decline in switching costs, implying that switching costs made the market less competitive. Despite rapid growth in the market, the firms' incentive to exploit their existing "locked-in" users was greater than their incentive to "lock-in" new consumers. This is only the second empirical test of the effect of switching costs on price levels in such a single-price regime. The results are consistent with that of the earlier test, but are obtained in a setting that provides a clear control group to exploit. I use the advent of number portability for toll-free services to measure its effect on prices. I employ a difference-in-differences approach with toll services, which were always portable and had virtually identical marginal costs, as the control. In the empirical switching costs literature a persistent problem has been the difficulty of isolating switching costs that are embedded in complicated pricing schemes. In this paper, I offer a unique setting with a clear control group in which to isolate them.

That switching costs made the toll-free market, which experienced rapid growth, less competitive, is significant evidence that this is likely true for slower growth markets in which there is less incentive to price lower to attract new consumers. This result is important because switching costs are present in many markets in which firms face constraints on price discrimination between new and old consumers. The results also have implications for decisions on portability in other telecommunications markets.

Although the primary contribution of this paper is to the switching costs literature, it makes a secondary contribution. A perennial problem in studies of the telecommunications industry has been the difficulty of measuring discounts for services, especially business services. Previous papers have either approximated these discounts or avoided studying business services altogether.[31] I construct a unique data set that fully captures discounts for large users.

Much additional empirical switching costs work is needed. Evidence from additional markets in which firms cannot price discriminate would be useful. It would also be useful to study the effect that switching costs has on entry when firms cannot price discriminate. How the presence of switching costs affects firms' use of second-degree price discrimination, such as volume discounts, would also be important but would require both theoretical and empirical work.

[31] For example, Knittel (1997) avoids studying business customers: "Residential rates are only used given the higher percentage of businesses that subscribe to discount plans and thus do not pay the retail list rate" (page 529). Even a paper entitled "Competition for 800 Service," by Kaserman and Mayo (1991) contains no actual price data besides a statement that, "For interstate 800 service AT&T has reduced prices by approximately twenty percent since 1986" (page 405).

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Table 1 Estimates of Customer Switching Between Toll-Free Providers in 1989, 1991 and 1993

	AT&T	MCI	Sprint	Other	Total
1989 Total	153	3	1	4	161
(% of market)	(95%)	(2%)	(1%)	(2%)	(100%)
Switched From	4				4
(% of 1991 Total)	(2%)				(2%)
Switched To		1	1	2	4
(% of 1991 Total)		(13%)	(33%)	(29%)	(2%)
1991 Total	170	8	3	7	188
(% of market)	(90%)	(4%)	(2%)	(4%)	(100%)
Switched From	6				6
(% of 1993 Total)	(3%)				(3%)
Switched To		3	1	2	6
(% of 1993 Total)		(25%)	(9%)	(15%)	(3%)
1993 Total	194	12	11	13	230
(% of market)	(85%)	(5%)	(5%)	(6%)	(100%)

Source: Sample contains all customers with sales of $5 million or more in the *Directory of Mail Order Catalogs* 4th (1989), 5th (1991) and 7th (1993) editions. Switching is detected based on the customers' NXX code in their toll-free number.

Table 2 AT&T VPN Contracts Sample Descriptive Statistics, n = 219

Variable	Mean	Std	Min	Max
On-to-On Toll Service Price ($/minute)	0.0622	0.00894	0.0410	0.102
Off-to-On Toll Service Price ($/minute)*	0.0923	0.00993	0.0715	0.132
Off-to-On Toll-Free Service Price ($/minute)	0.108	0.0143	0.0828	0.181
Off-to-Off Toll Service Price ($/minute)	0.168	0.0112	0.138	0.223
Off-to-Off Toll-Free Service Price ($/minute)	0.190	0.0185	0.152	0.260
On-to-On Toll Marginal Cost ($/minute)	0.0130	0.000	0.0130	0.0130
Off-to-On Toll Marginal Cost ($/minute)*	0.0485	0.00204	0.0462	0.0518
Off-to-On Toll-Free Marginal Cost ($/minute)	0.0481	0.00114	0.0470	0.0504
Off-to-Off Toll Marginal Cost ($/minute)	0.0798	0.00322	0.0770	0.0882
Off-to-Off Toll-Free Marginal Cost ($/minute)	0.0807	0.00281	0.0784	0.0886
Contract Revenue ($ million/month)	1.37	1.76	0.108	16.2
Duration (years)	3.71	1.01	3	9
Average Voice Price ($/minute)	0.107	0.0109	0.0828	0.159
Average Voice Marginal Cost ($/minute)	0.0485	0.00360	0.0130	0.0565
Revision	0.575	0.495	0	1
Portability Dummy	0.470	0.500	0	1
Portability Decision Dummy	0.279	0.449	0	1
Previous Market Share	0.705	0.0302	0.667	0.800
Voice Network Dispersion	0.128	0.208	0	1
International Schedule	0.128	0.208	0	1
No Toll-Free Service	0.105	0.307	0	1

* Applies to off-to-on or on-to-off service
Sample includes the 219 AT&T VPN contracts issued between February 1990 and October 1994.

Table 3 Stand-Alone Services Quarterly Prices Descriptive Statistics, n = 45

Variable	Mean	Std	Min	Max
Toll Price – AT&T	0.101	0.0198	0.0631	0.128
Toll-Free Price – AT&T	0.107	0.0262	0.0592	0.135
Toll Price – MCI	0.0880	0.0174	0.0528	0.113
Toll-Free Price – MCI	0.0994	0.0261	0.0538	0.132
Toll Marginal Cost	0.0494	0.00531	0.0384	0.0597
Toll-Free Marginal Cost	0.0500	0.00488	0.0396	0.0597
AT&T Previous Market Share	0.708	0.102	0.589	0.959
MCI Previous Market Share	0.190	0.0661	0.0323	0.263
Portability Dummy	0.533	0.505	0	1

Sample includes quarterly prices for AT&T and MCI stand-alone services between the fourth quarter of 1988 and the first quarter of 1999.

Table 4 Estimated Policy Function for Average Voice Price in Sample of AT&T VPN Contracts
Dependent Variable: Average Voice Price

	1	2	3	4	5
Independent Variable	Base Model I	No Toll-Free Service	Base Model II	Five-Year Duration	New Contracts Only
Intercept	0.153***	0.162***	0.114***	0.127***	0.119***
	(0.0251)	(0.0226)	(0.0188)	(0.0136)	(0.0178)
Marginal Cost	0.738*	0.569	0.686**	0.277	0.553
	(0.425)	(0.429)	(0.348)	(0.191)	(0.346)
Previous Market Share	-0.0757	-0.0756			
	(0.0641)	(0.0588)			
Portability Dummy	-0.00469***	-0.00586***	-0.00452***	-0.00817***	-0.00567***
	(0.00177)	(0.00180)	(0.00166)	(0.00204)	(0.00199)
Log Contract Revenue	-0.00420***	-0.00421***	-0.00426***	-0.00337**	-0.00384***
	(0.000580)	(0.000659)	(0.000593)	(0.00102)	(0.000814)
Duration	-0.000142	$-8.16\text{x}10^{-5}$			
	(0.000515)	(0.000533)			
Voice Network Dispersion	0.00464*	0.00553*	0.00441*	0.00149	0.000958
	(0.00258)	(0.00301)	(0.00252)	(0.00244)	(0.00224)
International Schedule	-0.00182	-0.00173			
	(0.00139)	(0.00150)			
No Toll-Free Service		-0.00507*			
		(0.00247)			
No Toll-Free Service – Under Portability		0.00508			
		(0.00526)			
Observations	219	219	219	57	126
Adjusted R^2	0.276	0.284	0.277	0.345	0.213

Newey-West (1987) standard errors are in parentheses. The errors allow for heteroskedasticity and for autocorrelation up to and including a lag of 5 for models 1, 2, 3 and 5 and 3 for model 4. The bandwidth parameter is chosen based on Andrews (1991).
* Significant at the 10% level. ** Significant at the 5% level. *** Significant at the 1% level.
Column 1 contains the base model, which includes all variables but does not distinguish contracts with toll-free service from those without. Column 2 distinguishes the effect of portability on contracts with toll-free service from those without. Column 3 contains base model II, which is base model I with all insignificant variables excluded. Column 4 is base model II estimated on only contracts of five-year duration. Column 5 is base model II estimated on only original contracts.

Table 5 Estimated Policy Function for Average Voice Price in Sample of AT&T VPN Contracts
Controlling for Contract Revenue Endogeneity and Portability Decision
Dependent Variable: Average Voice Price

	1	2	3
Independent Variable	Base Model I	Similar Contract Revenue	Portability Decision Variable
Intercept	0.153***	-0.240	0.192***
	(0.0251)	(0.197)	(0.0258)
Marginal Cost	0.738*	-0.944	0.520
	(0.425)	(1.67)	(0.402)
Previous Market Share	-0.0757	0.741*	-0.124**
	(0.0641)	(0.397)	(0.0525)
Portability Implementation Dummy	-0.00469***	-0.0107**	-0.00840***
	(0.00177)	(0.00433)	(0.00241)
Portability Decision Dummy			-0.00364*
			(0.00193)
No Toll-Free Service		-0.00972*	-0.00521**
		(0.00536)	(0.00257)
No Toll-Free Service – Under Portability		0.00589	0.00517
		(0.00597)	(0.00508)
Log Contract Revenue	-0.00420***		-0.00410***
	(0.000580)		(0.000680)
Duration	-0.000142	-0.00143	-0.000184
	(0.000515)	(0.00123)	(0.000534)
Voice Network Dispersion	0.00464*	-0.00162	0.00487*
	(0.00258)	(0.00735)	(0.00283)
International Schedule	-0.00182	-0.00574	-0.00174
	(0.00139)	(0.00398)	(0.00149)
Observations	219	20	219
Adjusted R^2	0.276	0.380	0.292

Newey-West (1987) standard errors are in parentheses. The errors allow for heteroskedasticity and for autocorrelation up to and including a lag of 2 for model 1, 5 for model 2 and 3 for model 3. The bandwidth parameter is chosen based on Andrews (1991).
* Significant at the 10% level. ** Significant at the 5% level. *** Significant at the 1% level.
Column 1 contains the base model, which includes all variables but does not distinguish contracts with toll-free service from those without. Column 2 contains a model using only contracts with size between $3 and $9 million per month. Column 3 distinguishes contracts issued after the portability decision but before implementation.

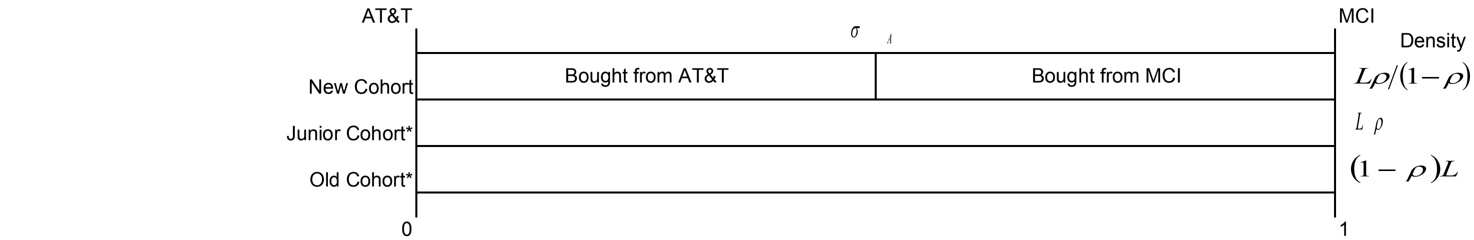
Table 6 Estimated Policy Function for Quarterly Price of AT&T and MCI Stand-Alone Services from Fourth Quarter 1988 through First Quarter 1999
Dependent Variable: Quarterly Price

Independent Variable	AT&T Toll	AT&T Toll-Free	MCI Toll	MCI Toll-Free
Intercept	-0.0314	-0.0508	0.0235	0.0389
	(0.0248)	(0.0338)	(0.0262)	(0.0279)
Marginal Cost – Toll	1.85***		1.72***	
	(0.405)		(0.444)	
Marginal Cost – Toll-Free		2.76***		1.91***
		(0.537)		(0.553)
Previous Market Share	0.0625***	0.0405**	-0.0944	-0.145***
	(0.0153)	(0.0184)	(0.0570)	(0.0349)
Portability Dummy	-0.00549	-0.0160**	-0.00233	-0.0143**
	(0.00481)	(0.00661)	(0.00579)	(0.00712)
Observations	45	45	42	45
Adjusted R^2	0.744	0.751	0.707	0.796

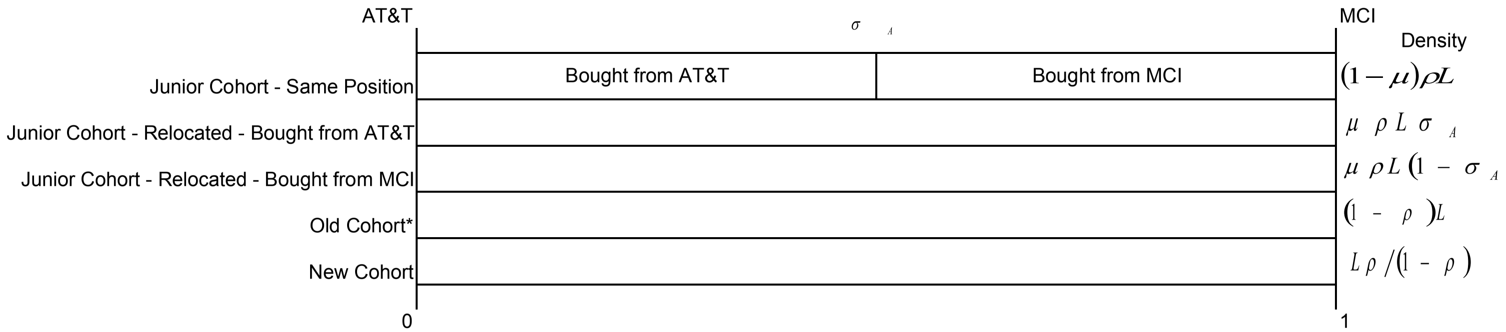
Newey-West (1987) standard errors are in parentheses. The errors allow for heteroskedasticity and for autocorrelation up to and including a lag of 1.
* Significant at the 10% level. ** Significant at the 5% level. *** Significant at the 1% level.

Figure 1

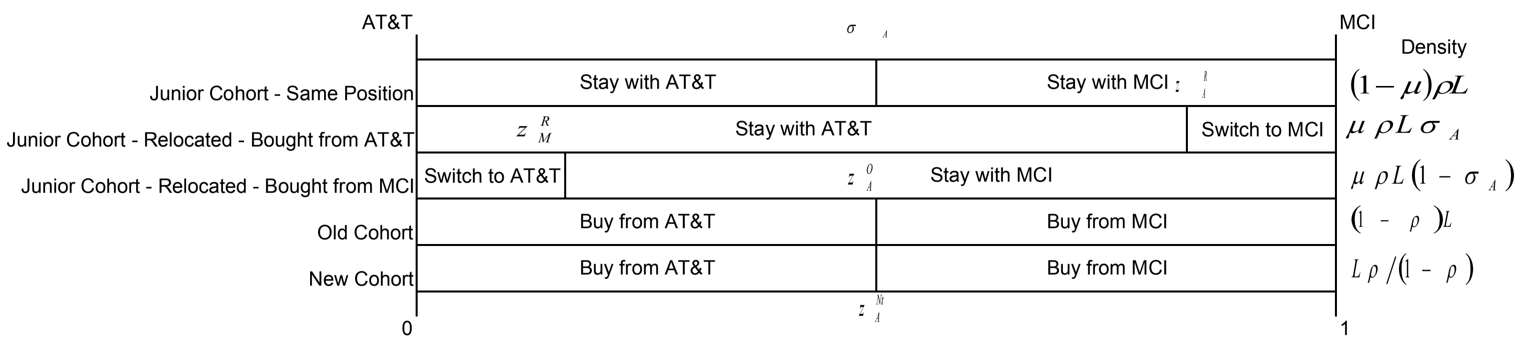
Panel A: Densities and Positions of Consumers in Market at End of the Previous Time Period



Panel B: Densities and Positions of Consumers in Market at Beginning of the Time Period



Panel C: Densities and Positions of Consumers in Market Within the Time Period



* Purchases not shown since purchase history is irrelevant for these cohorts.

Figure 2: Equilibrium Prices as a Function of Switching Costs from Theoretical Model for Selected Parameter Values

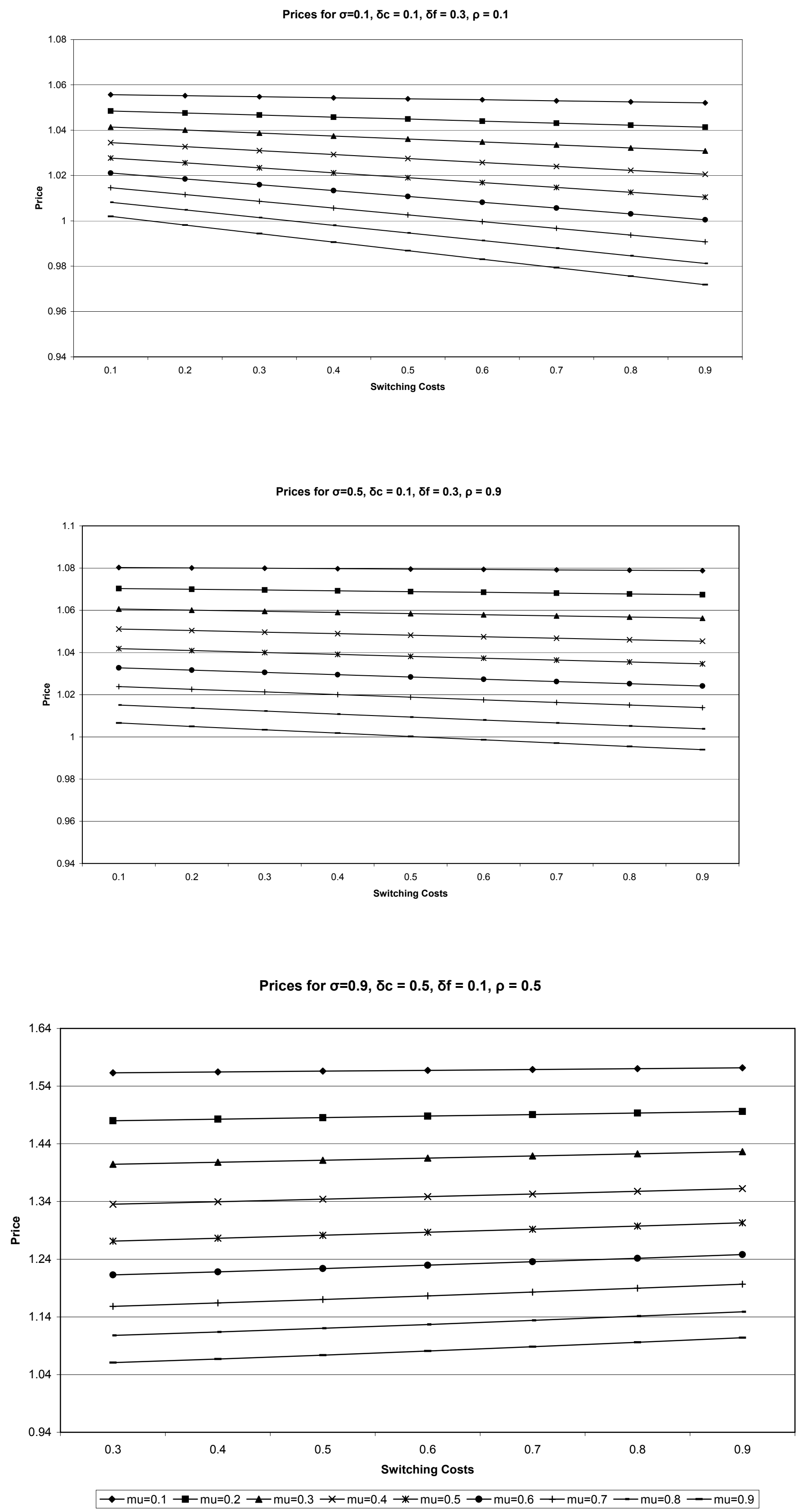
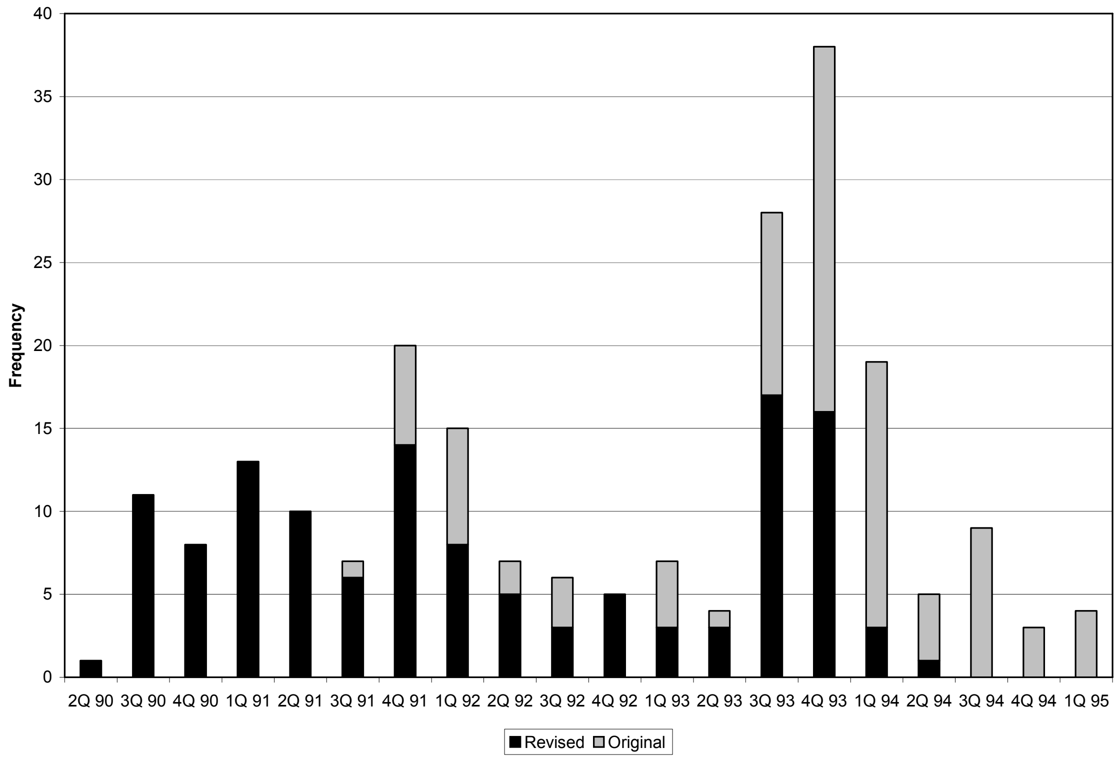


Figure 3 Distribution of Origination and Revision Dates for VPN Contracts in Sample



Number of AT&T VPN contracts originated and revised in each quarter during the sample period. Sample includes the 219 AT&T VPN contracts issued between February 1990 and October 1994.

Figure 4 Margins on AT&T and MCI Stand-Alone Toll-Free and Toll Services Between Fourth Quarter of 1988 and First Quarter of 1999

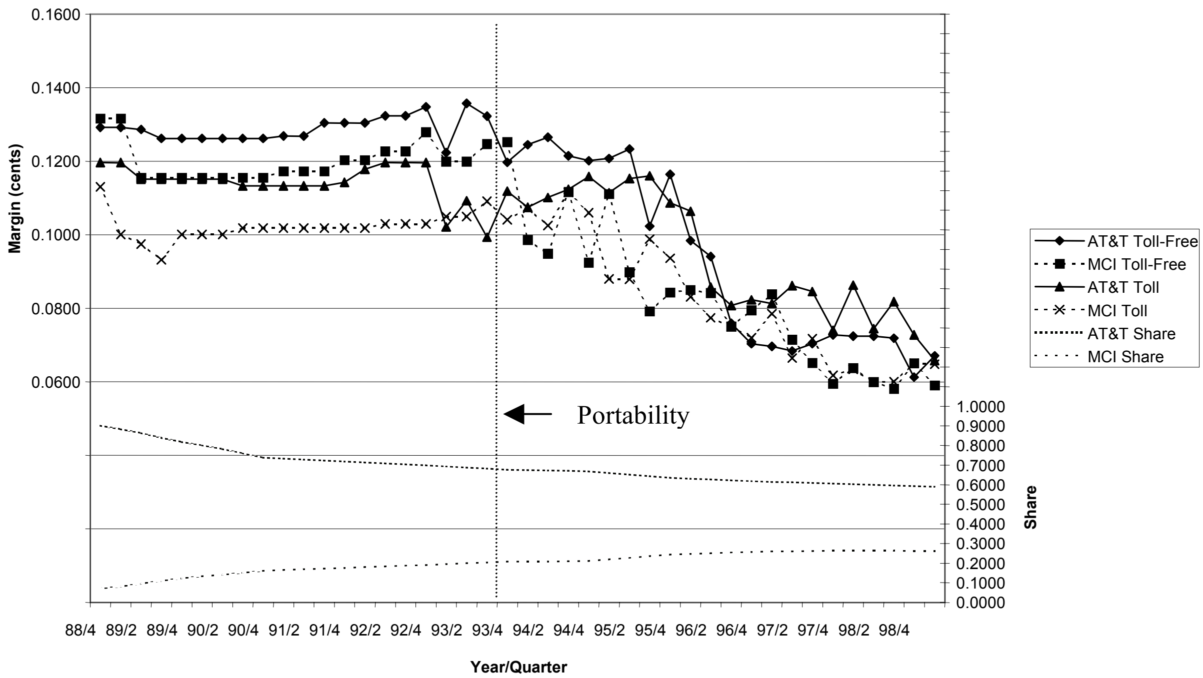
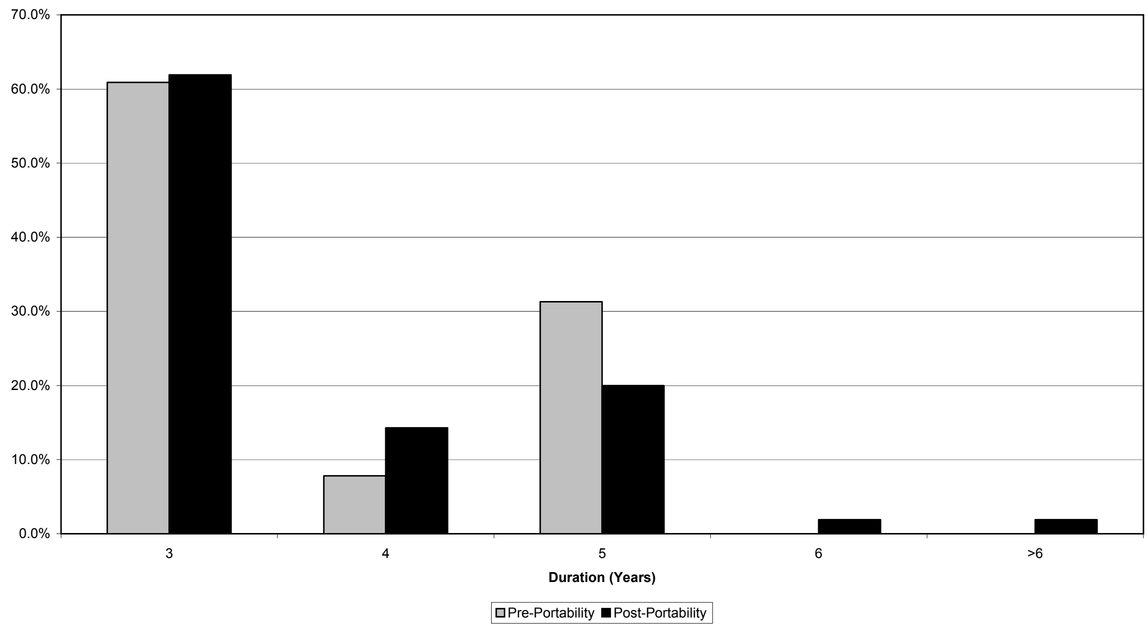


Figure 5 Distribution of Durations for Sample of AT&T VPN Contracts



Percentage of contracts in the sample of 219 AT&T VPN contracts that expire in the given number of years. The light shaded bars are for contracts issued before portability and the dark bars for contracts issued after portability.

Appendix 1 Position of Marginal Young Consumer

The marginal new consumer is indifferent between buying from AT&T and MCI after considering the effect it has on her future utility:

$$r - P_A - z_A^N + \delta_C(1-\rho)\left\{\mu\left[\int_0^{z_A^{R'}}\left(r - P_A^{'} - b\right)db + \int_{z_A^{R'}}^{1}\left(r - P_M^{'} - s - (1-b)\right)db\right] + (1-\mu)\left[r - P_A^{'} - z_A^N\right]\right\} =$$

$$r - P_M - \left(1 - z_A^N\right) + \delta_C(1-\rho)\left\{\mu\left[\int_0^{z_M^{R'}}\left(r - P_A^{'} - s - b\right)db + \int_{z_M^{R'}}^{1}\left(r - P_M^{'} - (1-b)\right)db\right] + (1-\mu)\left[r - P_M^{'} - \left(1 - z_A^N\right)\right]\right\}$$

where δ_C is the consumers' discount factor and primes indicate next period values. On the left-hand side of the equation is the consumer's discounted expected utility from purchasing from AT&T. The first term is the profit obtained in the current period. The two integrals measure the utility if the consumer's position changes in the next period and are multiplied by μ, the probability that they change. The first integral measures expected utility if the consumer buys from AT&T again while the second integral measures expected utility if she switches to MCI. The last term on the left-hand side measures the expected utility if the consumers' preferences do not change. The right-hand side is analogous if the consumer purchases from MCI. The utilities in later periods cancel out since the consumer will purchase from her favorite firm regardless of previous purchase history. Using

$P_M^{'} - P_A^{'} = e\left(1 - 2\sigma_A^{'}\right)$, $z_A^{R'} - z_M^{R'} = s$, $z_A^{R'} + z_M^{R'} = P_M^{'} - P_A^{'} + 1 = 1 + e\left(1 - 2\sigma_A^{'}\right)$,

$\left(z_A^{R'}\right)^2 - \left(z_M^{R'}\right)^2 = s\left(1 + P_M^{'} - P_A^{'}\right) = s\left(1 + e\left(1 - 2\sigma_A^{'}\right)\right)$ and

$\sigma_A^{'} = f(\sigma_A) = \rho z_A^N + (1-\rho)\rho\left[\mu\left(\sigma_A z_A^R + (1-\sigma_A)z_M^R\right) + (1-\mu)\sigma_A\right] + (1-\rho)^2 z_A^O$:

$z_A^N = a_1 + a_2\sigma_A + b(P_B - P_A)$ where $a_1 = \dfrac{1 + \delta_C(1-\rho)\left(1 + e(2-\rho)\rho - \mu(1 - e\rho(2\rho - 3)(1-s)) + e\mu^2(1-\rho)\rho(1-s)^2\right)}{2\left(1 + \delta_C(1-\rho)(1 + e\rho - \mu(1 + e\rho(1-s)))\right)}$,

$a_2 = -\dfrac{\delta_C e(1-\rho)^2\rho(1 - \mu(1-s))^2}{\left(1 + \delta_C(1-\rho)(1 + e\rho - \mu(1 + e\rho(1-s)))\right)}$ and $b = \dfrac{1 - \delta_C e(1-\rho)^2(1 - (1-\mu)\rho)(1 - \mu(1-s))}{2\left(1 + \delta_C(1-\rho)(1 + e\rho - \mu(1 + e\rho(1-s)))\right)}$.

The coefficients for AT&T's market share transition function, $f_A(\sigma_A)$ are:

$\eta = \rho(a_1 + be) + (1-\rho)\rho\dfrac{\mu}{2}(1 - s + e) + \dfrac{(1-\rho)^2}{2}(1+e)$ and $\theta = \rho(a_2 - 2be) + (1-\rho)\rho(1 + \mu(s - 1 - e)) - (1-\rho)^2 e$.

Appendix 2 Solving the Theoretical Model

Substituting (2) into (3), (4), (5), (6) and (8) and then these five equations into (9), I can equate the coefficients in (10) to those in (1) to obtain:

(A1) $k = (d-c)\left(\rho S/(1-\rho)(a_1+be)+\mu S\left(\frac{1-s+e}{2}\right)\right)+\delta_F\left(k+l\eta+m\eta^2\right)$

(A2) $l = (d-c)(\rho S/(1-\rho)(a_2-2be)+\mu S(s-e)+(1-\mu)S)+e\left(\rho S/(1-\rho)(a_1+be)+\mu S\left(\frac{1-s+e}{2}\right)\right)+\delta_F(\theta l+2m\eta\theta)$

(A3) $m = e(\rho S/(1-\rho)(a_2-2be)+\mu S(s-e)+(1-\mu)S)+\delta_F m\theta^2$

Maximizing (10), the first-order condition is:

(A4) $(P_A-c)\left[\rho/(1-\rho)\frac{\partial z_A^N}{\partial P_A}+\mu\rho\left(\sigma_A\frac{\partial z_A^R}{\partial P_A}+(1-\sigma_A)\frac{\partial z_M^R}{\partial P_A}\right)+(1-\rho)\frac{\partial z_A^O}{\partial P_A}\right]+$

$\left[\rho/(1-\rho)z_A^N+\mu\rho\left(\sigma_A z_A^R+(1-\sigma_A)z_M^R\right)+(1-\mu)\sigma_A+(1-\rho)z_A^O\right]+\delta_F(l+2mf_A)\frac{\partial f_A}{\partial P_A}=0$

The second-order condition for the problem is:

(A5) $2\left[\rho/(1-\rho)\frac{\partial z_A^N}{\partial P_A}+\mu\rho\left(\sigma_A\frac{\partial z_A^R}{\partial P_A}+(1-\sigma_A)\frac{\partial z_M^R}{\partial P_A}\right)+(1-\rho)\frac{\partial z_A^O}{\partial P_A}\right]+2\delta_F m\left(\frac{\partial f_A}{\partial P_A}\right)^2<0$

I confirm in my numerical solutions that this holds. Substituting the equilibrium market shares (3) for z_A^N, (4) for z_A^R, (5) for z_M^R and (6) for z_A^O into the first-order condition and using (2) yields:

(A6) $(P_A-c)\left[-\rho/(1-\rho)b-\frac{1}{2}(\mu\rho+1-\rho)\right]+\left[\rho/(1-\rho)(a_1+a_2\sigma_A+be(1-2\sigma_A))+\mu\rho\left(\sigma_A s+\frac{1-s+e}{2}-e\sigma_A\right)+\right.$

$\left.(1-\mu)\sigma_A+\frac{1}{2}(1-\rho)(1+(e(1-2\sigma_A)))\right]-\delta_F(l+2m(\eta+\theta\sigma_A))\left(\rho b+\frac{1}{2}(1-\rho)(\mu\rho+1-\rho)\right)=0$

Solving for P_A and equating the constants to those in (2) yields:

$$\text{(A7)} \quad d = c + \frac{\rho/(1-\rho)(a_1 + be) + \mu\rho\left(\frac{1-s+e}{2}\right) - \delta_F (l + 2m\eta)\left(\rho b + \frac{1}{2}(1-\rho)(\mu\rho + 1 - \rho)\right)}{\rho/(1-\rho)b + \frac{1}{2}(\mu\rho + 1 - \rho)}$$

$$\text{(A8)} \quad e = \frac{\rho/(1-\rho)(a_2 - 2be) + \mu\rho(s-e) + (1-\mu) - 2\delta_F m\theta\left(\rho b + \frac{1}{2}(1-\rho)(\mu\rho + 1 - \rho)\right)}{\rho/(1-\rho)b + \frac{1}{2}(\mu\rho + 1 - \rho)}$$

I use Mathematica to solve equations (A1) through (A3), (A7) and (A8) analytically. I first solve equations (A8) and (A3) to eliminate m and obtain e as a function of θ. This is a quadratic equation in e which yields up to two roots as a function of θ^2. I then use this result along with (8) to eliminate e and solve for θ as a function of the other parameters. This yields a quartic equation in θ which can yield up to four roots for each of the two possible values for e. This can produce up to eight possible values for θ. I choose the stable solution(s) (i.e. $|\theta| \leq 1$)[1]. In all my solutions, I obtained a unique stable solution.

All of the coefficients can then be calculated. Equation (3) yields a_1, a_2 and b, (8) yields η, (A3) yields m, (A2) yields l, (A7) yields d and (A1) yields k. Finally, I check that the necessary constraints on the problem are satisfied (the second order condition is met, individual rationality for each of the marginal consumer types holds and the marginal young consumer prefers to purchase when young rather than waiting to purchase until old).

In all my numerical solutions, θ and e have been positive. This implies that if firms' shares are not equally divided, the firm with the larger share prices higher than the firm with the small share and that firms' shares converge to one-half over time. Also, in all my numerical solutions, k, l and m have all been positive so that the firms' profits are increasing in its share.

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[1] Note that if $|\theta| > 1$ the firms' shares diverge.

Appendix 3 Data Sources & Methods

$w_{i,j}$ $j = 1,2,..,5$ (Mix of voice usage): Contracts specify four types of ports corresponding to telephone numbers. Measured ports and rate option 1 measured remote ports were toll numbers carried over a dedicated line. Rate option 2 measured remote ports were toll-free numbers carried over a dedicated line. Outside ports were toll numbers carried over switched lines. Separate documents, not publicly available, specified port access telephone numbers that defined the total number of toll-free numbers carried over switched or dedicated lines. The following matrix defines the five types of voice services that contracts can contain:

		Calls To		
		Measured port or Rate option 1 measured remote port	Rate option 2 measured remote port	Outside ports
Calls From	Measured port or rate option 1 measured remote port	1		2
	Outside ports	2		3
	Port access telephone numbers	4	5	

Let m_i equal the number of measured ports, $r1_i$ rate option 1 measured remote ports, $r2_i$ rate option 2 measured remote ports, o_i outside ports and p_i port access telephone numbers in contract i. Based on the above matrix, the weights assigned to voice service j in contract i, $w_{i,j}$, is given by the equations:

$$2(w_{i,1} + w_{i,1}) + w_{i,4} = m_i + r1_i \qquad w_{i,5} = r2_i$$

$$2(w_{i,2} + w_{i,3}) = o_i \qquad w_{i,4} + w_{i,5} = p_i$$

Because the contract provides $m_i, r1_i$ and $r2_i$ but not o_i and p_i (since they do not affect AT&T's fixed costs), we have four equations and seven unknowns. Using the assumptions in MacAvoy (1995, p.107), I assume $w_{i,2} = 3.25w_{i,1}$ and $w_{i,3} = 0.75w_{i,1}$. Finally, I impose: $w_{i,4} = \max\{3.25/0.75\, w_{i,5}, w_{i,2}\}$ (off-to-on toll-free calls occur in at least as high a proportion to off-to-off toll-free calls as off-to-on toll calls do to off-to-off toll calls, and there are at least as many off-to-on toll-free calls as off-to-on toll calls). I solve these seven equations and impose $\sum_{j=1}^{5} w_{i,j} = 1$ to express the weights as fractions.

$p^t_{A,i,j}$ $j = 1,2,...5$ (per-minute voice prices): Contracts tailor per-minute voice rates to time of day and distance. I use the per-minute rate for the most common call placed, a daytime call of four hundred miles. Contracts often contain monthly volume discounts for voice service. In applying these discounts I assumed the user consumed $revenue_i$ and mix of voice usage given by $w_{i,j}$.

c^t_j $j = 1,2,...,5$ (Marginal cost of voice usage): Marginal cost of voice calls includes access fees, operational costs and, for toll-free calls, database lookup fees. IXCs pay LECs per-minute access fees, which are regulated and published in tariffs with the FCC, to complete the switched portion of calls. Access fees vary across the five call types depending on whether neither, one or both ends of the call are switched. Since access fees vary slightly across LECS and the telecommunications operations of VPN users span multiple LECs, I use an average across all LECs published in FCC (1999). Access fees declined during the period of my study as the FCC shifted the cost of the local infrastructure toward monthly fees for residential long-distance consumers. I take estimates of operational costs from court testimony by AT&T in their June 1990 application to provide intrastate toll-free service in California.[2] Operational costs are constant over all output levels until demand exceeds the capacity of the lines. There is significant evidence that the three firms' capacity constraints were not binding during the time period of my study. Huber et. al. (1992, p.321) cites several studies. Another possible capacity constraint is the supply of toll-free numbers, but the industry did not run out of numbers for the 800 prefix until 1996, and 60% of the numbers were still available in April 1993 (FCC, 1999). After portability, the FCC allowed the LECs to charge a per-query fee to the IXCs for each lookup of an 800-number. Since this fee varied across LECs and VPN users generally span multiple LECs, I average across the nine major LECs and assume the average length of a toll-free call is 3.6 minutes.[3]

$revenue_i$ (Monthly contract revenue): 120% of the minimum volume commitment per month specified in the contract. Users avoid falling below the minimum because penalties require paying the shortfall, and exceeding the minimum by too far since they could have negotiated further volume discounts under a larger contract.

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[2] John Sumpter estimated operational costs for switched toll service to be 1.01 cents, switched toll-free service to be 1.08 cents, dedicated toll service to be 1.30 cents and dedicated toll-free service to be 1.29 cents in testimony on behalf of AT&T to obtain authority to provide intrastate service in California. Application of AT&T Communications of California, Inc. (U 5002 C), June 18, 1990 as reported in MacAvoy (1996).

[3] The nine LECs for which I have data are Ameritech, Bell Atlantic Corp., BellSouth Corp., Nynex, Pacific Telesis Group, Southwestern Bell Corp., US West Inc., GTE Telephone Co. and Southern New England Telephone Co. This data is taken from "Rates May Deter Use of 800 Portability," *Network World*, May 10, 1993, pp. 23, 24 and 34. 3.6 minutes is average length of call according to Strategic Telemedia (1996), p. 64.

Telecommunications consultants generally advise users to sign contracts so that expected usage is 120% of revenue commitment.

$duration_i$ (Contract duration): The minimum time commitment allowed under the contract. The exit penalties on all contracts required users to pay the minimum revenue commitment in each year of the contract regardless of how many minutes they consumed. Since prices were falling during this period, the minimum time commitment was most favorable to users.

$\sigma_A^{t-duration_i}$ (AT&T's previous market share of toll-free services): Annual toll-free revenue estimates by firm are available from Levinson, et. al. (1990) from 1985 to 1990 and Strategic Telemedia (1997) from 1992 to 1997. To concatenate these two sources, I stacked them in a regression on an AT&T dummy, an MCI dummy, a source (Levinson versus Strategic Telemedia) dummy and an estimate of total long-distance revenues from the FCC (1998). Using the regression results, I obtained predicted values of annual toll-free revenues assuming that Strategic Telemedia was the source. To obtain quarterly revenues, I assumed the same seasonality as total long-distance revenues reported in FCC (1998). Since I do not have estimates of toll-free revenues by user size, I assume that the time trend in quantities is the same for different sized users.[4]

$vdisp_i$ (Voice network dispersion): Number of remote dedicated voice lines as a fraction of total number of dedicated voice lines. IXCs leased dedicated voice lines from the LECs paying per-month fees regulated and published in tariffs filed with the FCC. Dedicated voice lines are of two types: access (high-volume lines terminating at an AT&T switching office) or remote (low-volume lines terminating at the subscriber's premises). The number of access lines is equal to the number of measured ports (m_i) specified in the contract. The number of remote lines is equal to the number of rate option 1 and 2 remote ports $(r1_1 + r2_i)$.

[4] The *Telecommunications Market Sourcebook* (Frost & Sullivan, 1995) provides evidence that the mix in revenues did not change much between dedicated service, used primarily by large users, and switched service, used primarily by small users, between 1992 and 1998 (page 15-8).