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Compatibility and Pricing with Indirect Network Effects: Evidence from ATMs

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Incompatibility in markets with indirect network e¤ects can a¤ect prices if consumers value ?mix and match?combinations of complementary network components. In this paper, we exam- ine the e¤ects of incompatibility using data from a classic market with indirect network e¤ects: Automated Teller Machines (ATMs). Our sample covers a period during which higher ATM fees increased incompatibility between ATM cards (which are bundled with deposit accounts) and other banks?ATM machines. A series of hedonic regressions suggests that incompatibility strengthens the relationship between deposit account pricing and own ATMs, and weakens the relationship between deposit account pricing and competitors?ATMs. The e¤ects of incom- patibility are stronger in areas with high population density, suggesting that high travel costs increase both the strength of network e¤ects and the importance of incompatibility in ATM markets.

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Compatibility and Pricing with Indirect Network Effects: Evidence from ATMs

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Abstract

Incompatibility in markets with indirect network effects can affect prices if consumers value "mix and match" combinations of complementary network components. In this paper, we examine the effects of incompatibility using data from a classic market with indirect network effects: Automated Teller Machines (ATMs). Our sample covers a period during which higher ATM fees increased incompatibility between ATM cards (which are bundled with deposit accounts) and other banks' ATM machines. A series of hedonic regressions suggests that incompatibility strengthens the relationship between deposit account pricing and own ATMs, and weakens the relationship between deposit account pricing and competitors' ATMs. The effects of incompatibility are stronger in areas with high population density, suggesting that high travel costs increase both the strength of network effects and the importance of incompatibility in ATM markets.

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1 Introduction

In order to perform an Automated Teller Machine (ATM) transaction, consumers must employ both an ATM card and an ATM. In the parlance of the literature on network economics, this creates an indirect network effect: a feedback effect between complementary components of a system, through which consumers' value of any one component is connected to the availability of another.[1] Indirect network effects exist in many markets with emerging technologies; computer hardware and software, operating systems and spreadsheets, and different audio/visual systems are a few well-known examples. In ATM markets as in some of these other examples, integrated firms sell both components of the system: ATM cards (via deposit accounts) and ATMs. This creates an internalized network effect, in which an increase in the availability of a bank's own ATMs increases consumers' willingness to pay for deposit accounts. Furthermore, ATM machines can operate on shared networks, allowing consumers to use their card at an ATM owned either by their own bank or another bank. This permits consumers to *mix and match* components sold by different firms.

Compatibility between components offered by different firms is important in markets with indirect network effects.[2] Compatibility allows consumers to construct a wider array of mix and match goods, increasing their choice sets.[3] In ATM markets, compatibility depends on whether consumers can use their cards with other banks' ATM machines. In its brief history, the ATM market has exhibited varying degrees of compatibility. While at its inception the market exhibited complete incompatibility because ATMs accepted only ATM cards issued by their owning bank, over the 1980s compatibility emerged as banks formed shared networks that allowed customers to use their cards at other banks' "foreign" ATMs. At that point, banks' network membership determined the degree of compatibility. By the early 1990s, all banks essentially subscribed to common networks, allowing full compatibility between cards and competitors' ATMs.

In this paper, we examine the empirical effects of a later shift toward incompatibility between cards and foreign ATMs. In an environment where banks operate on shared networks, incompatibility between deposit accounts and competitors' ATMs results from banks' imposition of fees associated with foreign transactions. There are two such fees: a *foreign fee* levied by the customer's home bank and a *surcharge* imposed by the bank owning the foreign ATM. Both foreign fees and

[1] Economides (1989, 1991) and Matutes and Regibeau (1988, 1992) cite ATMs as an example of a market with indirect network effects.

[2] While our focus is on compatibility, markets with network effects raise a number of other questions related to competition and economic welfare. These other issues are the subject of a wide theoretical (and smaller empirical) literature.

[3] We focus here on the short-run relationship between compatibility and pricing. Longer-run issues (such as the relationship between compatibility and product characteristics) are the focus of other work in the area (e.g., Knittel and Stango 2004).

surcharges create incompatibility, although in slightly different ways. Because customers link their valuation of deposit accounts to the surcharging behavior of other banks owning ATMs in their local market, incompatibility of a given bank's card with other ATMs depends on the surcharges imposed by other banks. Following the literature on network economics, we expect incompatibility to change the relative importance of the complementary components in the system. Because incompatibility makes competitors' ATMs less accessible, it should reduce the strength of the relationship between them and deposit account pricing. It may also strengthen the link between own ATM density and deposit account pricing. The extent of these changes should depend on the degree of incompatibility.[4]

We take advantage of a quasi-natural experiment to identify these effects. Before 1996, the largest shared networks barred banks from imposing surcharges, while after 1996 they removed the ban and surcharges became widespread.[5] This represents a discrete move toward incompatibility. There is also a certain amount of variation after 1996 in the degree to which surcharging is adopted. Some banks adopt surcharging quickly, while others move more slowly. Finally, within the set of banks that surcharge we observe variation in the level of fees. While we include foreign fees in the analysis, they change little over our sample period, meaning that the post-1996 advent of surcharging provides the primary source of identification in the data.

Our data consist of bank/year observations for a panel of banks competing in local markets across the United States from 1994-1999. For each bank, we observe its average deposit account fees, ATM deployment across its markets, and ATM fees. This allows us to identify the own ATM access granted to consumers by having a deposit account with that bank. We can further distinguish the influence of available competitors' ATMs by constructing a measure of the competitors' ATMs available to that bank's customers. We measure incompatibility for each bank using a measure of the surcharges imposed by competitors in its local markets.

Our empirical approach consists of estimating a set of hedonic regressions linking deposit account pricing to account characteristics and the availability of ATMs associated with the account. The hedonic regressions establish that both own and competitors' ATMs are positively related to deposit account prices. We also examine how incompatibility changes the relationships between component availability and deposit account pricing. Our findings are broadly consistent with the implications of theory. We find that incompatibility reduces the strength of the link between other banks' ATM availability and deposit account prices and increases the strength of the link between own

[4]In the long run, this may also affect equilibrium ATM deployment (supply) decisions, based on the indirect network effect between demand for ATM cards and supply of ATMs.

[5]Nine states overrode the ban prior to 1996; we account for this in the empirical work below. See Prager (2001) for an examination of this episode. One state (Iowa) maintained its ban after 1996, but our sample contains no data from banks in Iowa.

ATM availability and deposit account pricing. Our results are robust to different measures of incompatibility, ATM availability, and deposit account prices.

We also attempt to understand how travel costs affect the relative importance of network effects and incompatibility. We find that network effects and the effects of incompatibility are much stronger in markets with high population density. Because high population density increases travel costs, we interpret this as consistent with the notion that travel costs are an important determinant of the relationship between ATM services and deposit account pricing. Given the weakness of the results in low density markets, however, we also admit the possibility that our model is well-specified for high-density markets but poorly specified for low-density markets.

The final section of the paper broadens the interpretation of our results within the hedonic framework. It is well known that hedonic regressions should not be strictly interpreted as identifying utility parameters; rather, they should be viewed as reduced form relationships reflecting the influence of other factors such as changes in costs and markups. We therefore present results from fuller specifications of the model that include independent variables capturing demand and supply effects. Our primary results remain qualitatively similar, suggesting that shifts in observable supply and demand influences are not responsible for our results.

These results shed light on an aspect of network effects—incompatibility—that previous work has found difficult to examine empirically. There is a small literature taking incompatibility as given, generally seeking to establish the existence of network effects.[6] Existing work on incompatibility is essentially limited to the study of competition between incompatible networks, and has employed fairly limited data on incompatibility.[7] Our work benefits from the ability to ob-

[6] Examples of work taking incompatibility as given include Gandal, Greenstein and Salant (1999), who study the link between operating system values and software availability in the early days of the microcomputer market. They find evidence supporting the existence of indirect network effects. More recent work by Gandal, Kende and Rob (2002) tests for indirect network effects in the adoption of Compact Disks (CDs) and CD players. Rysman (2000) provides evidence supporting the existence of complementary demand relationships in a two-sided platform market (Yellow pages). More recent work by Shankar and Bayus (2002), Nair, Chintagunta and Dube (2003) and Karaca-Mandic (2003) applies structural econometric techniques to test for the existence of network effects in markets where compatibility is fixed.

[7] Gandal (1994, 1995) and Brynjolfsson and Kemerer (2001) find that computer spreadsheets compatible with the Lotus system commanded higher prices during the early 1990s. Our work differs from this early work, in that it estimates the effects of compatibility across different components of the network. It also differs in that it primarily relies on within-firm and within-market rather than cross-sectional variation in compatibility for identification. More precisely, the analyses in Gandal (1994, 1995) and Brynjolfsson and Kemerer (2001) do not separate within-firm from cross-sectional effects of compatibility. The datasets are panels, but too small to allow the examination of within-firm variation. In one other piece of work examining a different market, Greenstein (1994) finds that mainframe buyers prefer to upgrade to compatible systems, a result suggesting that compatibility between past and future hardware is important.

serve within-market changes in incompatibility and a measure of incompatibility that is continuous rather than discrete, although in practice our identification strategy relies on a fairly discrete shift toward incompatibility. Our work also adds to the existing empirical literature examining ATM markets. In general this literature does not focus on the indirect network effects linking ATM cards and machines, although it does in some cases test hypotheses that relate to network effects.[8]

2 Deposit Accounts and ATM Services

ATM cards are generally sold as part of the service bundle attached to a consumer's deposit account. The deposit account is a checking account into which the customer deposits funds, and from which the customer withdraws funds periodically.[9] The standard deposit account agreement also offers customers free access to the bank's own ATMs. ATMs allow bank customers to perform transactions electronically on their deposit accounts. Banks locate their ATMs "on-premise" at bank branches, and also "off-premise" at locations such as convenience stores, movie theaters, bars, and other locations where consumers typically need cash. In addition to deposit account services, banks offer savings account services and a wide variety of other financial services such as loans, brokerage and investment services and insurance. In principle, consumers can purchase these services from separate banks, and sometimes do.

While banks' strategic behavior is not the focus of our analysis here, it is worth highlighting the most important features of competition between banks. In the United States, approximately 10,000 commercial banks compete for deposit account customers in their local markets.[10] Smaller

[8] Hannan, et al. (2002) examine banks' propensity to impose surcharges as a function of a variety of characteristics, although they do not explicitly link their analysis to deposit account pricing. Prager (2001) tests whether small banks lost market share in states that allowed surcharges prior to 1996; this is implicitly a test of whether incompatibility favored banks with high-quality ATM fleets, although she does not pose the question in those terms. Hannan and McDowell (1984a, 1984b, 1990) explore the relationship between market concentration and ATM adoption. They find that markets in which large banks adopted ATMs became more concentrated during the 1980s, although they do not discuss their finding in terms of network economics. Finally, Saloner and Shepard (1995) examine the diffusion of ATMs from 1972-1979 and find that adoption occurred earliest for firms with many branches and deposits, a result they interpret as consistent with the existence of indirect network effects in demand. Gowrisankaran and Krainer (2003) estimate the welfare effects of the increase in ATM deployment stemming from the surcharge ban, although their model does not incorporate network effects.

[9] During our sample most ATM cards began serving as debit cards. We do not directly model the link between these markets, although it appears that they are linked. The advent of surcharging in 1996, for example, appears to have spurred increased use of debit cards for purchases. Consumers' ability to substitute away from ATM use following the imposition of surcharges would attenuate the link between surcharging and willingness to pay for deposit accounts. Provided this substitution is not perfect, we would still expect to see an effect of surcharging on willingness to pay for deposit accounts.

[10] Our data omit observations for credit unions and thrifts. However, these institutions collectively hold only a

banks often operate only within a small geographic area such as a county, in many cases using a single branch. The largest banks conduct operations in many states or even nationally, and can have thousands of branches and ATMs. Markets are typically assumed to exist at the county level, a convention that we adopt in our analysis in identifying banks' competitors.[11] There is considerable heterogeneity in market structure across regions, with rural markets typically being more concentrated than urban markets. Even within markets, there is considerable variation in banks' ATM strategies—some banks blanket their markets with ATMs, while others deploy them sparingly. As we will illustrate below, one of the most systematic differences across banks regarding ATMs is that large banks deploy them more aggressively than small banks (relative to maintaining branches, for example). Another is that ATM deployment is largely concentrated in areas of high population density. We discuss the implications of this fact in some detail below.

Banks subscribe to "shared networks" that allow their customers to use other banks' ATMs. In most cases access to these "foreign" ATMs is incomplete because it only allows consumers to withdraw cash; more complex transactions such as making deposits are not permitted through the shared network. The networks themselves are typically joint ventures formed by banks in order to share the fixed costs of interconnection infrastructure. Banks usually pay a fixed monthly or annual membership fee to the network. They also pay a "switch fee" for each transaction made by one of their customers on another bank's ATMs; the switch fee is roughly $0.40 on average during our sample, and does not vary significantly across networks or regions. Part (on the order of $0.10) of the switch fee is paid to the network, and the remainder flows to the ATM's owner in order to compensate it for providing services to a non-customer.

Bank customers therefore purchase from their home bank a bundle of services associated with the deposit account, including both an ATM card and unlimited access to that bank's ATMs. These bundles are differentiated both horizontally and vertically. Horizontal differentiation primarily stems from geography; consumers strongly prefer banks with branches and ATMs that are conveniently located.[12] Services other than deposits provided by banks can confer both horizontal and vertical differentiation. These complementary services include savings and money market accounts, loans ranging from mortgages to credit cards, and brokerage services. Large banks are more

small share of the deposit market.

[11] Some work treats multi-county MSAs rather than individual counties as markets in urban areas—in our case, doing so makes no difference empirically. This is due to our focus on within-market changes rather than cross-sectional differences. Any differences between the levels of variables measured at the county rather than MSA are likely to be constant for a given bank over time, and are swept out by bank fixed effects. Recently, the question of whether banking markets have become less local has come to light (see Radecki [1998] for a discussion). While this may be true for products such as mortgages, it is unlikely to be true for consumers' ATM usage, which is necessarily local.

[12] See Stavins (1999) for a discussion of the characteristics that consumers favor when making their deposit account choices.

likely to offer these services, although they become more widely available at banks of any size over our sample period. Vertical differentiation also exists across features of the deposit account; banks vary in quality of customer service, for example. A good deal of vertical differentiation stems from ATM availability; banks often use the size of their ATM fleet as a component of their marketing strategy.

For any given deposit account bundle, customers will also base their willingness to pay on the degree to which they can use other firms' ATMs. This depends on both the availability of those ATMs in the local market, and on the compatibility between cards and other banks' machines. Incompatibility in turn is a function of the fees imposed by other banks for such use. Because this relates so closely to the network literature on incompatibility, we now discuss that literature in order to motivate our empirical work.

3 Network Effects and Incompatibility

In recent years a wide-ranging theoretical literature has emerged examining the effects of compatibility in markets with indirect network effects.[13] Indirect network effects are strong complementary relationships in demand between component products that consumers assemble into systems. In such settings there is a further distinction between components that are "hardware" and components that are "software." In such settings, "hardware" is the component of the system that is durable or otherwise incurs greater switching costs. In the case of ATMs, cards are hardware because they require the purchase of a subscription good—the deposit account—that carries switching costs.

Considering the institutional detail of the ATM market, the most relevant models are those in which integrated firms sell both components of the system.[14] The compatibility issue then becomes whether Firm A's components will function with Firm B's complementary components, and vice versa. Transactions of this sort, in which consumers purchase components from different firms are known as "mix and match" transactions. While much of the theoretical literature considers cases of absolute compatibility or incompatibility, a related literature examines cases of partial compatibility, where for example consumers can attain compatibility by paying an "adaptor fee" enabling them to use otherwise incompatible software. The intuitions we highlight below are generally robust to whether compatibility is absolute or adaptor-based.

[13] See Katz and Shapiro (1994) for a review.

[14] Chou and Shy (1989), Church and Gandal (1992), and Matutes and Regibeau (1989) consider cases where network components are sold separately. Economides and Salop (1992) provide a comparison of market structures characterized by different forms of integration and ownership among component producers. Matutes and Regibeau (1992) examine a case where firms produce both components of the network, but may bundle them together.

The most general result of these models is that holding prices constant, incompatibility (weakly) reduces consumers' willingness to pay. The strength of this effect depends on the degree to which consumers want to "mix and match" components from different sellers. If demand for such transactions is zero, incompatibility leaves consumers unchanged, but if demand for mix and match transactions is high, incompatibility reduces aggregate willingness to pay. These effects may vary by firm; firms with high demand for mix and match transactions will experience a larger reduction in willingness to pay. In our sample, we would expect this implication to be reflected by a fall in prices as surcharging becomes prevalent, *ceteris paribus*.[15]

A second result of the network literature is that incompatibility shifts the relative importance of components, because it moves consumers' purchase decisions from the component to the system level. With full compatibility, a customer may purchase components separately, but with incompatibility a customer chooses between bundled systems offered by different sellers. In a hardware/software market, moving from component to system purchasing should therefore strengthen the empirical link between own software availability and hardware prices, and weaken the link between competitors' software availability and prices. In our setting, we can see this intuition by considering an environment with no ATM fees. In that case customers would value the only the total density of ATMs, without regard to their ownership. Once incompatibility exists, own ATMs become relatively more valuable than competitors' ATMs because competitors' ATMs are not fully compatible.

The fact that ATM and banking behavior involves travel is also important. Most models of ATM/banking competition portray consumers as facing travel costs to use ATMs. This influences, for example, the marginal decision regarding whether to use a close foreign ATM (which carries fees) or a more distant own ATM. This implication has a clear analogue in the hardware/software literature; in most theoretical models of hardware/software pricing, consumers find software availability valuable because it reduces the distance (in characteristic space) to their favorite software variety. While most theoretical models implicitly hold travel costs constant, in general we would expect that the implications discussed above would be stronger for consumers facing high travel costs. At zero travel costs, for example, consumers would never use a foreign ATM or pay fees as long as their home bank had one ATM somewhere. While quantifying travel costs is difficult, it is widely accepted that areas with high population density have significantly higher travel costs than non-dense rural areas. To account for this, in the empirical work below we present results for subsamples of high and low population density.

There are limitations to our approach. A first limitation is that it abstracts from the com-

[15] This abstracts from the selection effect that would lead customers with inherently high "mix and match" demand to migrate toward banks with large ATM fleets. Such a selection bias will reduce the estimated impact of surcharging.

patibility choice at the firm level. Firms clearly choose the level of incompatibility, meaning that it is jointly determined with other features of competitive equilibrium. In our case, the shift is plausibly exogenous for two reasons. First, firms were barred from surcharging prior to 1996 by the by-laws of the largest networks. The advent of surcharging therefore represented the removal of a constraint, rather than an endogenous shift in strategic behavior. Second, we examine how surcharging by a firm's competitors affect its pricing, rather than how its own surcharging affects its own pricing. Of course, in concentrated local banking markets such decisions are interrelated, but the relationship is less direct. A second limitation of our partial equilibrium approach is that it takes firms' characteristics as given—most notably their software quality, as measured by the size of their ATM fleet. There is little question that the advent of surcharging changed the business model for ATM operations and accelerated the deployment of ATMs; this will become apparent when we discuss the descriptive statistics below. However, for our purposes the deployment decision is not the margin of interest. We are interested in measuring how changes in deployment affect pricing for deposit accounts under both compatibility and incompatibility. Another limitation of our work is that while there is surely considerable consumer-level heterogeneity in willingness to pay, our data do not lend themselves to an examination of this heterogeneity.[16] Our approach is rather to estimate average effects. While this could be a concern if the distribution of consumers with different characteristics changed across firms based on the shift to incompatibility, we are unable to find evidence that this happened.[17]

4 Hedonic Specifications

A wide literature uses hedonic methods to estimate the relationship between product characteristics and prices.[18] The underlying hypothesis of the method is that products may be viewed as bundles of characteristics that are valuable to consumers. A hedonic regression attempts to uncover

[16] We do attempt to handle some heterogeneity in the sample through our analysis of the relationship between population density and network effects. However, we are unable to incorporate other consumer-level data. For example, one might imagine that income would affect the importance of network effects. There are no data at the market level, unfortunately, on income. (The Census publishes county/year level income data, but these are simply interpolated between the decennial census figures.)

[17] For example, we know that banks with high deposit balances/account will have lower price measures, because banks waive explicit deposit fees for customers with high balances. This would be a concern if the shift to surcharging caused the distribution of balances/account to shift across banks, because it would introduce a spurious correlation between surcharging and prices. In unreported results, we regress balances/account on our measure of incompatibility and find no relationship between them.

[18] The pioneering work of Rosen (1974) is often cited as justification for hedonic models measuring willingness to pay.

information about the marginal values of these characteristics to the typical consumer. The typical hedonic regression regresses price for product i at time t on a set of product characteristics X_{it} and (possibly) a set of fixed effects (α_i, α_t):

$$\ln(p_{it}) = X_{it}\beta + \alpha_i + \alpha_t + \varepsilon_{it}, \tag{1}$$

This is also the approach taken in some other studies of compatibility.[19] A strict interpretation of the hedonic specification is that the β coefficients represent willingness to pay (marginal value) attached to characteristics, while the α_i product dummies represent time-invariant price shifters. If the β and α_i coefficients remain constant over time, one can also interpret the time dummies as the basis for constructing a price index.[20] As a general point (one that is true in any regression), the β coefficients will be biased by the omission of unobserved characteristics that are correlated with X_{it}.

More formally, it has been well documented in recent years that in general the β coefficients will not reflect underlying utility parameters, as is sometimes assumed in hedonic modeling. Rather, the coefficients should be viewed as coming from a reduced form model capturing a combination of cost- and demand-based influences on prices, as well as any markups over marginal cost resulting from product differentiation or oligopolistic behavior.[21] The literature focusing on this issue has identified a set of assumptions under which the baseline hedonic regression above provides estimates of consumer willingness to pay. In particular, under perfect competition with linear or log-linear marginal costs, a hedonic regression will capture the contribution of each characteristic to marginal cost (and hence marginal value).[22] Under imperfect competition the hedonic coefficients will represent marginal values only if the relationship between characteristics and utility follows particular functional forms.[23] However, it is unlikely that these assumptions hold in our data, for reasons we discuss below. Therefore, in section 5 below we present a variety of alternatives to the baseline hedonic model in order to assess the robustness of our results. We also attempt to be circumspect about interpreting our results as strictly measuring changes in willingness to pay.

Returning to the specification above, in our case we estimate the relationship between prices for deposit accounts and characteristics of deposit account bundles. The unit of observation is

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[19] See, *e.g.*, Gandal (1994).

[20] See Triplett (1986).

[21] See Triplett (1986, 1988) for early discussions of this point in the context of the confusion between "resource costs" and "valuation." Pakes (2003) treats the issue more formally by constructing bounds on the relationship between reduced form coefficients as compensating variation (*i.e.*, willingness to pay).

[22] This discussion follows Feenstra (1995).

[23] See Feenstra (1995) for details. The condition relates to the function describing the "durability" component $h(X_{it})$ of quality; if this function it homogeneous of degree one in product characteristics, the hedonic regression captures marginal values even under imperfect competition.

the bank/year level. Our measure of deposit account prices divides annual income associated with deposit accounts by year-end balances in these accounts:

$$p_{it} = \frac{FeeInc_{it}}{Deposits_{it}}. \tag{2}$$

This measure reflects the annual price per dollar of deposit account balances.[24] The fee income measure includes revenue from monthly account fees, fees on bounced checks, per-check transaction charges, extra fees for returned checks, and in rare cases fees for the use of tellers' services. It also includes "foreign fee" revenue; we discuss the implications of this below. It does not include income from surcharges, as surcharge revenue is collected from non-customers and therefore falls into a separate revenue category. While this measure of prices is commonly used in the banking literature, a concern is that it may not fully reflect the marginal prices that consumers pay for deposit accounts. In our case, this is less of a concern because we use price as the dependent variable; measurement error will therefore only bias our coefficients of interest to the degree that it is correlated with our right-hand side variables. We also include bank fixed effects, meaning that we require only that within-bank variation in this measure is correlated with within-bank variation in true marginal prices. Nonetheless, we estimate our model using a number of alternative price measures; our results are robust to the use of these alternative measures.

Characteristics include those associated with ATMs and those associated more generally with deposit accounts. Account characteristics include the number of branches per square mile owned by the bank in all of its local markets (counties), the number of employees per branch, and the average salary per employee. The last variable attempts to capture service quality, although it is also clearly correlated with average costs. To capture the possibility that consumers value obtaining banking services outside their home county, we also include the number of counties in which the bank operates. We also observe a number of bank-level characteristics that do not vary over time (or vary only slightly). These characteristics include whether the bank is a subsidiary of a large bank holding company, whether the bank offers credit card, money market or brokerage accounts, and a dummy variable indicating whether the bank operates in multiple counties. While we can not include these characteristics in our hedonic regression because we also include bank fixed effects, we use a two-stage procedure to estimate the relationship between these characteristics and prices.[25] Appendix B outlines this procedure and presents results, which we summarize below.

ATM characteristics include both the ATMs owned by bank i, and the ATMs owned by its competitors in the local markets in which it competes. Both types of ATMs should increase will-

[24] See the Data Appendix for more detail on the construction of this variable.

[25] As suggested by Chamberlain (1982), we regress the estimated fixed effects from the first stage on the fixed bank characteristics.

ingness to pay for the deposit account based on the indirect network effect relating deposit accounts and ATMs. In the absence of ATM fees (incompatibility), all banks' ATMs might be equally valuable to consumers, although consumers may prefer their own banks' ATMs if they offer greater functionality (such as deposit-taking).

This implies that in the absence of incompatibility, prices should be related to bank characteristics, own ATM density and competitors' ATM density:

$$\ln(p_{it}) = X_{it}\beta + \gamma_1 \ln(OwnDens_{it}) + \gamma_2 \ln(CompDens_{it}) + \alpha_i + \alpha_t + \varepsilon_{it}. \tag{3}$$

We measure density as ATMs per square mile over all counties in which the bank operates. We use logs to reflect the fact that each additional machine reduces the expected travel distance to use an ATM by a successively smaller amount. One issue with this specification is that we have only partial data on competitors' ATMs. Our data source provides information regarding the ATM deployment of the largest 300 issuers in the United States; these issuers collectively hold a significant majority of all ATMs during our sample period, but not all. In order to deal with this, we estimate the number of ATMs deployed by each bank's competitors for which we do not observe actual deployment.[26] We have used a variety of techniques for this estimation, an issue discussed in Knittel and Stango (2004).[27] We outline the estimation procedure in Appendix B, and discuss its implications below.

4.1 Specifying Incompatibility

Incompatibility should change the relative (net) value of own and competitors' ATMs. It makes competitors' ATMs relatively less attractive by increasing the explicit costs associated with traveling to a competitors' ATM. It also makes own ATMs more relevant because on the margin, consumers will likely make more transactions at their bank's ATMs. We therefore allow incompatibility to affect prices by interacting it with ATM density:

$$\begin{aligned} \ln(p_{it}) \quad = \quad & X_{it}\beta + \gamma_1 \ln(OwnDens_{it}) + \gamma_2 \ln(CompDens_{it}) + \gamma_3 \ln(OwnDens_{it})Incompat_{it} \\ & + \gamma_4 \ln(CompDens_{it})Incompat_{it} + \gamma_5 Incompat_{it} + \alpha_i + \alpha_t + \varepsilon_{it}. \end{aligned} \tag{4}$$

[26] We do not have data on ATM deployment by Independent Service Operators (ISOs), who began deploying machines after the advent of surcharging. Aggregate data indicate that by 1999, ISO-deployed ATMs comprised ten percent of ATMs nationwide. The effect of these ATMs on prices is an omitted variable in our specifications.

[27] Almost all smaller issuers deploy roughly one ATM per branch, with deployment growing slightly over time. Aggregate data from the Card Industry Directory confirm this; in every year between 1994 and 1999, the roughly 10,000 issuers outside the top 300 deploy a total of 10,000 ATMs.

We also include the level of compatibility. While there is no clear theoretical justification for doing so, it is possible that there are other changes in bank characteristics or consumer behavior that are correlated with the shift toward surcharging. Including the level of compatibility may control for such factors. We discuss this point more thoroughly in section 6.

We measure incompatibility in three ways. First, because the primary change in compatibility was discrete following elimination of the surcharge ban, we construct a dummy variable equal to one if the state in which a bank has primary operations allows surcharging.[28] This variable is equal to one for all observations after 1996. The second way we measure incompatibility is by estimating the average surcharge a consumer would pay for using another bank's ATM. This measure is:

$$E\left[Surcharge_{it}\right] = \sum_{-i} w_{-it} Surcharge_{-it}. \tag{5}$$

The average surcharge is weighted, where the weights are the shares of total ATMs held by other banks in bank i's local market(s). The motivation for this specification is an assumption that consumers know something about the distribution of ATMs and ATM fees in their local market, but do not have perfect knowledge regarding either specific fees at each ATM or the locations in which they will experience an unanticipated need for cash.[29] Because we possess surcharge data for only the largest ATM issuers in each market, constructing this average requires making an assumption about the surcharging behavior of smaller issuers. We outline these assumptions and discuss robustness in Appendix A; our results are quite robust to different assumptions about the behavior of smaller issuers.

We also construct an incompatibility measure that includes the bank's own foreign fees:

$$E\left[ForeignCost_{it}\right] = ForFee_{it} + \sum_{-i} w_{-it} Surcharge_{-it}. \tag{6}$$

This measure has the advantage that both foreign fees and surcharges affect the marginal degree of incompatibility between a card and competitors' ATM. However, the price measure includes foreign fee revenue, so using this measure will bias the coefficient on incompatibility because higher fees *per se* lead to higher prices. This limits our ability to interpret these coefficients. In practice, the results are quite similar using any measure of incompatibility, because nearly all of the variation in any incompatibility measure stems from the post-1996 regime change in surcharging.

Finally, while the largest networks barred surcharging prior to 1997, a number of states overrode the bans prior to 1997. While we do not observe the extent of surcharging in these states, we can identify their effects through a dummy variable $AllowSurch_{it}$. In some specifications below we also

[28] We define the state of "primary operations" as that where the bank holds the greatest dollar value of deposits.

[29] This is analogous to the modeling assumptions in Massoud and Bernhardt (2002).

include this other measure. This is particularly useful given that most variation in incompatibility occurs discretely in 1997; the $AllowSurch_{it}$ variable provides a test against the hypothesis that the value of ATMs changed after 1996 due to some unobserved factor.

4.2 Econometric Issues

While these data are in principle very rich, we do face measurement issues in both our competitors' fees and ATMs variables. The presence of measurement error will bring the estimated coefficients toward zero, biasing against finding an effect of the ATM variables.[30] However, our empirical focus is more on testing whether there was a shift in the relationship between prices and ATM density following surcharging than on obtaining accurate point estimates of our coefficients. In other work where we focus more on the latter concern, we implement a statistical correction for measurement error and undertake a variety of robustness checks of the technique.[31]

A further econometric concern with our specifications above is endogeneity. We would expect that a bank's ATM density and deposit fees might be determined jointly as part of a bank's overall business strategy, or both affected by unobservable variables. Branch density and our other bank-level characteristics might also be endogenous for similar reasons. If banks set fees strategically, we might also expect competitors' surcharging to be related to a bank's ATM density or deposit fees. It is difficult to think of an appropriate (and large enough) set of instruments, although in other work we use higher moments of the observable variables as instruments with some success.[32] For the purposes of this paper, we view the joint changes in the observable variables as occurring because of the surcharge ban removal; this was a relatively exogenous event from the perspective of individual banks.

We also might expect that the coefficient on competitors' ATMs would be biased negatively by the fact that competitors' ATMs increase both willingness to pay for own deposit accounts and willingness to pay for competitors' accounts. Thus, they may increase total willingness to pay for a given bank, but shift its residual demand curve inward because it increases willingness to pay for its competitors' accounts by more. For this reason, we view the coefficients on competitors' ATMs as probably biased downward.

Finally, omitted variable bias may be a concern. There are two aspects to this. First, a concern might be that during our sample prices some factor other than ATMs or incompatibility is driving price changes. While this certainly might be true, it would have to be the case that the factor would be correlated both with within-bank changes in ATM density and within-bank price changes. Any

[30] See Fuller (1987) for a discussion of the problem and some solutions.

[31] See Knittel and Stango (2004) for details.

[32] See Knittel and Stango (2004).

common factor across banks leading to changes in prices would be controlled for by our fixed year effects. Furthermore, our identification strategy relies on changes in the variables of interest rather than levels. So, for example, an unobserved factor leading banks with low ATM density to experience falling prices relative to banks with high ATM density would not drive our results (though this is true in the sample); in our specification, identification comes from the effect of incompatibility on the relationship between changes in ATMs and changes in prices.

Second, while our focus is on the ATM market, during the time period of our analysis the availability of point-of-sale terminals for debit card use was growing rapidly. This is a concern, both because these terminals would affect willingness to pay and because their deployment is generally viewed as having accelerated after 1996 as consumers increasingly used debit to avoid surcharges. We explore this issue in related work, by including a variety of bank-level debit transaction measures in a structural model of deposit account demand.[33] We find no evidence that these measures bias our coefficients of interest. Moreover, to the extent that incompatibility itself led to increased debit terminal availability and changed the level of prices, including the level of incompatibility in the specification will control for terminal availability.

4.3 Data and Descriptive Statistics

Table 1 presents descriptive statistics for our sample. Appendix A outlines definition and measurement issues for these variables. We take our data from a variety of sources. The ATM-related characteristics come from the *Card Industry Directory*, an annual trade publication listing data on ATM fleets and fees for the largest three hundred ATM issuers. Many of those issuers are holding companies consisting of multiple banks; this gives us data for roughly 3700 bank/years over the sample period 1994-1999.

In most cases we report median values for our data, because the data are highly skewed. One source of skewness is bank size; for example, while the median bank size (in deposits) is $326 million, the mean is $2.3 billion. The tenth and ninetieth percentiles are $58 million and $5.8 billion. Another source of skewness is geographic diversity, realized largely through differences in branches and ATMs per square mile. The only variables for which we report means are those that are not skewed: deposit fees, ATM fees and our analogous measures for competitors, salary per employee and employees per branch.

The top rows show data by year regarding branches, ATMs, fees and the other variables included in the hedonic specification. Branches remain roughly constant, but ATMs (and competitors' ATMs) grow significantly over the sample period. The average level of deposit fees remains constant, although this is a bit misleading; we show below that among banks whose ATM fleets grew rapidly,

[33] See Knittel and Stango (2004) for details.

prices rose as well. Foreign fees remain roughly constant, while surcharges become quite prevalent between 1997 and 1999, which nearly doubles a customer's expected costs for using a foreign ATM. Salary per employee and employees per branch remain essentially constant. The number of counties the typical bank operates in grows over time, reflecting the cross-market consolidation that occurred in banking markets after their deregulation in the 1980s and 1990s.

5 Baseline Results

Table 2 presents the results of our hedonic regressions examining the relationship between incompatibility, bank/ATM characteristics and pricing. We show results from five specifications, one that omits incompatibility and four that include different measures of incompatibility. The results are quite robust to the measure of incompatibility.

The results show strong support for the existence of indirect network effects, both between deposit accounts and own ATMs, and also between deposit accounts and the complementary competitors' ATMs available in the local market. We find that own ATMs and competitors' ATMs are positively associated with deposit account prices. The own ATMs coefficient is statistically significant in all specifications but that in Model 2. The competitors' ATMs coefficient, on the other hand, is significant only in Model 2 (though it is nearly so in columns 4 and 5, and the variables are jointly significant in every specification). It is possible that the competitors' ATM coefficient is biased downward due to the effects of competition, as we noted in the econometric issues section above.

While in some cases the coefficient on competitors' ATMs is larger than that on own ATMs, this does not imply that competitors' ATMs are more strongly linked to prices than own ATMs. The ATM variables are in logs and the mean of competitors' ATMs is significantly higher than that for own ATMs, meaning that an increase of one ATM leads to a much smaller change in $\ln(competitors'\ ATMs)$ than in $\ln(ATMs)$. In every specification, adding one own ATM has a larger effect on price than adding one competitors' ATM. The magnitude of the results suggests that doubling the total number of ATMs available in the local market is associated with deposit account prices roughly 5-10 percent higher. While this is not an enormous effect in economic terms, it is perhaps best interpreted as a lower bound given the measurement error inherent in our measure of competitors' ATMs. And, for some banks we observe increases of 300 percent in ATM density over the sample period.

We also find significant evidence that incompatibility changes the relative importance of own and competitors' ATMs. Model 2 through 5 include the density/incompatibility interaction terms. In each case, the results suggest that incompatibility strengthens the relationship between own ATMs and deposit account prices, and weakens the relationship between competitors' ATMs and account prices. The results are robust to the incompatibility measure; furthermore, the pre-1996 incompatibility coefficients have similar signs, although they are not statistically significant. This provides weak evidence against the hypothesis that some other regime change occurred in 1996 that changed the relative importance of own and competitors' ATMs.

The sizes of the coefficients on the incompatibility measures suggests that at an expected competitors' surcharge of $0.60, competitors' ATMs essentially have no relationship with deposit account prices. While the sum of the coefficients does not change much after 1996 because the shifts in own and competitors' coefficients nearly offset each other, the relative importance of ATMs increases after 1996. Adding one own and one competitors' ATM to the market after 1996 affects prices more strongly, because more "weight" is on the component that is changing by more in percentage terms.

The coefficient on the level of incompatibility is negative and significant in the specification that uses expected foreign ATM cost as the measure of incompatibility, and positive in the specification that uses competitors' surcharges as the measure of incompatibility. It is difficult to attach any one interpretation to these coefficients, as they may measure the influence of any omitted variables that are correlated with incompatibility. The fact that the foreign cost coefficient is more negative than the surcharge coefficient does make sense, however. Foreign fees should reduce willingness to pay, and may have a stronger effect than surcharges in doing so.

While we do not discuss them in detail, the other coefficients show an intuitive relationship between bank characteristics and prices.[34] In most specifications branch density, salary per employee and employees per branch are positively related to prices, although only the coefficients on employees per branch are statistically significant. The results suggest that there is essentially no systematic relationship between geographic breadth (as measured by number of counties) and prices. Referring to the results in Appendix B, we also find a positive relationship between price and whether the bank is a member of a bank holding company, operates in multiple counties, and offers brokerage services.

6 Alternative Specifications

6.1 Capturing the Demand for "Mix and Match" Transactions

The specifications above pool the data, effectively assuming that the hedonic relationship is identical across the range of markets and firms for which we observe data. Within the context of classic hedonic modeling, it assumes that the value that consumers attach to mix and match transactions is constant across markets (assuming that our coefficients reflect this marginal value). Most models of

[34] Note that the bank-level fixed effects capture bank characteristics that do not vary over time.

ATM usage view consumers' valuation of ATM access as dependent on the travel costs they face.[35] This implies that the network effects associated with ATMs and the effects of incompatibility should depend on travel costs. In order to explore this possibility, we stratify our sample by the population density of banks' local markets, under the assumption that population density is correlated with travel costs.

Table 3 presents summary data for our sample stratified in two ways. First, we separate banks into those operating in areas of high population density from those operating in areas of low population density. We also separate large and small banks, based on local ATM share. We categorize as "high density" any bank operating in areas with an average population density above the sample median, and the remainder as operating in "low density" areas.[36] We further segment these subsamples, treating as "large" any bank in the subsample with a share of the local ATM market larger than the median (for that subsample).

These data show a clear pattern, that is not only informative regarding the travel cost story but also sheds light on variation in the data that identifies our earlier results. The greatest changes following the advent of surcharging occurred by large banks in dense areas. The most dramatic changes are in ATM density, which doubles for large high-density banks but is unchanged for smaller high-density banks. This is associated with equally dramatic changes in prices. Large banks charge significantly higher ATM fees. They also charge higher deposit fees. More importantly, this deposit fee gap grows significantly after the advent of surcharging, from \$0.60 in 1995 to \$1.66 in 1999. There is little evidence of such change in low density areas. While there are differences between large and small banks, they are not nearly so dramatic. Nor do they change very much after the advent of surcharging.

Table 4 presents results from our hedonic models for subsamples based on density. The difference is striking. In the high-density subsamples, the relationship between ATMs and deposit prices is extremely strong, while in the low-density subsamples the relationships are essentially nonexistent. The strength of the indirect network effect associated with own ATM density essentially triples, while the effect of incompatibility strengthens the network effect in high density markets. This is consistent with a view that travel costs increase the network effects between deposit accounts and ATM access, and also increase the importance of compatibility between accounts and own ATMs. The indirect network effect associated with competitors' ATMs is positive and nearly significant in high density markets. In stark contrast, there is a negative correlation in low density markets

While it seems sensible that the results should be stronger in high-density markets, it does

[35] See, e.g., Massoud and Bernhardt (2002) and McAndrews (2001).

[36] The sample median population density is 201 per square mile (measured at the county level). This is a density typical in a small urban area. Because our data cover only the largest three hundred ATM issuers, and these issuers operate primarily in metropolitan areas, the sample of markets is disproportionately high-density.

seem a bit surprising that the results are nonexistent in low-density markets. While one possibility is simply that travel costs are low enough to render ATMs (and by extension incompatibility) irrelevant, another possibility is simply that our model is well-specified for high-density markets and poorly specified for low-density markets. Our functional form may describe high-density markets more accurately, for example. Evidence in favor of this comes from the other coefficients. Branch density, for example, is positively and significantly related to prices in high-density markets but not in low-density markets; our priors tell us that branches would be relatively more important in markets where consumers do not value ATMs (though this is only a conjecture). Similarly, ln(*number of counties*) is positively related to prices in high-density markets—a result we find intuitive—but negatively related to prices in low-density markets. This pattern seems to suggest that specification error may be a problem in low-density markets. Given this inconclusive evidence, we interpret our results as finding strong evidence for the existence of network effects and an economically relevant relationship between incompatibility and pricing in high-density markets, while in low-density markets we are unsure whether our (non-)results reflect lower travel costs or specification error for these markets.

6.2 More Flexible Specifications

While the hedonic specifications above are informative, it is risky to interpret the coefficients as purely reflecting consumer tastes.[37] Pakes (2003) notes that generally we should view a hedonic relationship between prices and product characteristics as a reduced form specification of a richer model in which "the hedonic function is the expectation of marginal costs plus that of the markup conditional on 'own-product' characteristics." Feenstra (1995) goes beyond this general point to explicitly model the exact relationship between prices, costs, markups and characteristics for particular functional forms of costs and utility. He notes that if firms have log-linear marginal costs, we can represent the relationship between prices and product characteristics (with slight changes in notation) as:

$$\begin{aligned} \ln(p_{it}) &= X_{it}\beta + \gamma_1 \ln(OwnDens_{it}) + \gamma_2 \ln(CompDens_{it}) \\ &\quad + \gamma_3 \ln(OwnDens_{it}) Incompat_{it} + \gamma_4 \ln(CompDens_{it}) Incompat_{it} \\ &\quad + (\ln p_{it} - \ln c_{it}) + \alpha_i + \alpha_t + \varepsilon_{it}. \end{aligned} \tag{7}$$

where the α terms capture shifts in marginal cost, and for simplicity we include in the X vector both deposit account characteristics and the ATM- and incompatibility-related variables. The term

[37] References making this point include Triplett (1986, 1988).

$(\ln p_{it} - \ln c_{it})$ represents the markup of price over marginal cost. If this markup is non-zero and correlated with any variables in X, the β coefficients will be biased.

In our case, we certainly expect markups over marginal cost to be positive, as pricing for deposit accounts takes the form of a two-part tariff and we are essentially measuring average prices. There is also considerable evidence that banks possess short-run market power (leaving aside the question of whether they earn supercompetitive returns in either the short or long run). The concern in our case is that markups are correlated either with incompatibility, or with other variables in X. A simple specification capturing this possibility is one that models the unobserved markup as a function of incompatibility, *i.e.*:

$$\ln p_{it} - \ln c_{it} = \delta_1 + \delta_2 Incompat_{it}$$

In this specification, markups are composed of a constant term and a term that varies with incompatibility, suggesting the following specification:

$$\begin{aligned} \ln(p_{it}) \quad = \quad & X_{it}\beta + \gamma_1 \ln(OwnDens_{it}) + \gamma_2 \ln(CompDens_{it}) \\ & + \gamma_3 \ln(OwnDens_{it}) Incompat_{it} + \gamma_4 \ln(CompDens_{it}) Incompat_{it} \\ & + \delta_1 + \delta_2 Incompat_{it} + \alpha_i + \alpha_t + \varepsilon_{it}. \end{aligned} \tag{8}$$

In this case the constant markup δ_1 is absorbed into the constant term (or fixed effects), while the coefficient δ_2 measures the effect of incompatibility on markups. This specification is in fact the one estimated in columns 2 and 3 of Table 2. In those results we find that the coefficient on incompatibility is negative when foreign fees are included in incompatibility, and positive when only surcharges are included in incompatibility. This makes it difficult to attach a single interpretation to this (admittedly restrictive) model.

More broadly, Pakes (2003) notes that markups conditional on product characteristics may be a complex function of product characteristics as well as factors affecting the equilibrium point elasticity of demand, such as factors shifting costs and residual demand.[38] Given our data, we are unable to separate the effects of ATM-related variables on willingness to pay from their effect on markups. However, we can employ a richer specification including cost- and demand-related variables, in an attempt to mitigate any bias introduced by correlation between these factors and our variables of interest. We therefore construct the following specification:

[38] Pakes (2003) also notes that markups may depend on competitors' product characteristics. In unreported specifications, we include a variety of such characteristics (such as the fraction of competitors offering credit cards, money market funds and brokerage services). None are statistically significant.

$$
\begin{aligned}
\ln(p_{it}) \quad = \quad & X_{it}\beta + \gamma_1 \ln(OwnDens_{it}) + \gamma_2 \ln(CompDens_{it}) \\
& + \gamma_3 \ln(OwnDens_{it})Incompat_{it} + \gamma_4 \ln(CompDens_{it})Incompat_{it} \\
& + \delta_1 + \delta_2 Incompat_{it} + Z_{it}\lambda + \alpha_i + \alpha_t + \varepsilon_{it}. \qquad (9)
\end{aligned}
$$

We include three variables in Z_{it}: the ratio of noninterest expenses to assets for the bank, its net interest margin on all of its loans, and the average savings rate on its deposits.[39] Each of these variables are measured in percentage points.[40] While the noninterest expense ratio may include both fixed and variable costs, it may be correlated with marginal cost. The interpretations of the net interest margin and savings rate are less clear, as they likely measure components of both costs and willingness to pay. The savings rate, for example, represents both an opportunity cost of funds for the bank (affecting its costs) and for consumers (affecting their substitution between checking and savings accounts). The net interest margin operates similarly. Thus, we remain agnostic about the expected signs of these coefficients. To explore the possibility that incompatibility affected the influence of these variables on markups, we also estimate a specification that interacts them with incompatibility:

$$
\begin{aligned}
\ln(p_{it}) \quad = \quad & X_{it}\beta + \gamma_1 \ln(OwnDens_{it}) + \gamma_2 \ln(CompDens_{it}) \\
& + \gamma_3 \ln(OwnDens_{it})Incompat_{it} + \gamma_4 \ln(CompDens_{it})Incompat_{it} \\
& + \delta_1 + \delta_2 Incompat_{it} + Z_{it}\lambda + Z_{it}Incompat_{it}\pi + \alpha_i + \alpha_t + \varepsilon_{it}. \qquad (10)
\end{aligned}
$$

Table 3 presents results from these three specifications. All specifications use the expected level of competitors' surcharges as a measure of incompatibility. The most salient aspect of the results is that in all three specification, the inclusion of the richer set of controls leaves our qualitative results regarding indirect network effects and incompatibility unchanged. In every specification the signs of the coefficients are identical to those in the earlier results. The coefficients on own and competitors' ATMs are estimated less precisely, but as we discuss below, this may be an artifact of the fact that we are grouping high and low population density markets together; when we separate the two, the coefficients on own and competitors' ATMs become more positive and statistically significant (for high density markets). The incompatibility terms remain statistically significant.

[39] We obtain these variables from the Call Reports. All variables are annualized. Noninterest expenses are yearly expenses divided by total assets. The net interest margin is aggregate loan income minus aggregate loan losses divided by total loan balances, all measured in dollars. The savings rate is total interest expense on savings accounts divided by total savings balances, all measured in dollars.

[40] The sample means for the noninterest expense ratio, the net interest margin and the savings rate are 1.63%, 1.21% and 2.58% respectively.

This suggests that our empirical results accurately reflect the existence of indirect network effects and the effect of incompatibility.

The coefficient on the level of incompatibility varies in magnitude, but is positive and highly significant in every specification. Again, it is difficult to interpret the coefficient as strictly measuring changes in markups. One interpretation of this result is that incompatibility relaxes price competition by strengthening horizontal and vertical product differentiation. Without ATM fees of any sort, ATM fleet size is not a source of horizontal or vertical product differentiation. As fees rise, consumers living or working near a bank's ATMs will find that bank's deposit account more attractive because it allows them to avoid surcharges; this increases horizontal differentiation. Furthermore, as incompatibility increases banks with large ATM fleets become relatively more attractive to all customers who use ATMs.[41] Another interpretation is that incompatibility led to other changes in omitted variables (such as debit terminal availability) that are positively correlated with prices.

The cost/demand variables are statistically and economically significant, although the terms interacting them with incompatibility are not (with the exception of that on the savings rate). The noninterest expense ratio is positively related to prices, as expected. An increase in the ratio of one standard deviation (within-firm) is associated with a price approximately 10% higher. The net interest margin is positively related to prices. This is a bit puzzling, as it seems inconsistent with a cost-based explanation if loan rates reflect the marginal return on dollars held in deposit accounts, and inconsistent with a demand side explanation, as higher loan rates make complementary deposit accounts less attractive to consumers. It may be correlated with an unobserved cost shifter that which would make both loan rates and deposit account prices higher. Finally, the savings rate is positive and statistically significant. A one standard deviation increase in the savings rate is associated with a three percent increase in deposit account prices. This may reflect a complementarity in demand across savings and checking accounts, or could reflect the fact that higher savings rates increase banks' cost of funds.

In concert, these results suggest that our baseline specifications accurately reflect the impact of network effects and incompatibility. While it is difficult to place too much weight on any particular interpretation of the results for the new variables, it is encouraging that the baseline results are stable to their inclusion. This is particularly true for the last specification, which includes both the level of incompatibility and a full set of incompatibility interactions. While we do not interpret the coefficients as representing the primitives of the utility function, it seems unlikely that our main

[41] Note that this shift is relative. Strictly speaking, incompatibility reduces willingness to pay for all banks' deposit accounts by making "mix and match" transactions more costly. However, the reduction in willingness to pay is much smaller for banks with large ATM fleets, because their customers are less likely to require access to a foreign ATM.

results are simply driven by spurious correlation between our variables of interest and some other factor.

6.3 Alternative Measures of Price

Because our measure of prices is somewhat aggregate and rough, we explore the robustness of our results to alternative measures of price; results of the baseline model using alternative measures of price are shown in Table 6. One specification estimates the model using the level of prices rather than the log. A second specification uses total accounts rather than total deposits in the denominator, and a third uses the level of the account-based price rather than the log. Finally, our final alternative specification uses the price measure defined above, but also includes the share of total deposits held in checking accounts and the level of deposits per account as right-hand side variables. This controls for a number of issues. First, within-bank variation in the share of deposits held in checking accounts would change measured prices, which would be a concern if such variation were correlated with our right-hand side variables of interest. Second, within-bank variation in deposits per account might affect measured prices if banks waive deposit fees for customers with high balances per account. Again, this would be a concern if such variation were correlated with our variables of interest. However, as the results in Table 6 indicate our results are quite robust to the price measure that we use.

7 Conclusion

We set out in this paper to test whether a hedonic model can uncover economically significant indirect network effects. We also test whether changes in the compatibility of components in a network system affect prices in a material way. For high-density, primarily urban markets, we find strong evidence of these links between bank deposit accounts and ATMs. One novelty of our result is that we find significant relationships between a bank's deposit accounts and the density of ATMs deployed by its competitors in the local market. In the context of the network economics literature, this represents a link between hardware pricing and the availability of competitors' software.

We also find that the incompatibility of these machines with deposit accounts—as measured by ATM surcharges—is associated with deposit account price movements. This pattern of results suggests that the interplay between compatibility and pricing is important, and that links between pricing and quality for different products linked by indirect network effects can be quite strong. This is particularly useful to know since some previous studies of network markets have examined only one component.

A Data Appendix: Sources and Variable Construction

A.1 Primary Data Sources

We take our data from four principal sources. The first is the Card Industry Directory, an annual trade publication listing detailed data on ATM and debit card issuers. The Card Industry Directory contains data for the largest 300 ATM card issuers, who collectively own roughly 80 percent of the nation's ATM fleet during our sample period. These issuers are most often commercial banks, although some are bank holding companies, credit unions or thrifts. The sample period covered in our data set runs from 1994 to 2002. Data are measured on January 1 of each year.

We also take data from the FDIC Reports of Condition and Income, or Call Reports. The Call Report data are collected quarterly by the FDIC for every commercial bank in the country. The Call Reports contain detailed balance sheet and income data for each bank. They also indicate which bank holding company owns the bank. Thus, if the Card Industry Directory contains a listing regarding ATM issuance for a bank holding company, we can match that data with the corresponding data for each bank owned by the holding company. The Call Reports do not contain data for credit unions or thrifts; we drop them from the sample.

We supplement the above with data from the FDIC Summary of Deposits Database (SOD). The SOD lists the location of branches for every bank and thrift in the country. It also lists the deposits held at each branch. It does not contain data on branch location for credit unions. We assume that each credit union has one branch, located in its home county, and that all of that credit union's deposits are held at that branch. This assumption is unlikely to affect our results. SOD data are collected each June.

A.2 An Observation in Our Data

By cross-referencing the data sets above, we obtain observations at the issuer level describing each issuer's balance sheet activity and ATM activity. We also use the geographic data from the SOD to derive information about the market(s) in which the issuer competes. Because the data are measured at different times, we must establish a concordance between the dates in the different data sets. We establish the concordance based on the fact that our analysis includes deposit prices as LHS variables, and ATM-related variables as RHS variables. While these may be jointly determined, to mitigate the endogeneity problem we match ATM-related data for each January with six-month ahead data from the other data sets. Thus an observation from 1994 contains ATM-related data from January 1994, while all other data are from June 1994. We describe these data below.

A.2.1 Pricing for Accounts and ATMs

For each issuer, we observe its income associated with deposit accounts over the year preceding the observation date. The primary component of such income is income from monthly service charges on deposit accounts. It also includes foreign fee income paid by its customers stemming from the use of other issuers' ATMs. It also includes a variety of other fees such as NSF fees for bounced checks and other penalty fees on deposit accounts. If the issuer is a bank holding company, we sum its deposit fee income for all banks in the holding company.

To develop our measure of prices, we divide income on deposit accounts by the end-of-year dollar value of deposits (in thousands). This price measure therefore represents the average fees paid per dollar of deposits. This measure omits the additional opportunity cost of holding deposits in checking, which is the forgone savings interest income. However, it is likely that the measurement error associated with omitting this component of "prices" is similar across banks, and within banks over time.[42]

Another issue associated with using this price measure is that banks typically offer consumers account options with lower explicit fees in exchange for maintaining higher minimum balances. If banks differ systematically in the composition of their customer bases, we will understate fees at banks with high deposits per customer (assuming those customers sort into accounts designed for them).

A practical difficulty with using this measure of fees is that the numerator is a flow measure over the previous year, while the denominator is a stock measure at end-of-year. This creates measurement error for banks with large deposit acquisitions or divestitures during the year. Indeed, there are a significant number of observations with implausibly small or large fee measures. To check that these were outliers stemming from measurement error, we measured the year-to-year percentage change in deposits for observations with exceedingly small or high fee measures; we found that in most cases such observations were for banks that experienced extremely large changes in deposits (more than fifty percent in absolute value). We drop these observations. In unreported specifications we also include these observations but truncate the fee variable at "reasonable" values, with little difference in the qualitative results.

For each issuer in the Card Industry Directory, we also observe its foreign ATM fee and surcharge at the beginning of the year for the observation. In some cases, the bank lists a range for these fees. In that case, we use the highest fee reported. In the empirical work, this tends to understate the true relationship between fees and our other variables of interest.

[42] In Knittel and Stango (2004), we include a measure of the opportunity cost of funds in our price measure. Using the broader measure has little effect on the results in that paper.

A.2.2 Branch- and ATM-Related Variables

For each issuer, we observe its total deposits, ATMs and branches. We also observe the distribution of its deposits and branches across individual counties. Obtaining data on county size in square miles allows us to calculate the density of branches/ATMs per square mile within each county. For banks operating in multiple counties, we calculate the average number of branches and ATMs across all counties in which the bank operates.

In order to construct competitors' ATMs, we estimate the total number of competitors' ATMs in each county. We do this by estimating a within-sample regression of ATMs on branches, year dummies and year/branch interaction terms. To control for the fact that larger FIs have a greater ratio of ATMs to branches, we also interact the branch variables with the log of issuer size (in deposits). We then construct fitted values of ATMs for each FI for which we do not have ATM data. In order to check the sensibility of this procedure, we compared the fitted total number of ATMs from this procedure to aggregate data on ATM deployment. The figures match fairly closely. We also conduct in Knittel and Stango (2004) a wide variety of robustness checks, involving different methods of estimating competitors' ATMs.

A final point regarding the measurement of competitors' ATMs is that it omits ATMs deployed by Independent Service Operators (ISOs). This introduces measurement error, and may bias our measures of competitors' ATM density. This would be particularly important in urban markets where ISO ATM deployment was quite rapid after 1996.

B Second-Stage Hedonics

A number of bank-level characteristics are fixed at the bank level over time. This precludes their inclusion in the hedonic regressions, which also include bank fixed effects. However, we can learn something about the value of these other characteristics by examining their relationship to the fixed effects.

Starting with our estimates $\widehat{\alpha}_i$ of the bank fixed effects, we construct the vector Π_i of time-invariant bank characteristics. The first set of such characteristics describes the product offerings of each bank; there are dummies equal to one if the bank offers a credit card, money market accounts, or brokerage services. We also include a dummy if the bank has branches in multiple counties, and a dummy equal to one if the bank is part of a larger bank holding company. Some of these variables (particularly the product offering variables) vary over time for a small subset of banks. For these banks we use the average value of the dummy variable over the sample period as the independent variable.

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C Tables

Table 1. Descriptive Statistics

Variable	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
Branches/bank	6	7	7	7	8	7
Branches/square mile	0.008	0.008	0.008	0.008	0.009	0.008
ATMs/bank	7	8	10	11	14	14
ATMs/square mile	0.008	0.010	0.010	0.012	0.013	0.013
Competitors' ATMs/square mile	0.07	0.09	0.10	0.13	0.19	0.22
Deposit fees ($ per $1000 of deposits)	2.48	2.50	2.50	2.31	2.39	2.45
Foreign fee ($)	1.20	1.31	1.31	1.19	1.23	1.16
Surcharge ($)	n/a	n/a	n/a	0.67	0.91	0.95
Expected competitors' surcharge ($)	n/a	n/a	n/a	0.53	0.73	0.88
Salary per employee ($1000)	16	16	17	18	19	20
Employees per branch	17	16	16	16	16	15
Number of counties	4	4	5	7	9	11

Sources: Federal Reserve *Reports of Condition and Income* (Call Reports), various years; FDIC *Summary of Deposits*, various years; *Card Industry Directory*, various years.

Values are medians for ATM- and branch-related variables, means for all others.

Table 2. Baseline Hedonic Models

	Model 1	Model 2	Model 3	Model 4	Model 5
ln(own ATM density)	0.037**	0.018	0.029**	0.031**	0.029**
	(0.014)	(0.016)	(0.015)	(0.015)	(0.015)
ln(own ATM density)		0.014***	0.021***	0.027**	0.028***
x Incompatibility		(0.005)	(0.007)	(0.007)	(0.007)
ln(own ATM density)					0.016
x pre-1996 Incompatibility					(0.014)
ln(competitors' ATM density)	0.010	0.064***	0.017	0.020	0.020
	(0.013)	(0.017)	(0.014)	(0.013)	(0.013)
ln(competitors' ATM density)		−0.033***	-0.047***	-0.041***	-0.041***
x Incompatibility		(0.006)	(0.007)	(0.007)	(0.007)
ln(competitors' ATM density)					-0.019
x allow surcharges pre-1996					(0.024)
Incompatibility		−0.047*	0.418***		
		(0.026)	(0.100)		
ln(own branch density)	0.016	0.016	0.025	0.017	0.018
	(0.020)	(0.020)	(0.020)	(0.020)	(0.020)
ln(salary per employee)	0.0006	0.0007	0.0007	0.0006	0.0007
	(0.0004)	(0.0004)	(0.0005)	(0.0004)	(0.0005)
ln(employees per branch)	0.0003***	0.0003***	0.0003***	0.0003***	(0.0003)***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
ln(number of counties)	-0.007	-0.009	-0.005	-0.010	-0.011
	(0.010)	(0.011)	(0.011)	(0.011)	(0.011)
Number of Observations	3686	3686	3686	3686	3686

* - significant at 10 percent or better

** - significant at five percent or better

*** - significant at one percent or better

Notes: Dependent variable is ln(Deposit Fees).

All specifications include fixed year and bank effects.

Model 2 uses foreign ATM cost to measure incompatibility.

Model 3 uses competitors' surcharges to measure incompatibility.

Model 4 uses post-1996 dummy variable to measure incompatibility.

Model 5 adds dummy variable for states permitting surcharging before 1996.

Table 3. Summary Statistics by ATM Share and Population Density

Variable		1994	1995	1996	1997	1998	1999
Branches/	large bank, high density	0.037	0.036	0.038	0.042	0.035	0.039
square mile:	small bank, high density	0.012	0.012	0.012	0.011	0.013	0.012
	large bank, low density	0.007	0.008	0.008	0.008	0.009	0.012
	small bank, low density	0.004	0.004	0.004	0.006	0.005	0.005
ATMs/	large bank, high density	0.043	0.047	0.054	0.066	0.084	0.091
square mile:	small bank, high density	0.010	0.011	0.009	0.012	0.014	0.013
	large bank, low density	0.007	0.009	0.010	0.010	0.012	0.012
	small bank, low density	0.003	0.004	0.004	0.005	0.004	0.004
Deposit fees:	large bank, high density	2.87	2.89	2.89	3.01	3.29	3.29
	small bank, high density	2.37	2.32	2.15	2.06	1.91	1.82
	large bank, low density	2.46	2.72	2.87	2.92	2.54	2.73
	small bank, low density	2.51	2.40	2.40	2.42	2.28	2.43
Surcharge:	large bank, high density	n/a	n/a	n/a	0.82	1.11	1.18
	small bank, high density	n/a	n/a	n/a	0.47	0.95	0.91
	large bank, low density	n/a	n/a	n/a	0.92	1.27	1.25
	small bank, low density	n/a	n/a	n/a	0.84	1.10	1.05
Foreign fee:	large bank, high density	1.33	1.37	1.43	1.35	1.37	1.29
	small bank, high density	1.12	1.23	1.20	1.04	1.08	1.01
	large bank, low density	1.31	1.45	1.51	1.32	1.48	1.40
	small bank, low density	1.19	1.36	1.28	1.18	1.24	1.16

Notes: High and low density are above and below sample median.

Large/small banks are those above/below median deposit market share for density subsample.

Table 4. Hedonics in High and Low Population Density Markets

	Model 1	Model 2
ln(own ATM density)	0.045***	0.015
	(0.017)	(0.028)
ln(own ATM density)	0.046***	-0.017*
x Incompatibility	(0.009)	(0.010)
ln(competitors' ATM density)	0.031	-0.022
	(0.020)	(0.022)
ln(competitors' ATM density)	-0.066***	−0.015
x Incompatibility	(0.013)	(0.011)
ln(own branch density)	0.085***	0.006
	(0.027)	(0.033)
ln(salary per employee)	0.0002	0.032***
	(0.0005)	(0.003)
ln(employees per branch)	0.0004***	0.0006
	(0.0001)	(0.0007)
ln(number of counties)	0.032**	-0.044**
	(0.016)	(0.021)
Incompatibility	0.790***	0.133
	(0.173)	(0.145)
Number of Observations	1843	1843

* - significant at 10 percent or better

** - significant at five percent or better

*** - significant at one percent or better

Notes: Dependent variable is ln(Deposit Fees).

All specifications include fixed year and bank effects.

Model uses competitors' surcharges to measure incompatibility.

Models (1) and (3) use observations from high-density markets.

Models (2) and (4) use observations from low-density markets.

Table 5. Hedonics with Supply/Demand Regressors Added

	Model 1	Model 2	Model 3	Model 4
ln(own ATM density)	0.006	0.010	0.029	-0.002
	(0.016)	(0.015)	(0.019)	(0.029)
ln(own ATM density) x Incompatibility	0.018**	0.014*	0.052***	-0.006
	(0.007)	(0.008)	(0.012)	(0.011)
ln(competitors' ATM density)	0.014	0.013	0.015	-0.018
	(0.014)	(0.014)	(0.023)	(0.022)
ln(competitors' ATM density) x Incompatibility	−0.036***	-0.033***	-0.054***	0.007
	(0.007)	(0.007)	(0.014)	(0.013)
ln(own branch density)	0.033	0.033	0.132***	-0.011
	(0.025)	(0.025)	(0.034)	(0.039)
ln(salary per employee)	0.011***	0.011***	0.013***	0.005
	(0.002)	(0.002)	(0.003)	(0.004)
ln(employees per branch)	-0.0005	-0.0005	0.0002	-0.004***
	(0.0004)	(0.0004)	(0.0004)	(0.001)
ln(number of counties)	0.004	0.004	0.041**	-0.061***
	(0.014)	(0.014)	(0.020)	(0.022)
Incompatibility	0.270**	0.252**	0.690***	-0.042
	(0.112)	(0.112)	(0.186)	(0.165)
Non-interest expense ratio	0.216***	0.213***	0.155***	0.337***
	(0.017)	(0.019)	(0.024)	(0.032)
Net interest margin	0.023***	0.021***	-0.002	0.042***
	(0.006)	(0.006)	(0.008)	(0.008)
Savings rate	0.062***	0.095***	0.090**	0.094***
	(0.015)	(0.002)	(0.036)	(0.002)
Non-interest expenses x post-1996		0.001	-0.001	-0.001
		(0.002)	(0.002)	(0.002)
Net interest margin x post-1996		0.001	0.031**	-0.022
		(0.001)	(0.014)	(0.015)
Savings rate x post-1996		-0.092***	-0.058	-0.108***
		(0.026)	(0.043)	(0.034)
Number of Observations	3686	3686	1843	1843

* - significant at 10 percent or better

** - significant at five percent or better

*** - significant at one percent or better

Notes: Dependent variable is ln(Deposit Fees).

All specifications include fixed year and bank effects.

Model uses competitors' surcharges to measure incompatibility.

Table 6. Alternative Price Measures

	Baseline	Model 1	Model 2	Model 3	Model 4
ln(own ATM density)	0.046***	0.043***	0.140***	0.047***	0.140***
	(0.017)	(0.017)	(0.042)	(0.017)	(0.042)
ln(own ATM density)	0.046***	0.040***	0.092***	0.046***	0.092***
x Incompatibility	(0.009)	(0.009)	(0.022)	(0.009)	(0.022)
ln(competitors' ATM density)	0.044**	0.031	0.063	0.044**	0.063
	(0.020)	(0.020)	(0.049)	(0.020)	(0.049)
ln(competitors' ATM density)	-0.037***	−0.028***	-0.059***	-0.037***	-0.059**
x Incompatibility	(0.011)	(0.011)	(0.027)	(0.011)	(0.026)

Baseline uses specification from column 1, Table 4.

Model 1 includes deposits per account and % of total deposits in checking accounts on RHS.

Model 2 uses level (not log) of deposit fees as price.

Model 3 uses ln(fee income per account) as price.

Model 4 uses level of fee income per account as price.

Table A1. Second stage hedonics with time-invariant characteristics.

Variable	**Model 1**	**Model 2**	**Model 3**
Multi-county bank dummy	0.135***	0.019	0.183***
	(0.038)	(0.067)	(0.040)
Offers credit card	-0.049	0.061	-0.125**
	(0.052)	(0.090)	(0.054)
Offers money market	-0.025	-0.297	0.626
	(0.256)	(0.296)	(0.565)
Offers brokerage services	0.091**	0.085	0.075*
	(0.040)	(0.067)	(0.041)
Part of BHC	0.424***	0.483***	-0.022
	(0.092)	(0.105)	(0.108)
constant	-0.461*	-0.255	-0.636
	(0.270)	(0.317)	(0.572)
Number of Observations	1278	638	638
R^2	0.04	0.05	0.05

Specifications use first-stage results from model (3) of Table 2.

Model 1 uses entire sample.

Model 2 uses observations from high-density markets.

Model 3 uses observations from low-density markets.