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Empirically evaluating two-sided integrated network effects: The case of electronic payments

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Abstract

Many new technologies have two groups of users, whose ultimate benefit stems from interacting through a common network. For a technology to flourish, both kinds of users must adopt the technology. Lack of coordination can lead to an equilibrium where cost-savings are not realized, since no-one adopts. This can make cost-saving network technologies a policy issue. In the Automated Clearing House payments network there are two kinds of users: Originators of payments, and Receivers of payments. Since the presence of one group is complementary to the other, one group of users' decisions to join the network has a positive effect on the other group. This paper estimates these positive effects and finds them to be significant for both groups of users. The results suggest an inherent positive feedback mechanism in the adoption of ACH, meaning that policy intervention is not necessary.

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1 Introduction

Many new technologies are characterized by the presence of two distinct sides, whose ultimate benefit stems from interacting through a common network or standard. In these two-sided networks, a network effect occurs when an agent's decision to join the network on one side of the network confers positive benefits for agents on the other side of the network, independent of market mediated effects.

An alternative to checks for small recurring payments such as payroll and bill payment is an Automated Clearing House (ACH) transaction. The ACH network is a network with two sides: Originators and Receivers. Originators are the banks originating debits and credits on one side for commercial clients, and Receivers are the banks receiving these payment instructions and adding or subtracting payments from their customers' accounts on the other sides. Transactions between originators and receivers are cleared and settled by an ACH operator, which eliminates the need for bilateral ACH relationships between financial institutions.

The complementarity between origination and receipt capability means that network effects could be significant for the decision to adopt ACH. Adoption of ACH benefits banks, because ACH lowers storage, personnel and transport costs compared to checks. However, a bank only adopts ACH if reduced transaction costs are greater than ACH installation costs. Originating payroll electronically will be more cost effective if a large number of the employees have checking accounts at banks that are able to receive ACH transactions. Correspondingly, ACH receipt services will be more cost effective if a large number of employers use banks which offer electronic origination of paychecks. Therefore the value of adopting ACH technology as a receiver increases with the number of ACH origination technology adopters. And the value of adopting ACH technology as an originator increases with the number of ACH receipt technology adopters.

ACH is an attractive two-sided network for which to evaluate network effects, because due to federal bank reporting regulations, it is possible to get data on all potential adopters. ACH does however have two idiosyncracies which have to be addressed in estimation. In the classic two-sided network, the two sides are separate and distinct. However for ACH payment technology the potential adoptees on both sides of the network are the same financial institutions. Also, ACH payment technology is asymmetrically partially integrated. When you adopt the more expensive technology of origination, receipt capacity is automatically included in the software bundle.

In the model presented in this paper, exogenous changes lead to a positive feedback loop for ACH adoption. For example, an exogenous event such as the arrival of a new large corporate client encourages banks to adopt ACH origination. This in turn encourages banks to adopt ACH receipt on the other side of the network, and so on. In any cost savings technology which exhibits network effects, a lack of coordination can lead to an equilibrium where cost savings are not realized, since no-one adopts. And because no-one adopts, no-one has an incentive to adopt. The estimates of positive network effects found in this paper suggest that there is a positive feedback mechanism for the adoption of ACH. This suggests that the initial equilibrium where no-one adopts is unstable, and there is no need for policy intervention.

This paper exploits the potential of an unstable equilibrium where no-one adopts ACH to obtain alternative estimates of network effects. Using a likelihood bounds methods, modified from (Tamer 2002), it finds further evidence of positive network effects for the adoption of ACH.

2 Related Literature

(Farrell and Saloner 1985) and (Katz and Shapiro 1986) examine how adoption decisions for new technologies are affected by the presence of network effects. Since agents may not internalize the positive effect that their adoption of a technology has on other users, network externalities can delay or even prevent the adoption of Pareto-superior technologies.

Initial empirical attention focused on networks over which only one kind of agent interacted. This empirical work on "one-sided" network effects in technology adoption is problematic, since researchers have to resolve the problems of rigorously identifying and separating the effect of aggregated adoption decisions on an individual agent's decision. For example, (Economides and Himmelberg 1995) explore network effects in the US fax industry and calibrate the critical mass of fax users required to gain momentum. Their calibration is problematic, because their data do not allow them to control for the effect of the fall in the price of fax technology in the period in question. (Saloner and Shepard 1994) resolve this identification problem by using local networks in a panel data setting. They use data on banks' adoption of automated teller machines from 1972-1979, to show that the time a bank waits to adopt the ATM technology declines with the number of branches and the value of bank deposits. Using data on the number of deposits (which proxies the number of users) allows them to extrapolate scale economies from network effects, which are identified using the number of bank branches. This paper follows their strategy of using local markets in a panel data setting to identify network effects.

(Gowrisankaran and Stavins 1999) evaluate network effects exclusively on the Origination side of the ACH network. The paper identifies network effects both by evaluating whether there is clustering of ACH origination adoption, and by considering whether areas with concentrated financial market structures have exhibited greater ACH origination adoption. Using a natural experiment created by the ACH origination adoption of small branches of large banks, they estimate that, within a 30km wide local network, an exogenous increase of 20% in the deposit-weighted percentage of banks adopting ACH origination technology would increase the probability of another bank's adopting origination technology by 5-6%. (Ackerberg, Gowrisankaran, and Stavins 2002) present an extension to this work on by estimating a functional form for the Origination network model, and using this to distinguish whether the network effects come from the bank or the consumer level. They find that costs of adoption for banks are low, and are high for consumers.

The theoretical literature on network effects has expanded in recent years, to encompass the additional complications posed by two-sided networks. In these two-sided networks, a network effect occurs when an agent's decision to join the network on one side of the network confers positive benefits for agents on the other side of the network, independent of market mediated effects. (Armstrong 2003) provides a good survey of the theoretical literature. Two examples of note from the theoretical literature are (Rochet and Tirole 2002) who explore a model of platform competition with two-sided markets, and examine the determinants of price allocation and end-user surplus, comparing the outcomes with those under an integrated monopolist and a Ramsey planner. (Parker and Van Alstyne 2000) set up a theoretical model that can be used to explain why in two-sided networks, such as for Adobe Acrobat and Reader, a firm may give away the good to one side of the network for free.

(Dranove and Gandal 2000) look at a two-sided network by examining a technology adoption counterfactual. They measure empirically the effect on the market for DVDs of the announcement that the competing and incompatible DIVX technology was going to be released, in terms of how that announcement affected the underlying rate of growth in DVD sales. They found that the DIVX pre-announcement slowed adoption of DVD technology, which indicated both the existence of network effects and the importance of pre-announcements in strategic competition. (Gandal, Kende, and Rob 2000) explicitly estimate a positive feedback loop. They study the entry decisions of producers of compact disk players and producers of compact disks. They estimate the (direct) elasticity of adoption with respect to CD player prices and the (cross) elasticity with respect to the variety of CD titles, and find it to be significant.

(Rysman 2002) was the first to structurally evaluate a two-sided network. He uses a one-period simultaneous-move quantity-setting game to estimates network effects between users of Yellow Pages and advertisers in the Yellow Pages. To do this he estimates two demand curves simultaneously: a consumer demand curve for directory usage as a function of advertising, and an advertiser demand curve for advertising as a function of consumer usage. He finds network effects and goes on to measure the importance of the network effect by looking at how much potential surplus is foregone due to the market's failure to fully account for the network effect, and finds that the amount is large relative to the amount of deadweight loss resulting from imperfect competition. This empirical strategy in this paper differs from his because he assumes there is only one potential originator in each region of Yellow Pages, and he only considers a one-period setting.

One problem with previous work on technology adoption in two-sided networks is that for consumer goods it hard to obtain data on the full spectrum of potential adoptees of the technology, and get individual level data about them. For example, it is only possible to guess at who could be a potential advertiser in the Yellow Pages, by looking at outcomes. Studying network technology adoption in the banking industry is particularly attractive because federal law mandates that banking institutions publish information on themselves on a regular basis, so it is possible to obtain information on the full range of potential adopters.

3 Modeling adoption in two-sided networks

Let there be a network with two potential groups of users: Receivers and Originators. Receivers could be video console purchasers, credit card users, streaming video users, or Yellow Pages readers. Originators could be video game designers, merchants, streaming video providers or Yellow Pages advertisers. For all of these technologies, the decision to adopt on both sides is complementary to the other side's decision to adopt. Let Δ_o capture the network effect for potential originators of the cumulative receipt adoption decisions within the network. Let Δ_r capture the network effect for potential receivers of the cumulative origination adoption decision within the network. In addition let x be a vector of exogenous variables which increase the propensity to adopt the origination technology. And let z be a vector of exogenous variables that increase the propensity to adopt the receipt technology.

Consider the following m originator and n receiver binary game

$$o_{ijt} = \begin{cases} 1 & \text{if } (x_i\beta_i + S_o(r_{-ijt}, \Delta_o) + \epsilon) \geq 0 \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

where o_{ijt} is a binary indicator variable for the decision to adopt origination technology for agent i in network j at time t, and

$$r_{ijt} = \begin{cases} 1 & \text{if } (z_i\beta_i + S_r(o_{-ijt}, \Delta_o) + \epsilon) \geq 0 \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

where r_{ijt} is a binary indicator variable for the decision to adopt receipt technology for agent i in network j at time t.

$S_i(r_{-ijt}, \Delta_o)$ is a known function from $\{0,1\}^n R^l \rightarrow R$ that represents the effect of receivers' strategies on potential originator i's outcome. $S_r(o_{-ijt}, \Delta_o)$ is a known function from $\{0,1\}^m R^l \rightarrow R$ that represents the effect of originators' strategies on potential receivers i's outcome.

Assume, the vectors $(\epsilon_{11}, ..., \epsilon_{mT})$ and $(\epsilon_{11}, ..., \epsilon_{nT})$ have known distribution F (.) on R^m and R^n, with mean zero and unknown variance covariance matrix Ω. Also assume that $(\epsilon_{11}, ..., \epsilon_{mT})$ and $(\epsilon_{11}, ..., \epsilon_{nT})$ are independent of $x = (x_{it}, ..., x_{mT})$ and $z = (z_{it}, ..., z_{nT})$. Then the, observed vector of choice probabilities $Pr[o = (o_1, ..., o_m)|x]$ and $Pr[r = (r_1, ..., r_n)|z]$, can then be to estimate the vector of interest $\theta = ((\beta_i, \Delta_i), \Omega) \in \theta$, a compact subset of R.

4 Industry and Data Characteristics

4.1 The ACH Network

The US spends 3% of its GDP making payments (Humphrey, Pulley, and Jukka M. 2000). The US payments system costs more than European payment systems, largely because of American devotion to costly check-based forms of payments.

An ACH transaction can be an electronic credit, such as the deposit of payroll from a firm to an employee's bank account. An originating bank sends the credit to the ACH network on behalf of one of its corporate customers. A receiving bank receives the ACH transaction and adds the credit to the employee's checking account balance. Transactions between originators and receivers are cleared and settled by an ACH operator, which eliminates the need for bilateral ACH relationships between financial institutions. In the US, in the period studied by this paper, the Federal Reserve dominated this function with a 75% market share.

An ACH transaction can also be an electronic debit such as the payment of a utility bill. The use of ACH for debit transactions is not modeled in this paper. Employers' and employees' banks are likely to be near each other. However for bill payment the originating financial institution is not generally geographically close to the receiving institution. Since the identification strategy for network effects relies on ACH activity taking place within distinct local networks, it is not possible to evaluate the role of ACH debits. ACH technology adoption decisions depend on how many transactions the financial institution will process if it adopts. Since installation and set up costs for ACH adoption are fixed, the more ACH transactions a bank processes, the greater the per-transaction cost savings of adoption.

In the period 1995-97, the ability to receive ACH was automatically included in ACH origination software. Since ACH origination technology must be tailored to the bank's corporate clients, it is more expensive to adopt than ACH receipt technology.

I treat the decision to adopt the integrated origination-receipt ACH technology as the decision to adopt ACH origination. The potential bias from ignoring the receipt component of combined origination-receipt technology is mitigated by the fact that 83% of new ACH origination adopters in the sample had previously adopted ACH receipt.

The basic fees charged by the Federal Reserve Bank are the same for financial institutions who adopt ACH as a combined originator-receiver and for those who adopt ACH as a receiver only. There is a modest charge for installing a dedicated connection to the federal bank, if the financial institution does not already have it installed, and then a $30 monthly charge for connection to the ACH system.

4.2 Factors promoting ACH origination adoption

To obtain estimates of network effects for ACH origination, equation (1) must be tailored to the specific variables influencing a bank's ACH adoption decision.

The strategic response function $S_i(r_{-ijt}, \Delta_r)$ is modeled as an increasing function of the deposit-weighted proportion of banks who have adopted ACH receipt in the local network ($\%R_{jt}$). A bank's corporate client is more likely to use ACH for payroll if their workforce has checking accounts at banks which offer ACH receipt. Therefore, the potential cost savings of adopting ACH origination are greater for banks operating in a network where a higher proportion of other banks within the network have adopted ACH receipt technology. This interpretation of $S_i(r_{-ijt}, \Delta_r)$ makes two assumptions. First, the magnitude of the network effects Δ_r, is the same for all banks. Second, that there is no uncertainty over $\%R_{jt}$, before a bank decides whether to adopt.

The main exogenous factor promoting the adoption of ACH origination is the presence of firms with large numbers of employees. Historically in the US, the initial users of ACH origination have been firms with large payroll commitments (Wells 1996). NACHA estimates that a firm switching from a check-based payroll system to a direct deposit system saves \$1.21 - \$1.76 per check (NACHA 1999a). These savings come from reductions in payment processing times, and from lower bank charges. Cost savings per check are higher for firms with large payroll commitments than for small firms, since the costs of switching from a check-based to an electronic regime are largely fixed. This implies that the proportion of clients that will use ACH origination technology depends on how many large corporate clients the bank has. Though banks do not make available such commercially sensitive information, data on the number of firms with large payroll commitments in the local network is available. $LARGEFIRMS_{jt}$, the % of firms with over 50 employees in the region, is used to capture the presence of large firms.

4.3 Factors promoting ACH receipt adoption

Correspondingly, the average cost savings of adopting ACH receipt are greater for banks operating in a network where a higher proportion of other banks within the network have adopted ACH origination technology. A bank's personal customers will only switch to using ACH to receive payroll if their employer's bank offers ACH origination. I model the strategic response function $S_i(o_{-ijt}, \lambda_i)$ as being an increasing function of the deposit weighted proportion of other banks who have adopted ACH origination, $(\%O_{jt})$ in the local network. Again, this interpretation of $S_i(o_{-ijt}, \lambda_i)$ implies a homogenous network effect and perfect knowledge of other banks' actions.

The main exogenous factor promoting adoption of ACH receipt is federal mandate. The Debt Collection Improvement Act of 1996 (DCIA) mandated the federal government to convert most of its one billion annual payment transactions from paper checks to ACH by January 1999 (excluding tax refunds). footnote Public Law 104-134 This Act required that from July 1996, that federal payments to new recipients had to be made electronically. Federal payments cover federal wage, retirement and payments. This policy created an exogenous incentive for banks to adopt receipt technology, since some of their clients would soon require it to receive their payments. However, there was no symmetrical effect on the decision to originate, as all the payments originated from the US Treasury. Therefore, adoption would be more likely in cities with larger number of federal employees. $GOVEMP_{jt}$, the number of federal government employees within the region, captures the effect of favorable government policy towards ACH. Social Security payments were also nominally affected by the act. However they are not modeled explicitly in this paper because of a clause in the DCIA which allowed recipients to receive their payments by check if they certified they did not own a bank account.

4.4 Exogenous factors for both origination and receipt

Banks are more likely to adopt both ACH origination and receipt banks if they are bigger. Banks with a large number of private customers are more likely to recoup the initial fixed costs of installing ACH receipt, because the average cost of adoption per customer, is lower. In addition larger banks are more likely to have large firms as their corporate clients, who are instrumental for ACH origination adoption. Following (**?**), I measure the customer base of bank i by using deposits at that bank. I use a vector $DEPOSIT_{it}$ to proxy for bank size. $DEPOSIT_{it}$ consists of DEPOSIT1 (deposits), DEPOSIT2 (deposits squared) and DEPOSIT3 (deposits cubed) to capture the possibility that the relationship between the number of clients and deposits might not be strictly linear.

Take-up of ACH origination or receipt services depends on employers' and employees' tastes for using ACH rather than checks for payroll and billing in that network area. I use a REGION dummy for each local network area to reflect differences in tastes for electronic payments across different local networks.

The costs of adoption for both ACH origination and receipt declined over the period covered by my sample. From 1995-1997, financial institutions reduced their fixed costs across all components of ACH: Systems, Operational Labor, Operator Fees, and Other Operational Costs (NACHA 1999b). I use a dummy PERIOD for each of the different periods to capture this variation of costs of installing ACH origination and ACH receipt.

4.5 Anticipating future reactions of other banks

The strategic reaction functions in equations (1) and (2) don't allow for any dynamic effects. Specifically, the decision to originate only depends on r_{-ijt}, not r_{-ijt+1}, r_{-ijt+2} etc. Moreover the fact that r_{-ijt+1}, r_{-ijt+2} may be a function of the bank's origination adoption decision at time t is not explicitly modeled. However, a bank may also consider the likely effect of its ACH origination adoption decision on the future ACH receipt adoption decisions of other financial institutions. The larger the bank is relative to the network, the greater the impact its adoption of origination has on $\%O_{jt}$. The larger the increase in $\%O_{jt}$, the greater the positive effect on other neighboring banks' decisions to adopt ACH receipt. Consequently, the larger the relative size of the bank, the greater the ultimate effect its decision to adopt ACH origination has on the anticipated future level of $\%R_{jt}$.

Similarly a bank will also consider how its receipt decision affects the future ACH origination technology adoption decisions of other financial institutions. The larger the bank is relative to the network, the greater the impact its adoption of ACH receipt has on $\%R_{jt}$. The greater the change in $\%R_{jt}$, the greater the positive effect its decision to receive has on other neighboring banks' decisions to adopt ACH origination. Consequently, the larger the relative size of the bank, the greater the ultimate effect its decision to adopt ACH receipt has on the anticipated future level of $\%O_{jt}$. I model this anticipatory strategic effect as being a function of $RELSIZE_{ijt}$, the % of total deposits in local network j controlled by bank i, in period t.

5 Estimation

5.1 Methodology

Integrating these factors affecting ACH adoption into equations (1) and (2) gives

$$o_{ijt} = 1\{\Delta_o\%R_{jt} + \gamma RELSIZE + \beta DEPOSIT + \beta BIGFIRM + PERIOD_t + REGION_j + \epsilon \geq 0\} \tag{3}$$

where o_{ijt} is the binary indicator variable for bank i's decision to adopt ACH origination technology in network j at time t, and

$$r_{ijt} = 1\{\Delta_r\%O_{jt} + \gamma RELSIZE + \beta DEPOSIT + \beta GOVEMP + PERIOD_t + REGION_j + \epsilon \geq 0\} \tag{4}$$

where r_{ijt} is the binary indicator variable for bank i's decision to adopt ACH receipt technology in network j at time t.

Equations (3)and (4) are estimated by assuming an independently and normally distributed error, ϵ. This error ϵ captures unobservable differences in the tastes for electronic payments of banks.

5.2 Is entry reversible or not?

It is attractive to assume that the decision to adopt ACH is not easily reversible, and costs of entry are sunk. Industry literature suggests that banks market electronic payment and receipt of payroll to customers on the basis of long-term cost savings and convenience (FedACH 2002). Banks are unlikely to incur the sunk costs of setting up commercial clients to use ACH for payroll, and then in a subsequent period deny that service to corporate clients, in order to save $30 in connection charges that month.

This contrasts with (Gowrisankaran and Stavins 1999), who assume that ACH adoption is a repeated Nash game, where banks would process ACH in some periods, and then choose not to in subsequent periods. They justify this because of relatively low (around $30) cost of the monthly account charge.

Tables 2 and 3 display probit estimates of equations (3) and (4) for various assumptions about the cost of entry. In the first two columns costs are assumed sunk, and the decision to enter irreversible. The last column present estimates for versions of equations (3) and (4) which follow the assumptions of (Gowrisankaran and Stavins 1999) that costs are not sunk, and firms are free to enter and exit.

5.3 Resolving Endogeneity Issues

The maximum likelihood approach is valid for equations (3) and (4), if the errors ϵ are independently and normally distributed, and are independent of the sequence of explanatory variables. Using time and place dummies for identification of network effects relies on the assumption that tastes for ACH did not change at different rates across regions over the period. If, however, there was a positive shock to tastes for ACH in one network, which encouraged banks to adopt both ACH origination and receipt, then this time- and place-fixed effect identification strategy would wrongly ascribe this exogenous shock to network effects. An additional model which treated $\%R_{jt}$ and $\%O_{jt}$ as endogenously determined within the model, was estimated, to ensure that this unobserved heterogeneity did not bias the estimates of network effects. This model used the total number of government employees within the local network as instruments for $\%R_{jt}$, and the number of large firms within the local network as instruments for $\%O_{jt}$. The Amemiya Generalized Least Squares estimators for probit with endogenous regressors are presented in column 2 of tables 2 and 3.

5.4 Data

ACH was initially introduced in the US in the 1970s, and was first adopted by major banks in the 1980s. However, it was only in the late 1980s, when technology advanced to the stage where ACH could be filed electronically and no longer relied on banks filing individual magnetic tapes to the Federal Reserve, that the cost of ACH became attractive to the broad spectrum of banks. The 34-month panel (April 1995-December 1997) dataset used by this paper covers this expansion of ACH technology in the latter half of the nineties.

This paper assumes that the relevant local network for ACH is the branch's Metropolitan Statistical Area (MSA) for urban settings, and the branch's county for rural settings. Where applicable, primary metropolitan areas rather than consolidated metropolitan areas are used.

The dataset of potential ACH adopters amongst financial institutions was constructed from two sources. The FDIC summary of deposit databases for 1995-1997, provided information on bank deposits for 80,000 federally insured banks and thrift branches. This was augmented, by credit union data from the National Credit Union Association FOIA databases for 1995-1997

The raw ACH data contains the volume of both origination and receipt ACH transactions, by the routing number of institutions purchasing ACH services from the Federal Reserve Bank, by date. If a bank exhibited a non-zero level of ACH origination in a period, it was considered to have adopted origination technology, and correspondingly for receipt. Each month had around 20,000 observations of ACH volumes. These observations were merged by routing number with the federal quarterly call report databases. This mapped 72% of the ACH volume observations. Leaving 28% of the observations unmapped is problematic, because the researcher could wrongly assume that an institution had no ACH activity merely because its ACH activity could not be identified.

(Gowrisankaran and Stavins 1999) tackled this problem by excluding small banks and credit unions (the hardest to match institutions) from their dataset. Table (**?**) shows that by the late nineties, the adoption of ACH was generally high, and that it was only the smaller marginal institutions which had still to adopt. Therefore excluding small banks and credit unions is problematic, because they are precisely the more marginal institutions that by the mid 1990s were most likely to have not yet adopted ACH.

This paper's resolved these data matching difficulties by matching the previously unmatched observations of ACH volumes with the Federal Reserve's directory of ACH participants from 2000. Because the ACH volume observations date back to 1995, 4% could not be matched. This is an improvement on the 28% loss in previous research. Furthermore 500 of the credit union and 1500 of the bank records did not have deposit information, so could not be included in the dataset. One noticeable difference as a result of these improved matching techniques was that, unlike in (Gowrisankaran and Stavins 1999) sample, financial institutions did not repeatedly exit and enter the industry, which supports my assumption that ACH adoption is irreversible.

Because not every bank branch has its own ACH routing number, ACH activity was aggregated up over the banks various branches. If at the aggregate FDIC certificate level the bank received/originated ACH, then I assumed that it received/originated ACH in all its branches. Given the fixed costs of staff training and technology, it makes sense that, if a financial institution decides to offer ACH services, it will offer them throughout all its branches rather than through only a select few.

The proportion of banks who were ACH Receivers and Originators was calculated using all national and local banks in that local network. This is because the capacity for ACH transactions of both national and local banks within that local network influences the ACH adoption decision of individual banks. However, observations of the ACH adoption decision of financial institutions with branches in more than one MSA/rural county were excluded as dependent variables in the regressions. This was primarily to maintain the geographical accuracy of the data. A bank's decision to originate/receive ACH transactions is a weighted response to variables in all its branches. Since identification rests on analyzing geographically determined network effects, analysis must be confined to banks where the decision takes place only within one local network. Luckily, restricting the analysis to such banks is not as drastic as it initially

Table 1: Summary Statistics

Variable in dataset	Mean of Variable
Deposits ($100m) of all financial institutions	0.34
Deposits ($100m) of potential adopters	0.04
% of large firms (with over 50 workers) within region	4.83%
% of federal government employees in region	1.74%
% of financial institutions originating ACH in region, weighted by deposits	91.1%
% of financial institutions receiving ACH in region, weighted by deposits	74.1%

sounds. By 1995 almost all the national banks offered ACH services.

The US census bureau 1995-1997 County Business Patterns dataset provides data on the number of firms with over 50 employees on payroll in the region $BIGFIRM_j$. The percentage of employees who worked for the federal government ($GOVEMP_j$) within each local network from obtained from the Office of Personnel Management's "Fed Scope" database.

One caveat with the data set is that the Federal Reserve is not the only ACH operator in the US. Several other private networks (Visa, Electronic Payments Network, and American Clearing House) held an aggregate of between 25-30% of the market during the period in question.[1] Since an ACH transaction originated/received within the Federal Reserve system could be received/originated by one of these private organizations, it would be desirable to include them when evaluating network effects. However, the data are not available.

The summary statistics for the resultant dataset can be seen in Table 1. They show that banks are more likely to receive than originate. This is unsurprising given the higher costs of origination technology. .

[1]The growth of these private operators was hampered by Federal Reserve pricing policy, which meant that they paid the full fee for any ACH transactions with a Federal Reserve ACH participant. However, after 2000 the Federal Reserve then reduced the price they paid per transaction. By 2003, these private operators are projected to gain nearly 50% of the ACH market.

Table 2: ACH origination adoption

Variable	Sunk Cost: Marginal Effect	Sunk Cost (IV): Marginal Effect	Repeated Nash: Marginal Effect
$\%R_{ijt}$	0.2872	0.2290	0.8105
	(0.0007)	(0.0666)	(0.0018)
$RELSIZE_o$	0.0013	0.0009	0.0021
	(0.0001)	(0.0000)	(0.0000)
$LARGEFIRMS_{jt}$	0.4489	0.4714	0.9196
	(0.1878)	(1.7681)	(0.0444)
$DEPOSITS_{it}$ (\$10m)	0.0302	0.0302	0.3995
	(0.0145)	(0.0136)	(0.0050)
$DEPOSITS2_{it}$ (\$10m)	0.0002	-0.0009	-0.1021
	(0.1945)	(0.0146)	(0.0002)
$DEPOSITS3_{it}$ (\$10m)	-0.0003	-0.0002	-0.0065
	(0.0006)	(0.0006)	(0.0001)
Log-likelihood	-12,250	-13,198	-220,247
Observations	256,579	256,579	451,368
Model Description	Sample excludes institutions who adopted ACH origination previously	$\%R_{ijt}$ is instrumented, using $GOVEMP_j$. Sample excludes institutions who adopted ACH origination previously.	Sample is all financial institutions, including those who have originated in previous periods.

There were dummy variables for each of the regional networks and 34 time periods
Dependent variable o_{ijt} =1 if bank i adopts ACH origination technology in month t, o_{ijt} =0 otherwise.

6 Results and interpretation

Table 2 displays probit estimates of marginal effects, evaluated at the mean value of the variable, for equation (3), the decision to adopt origination technology. In all models, the estimated marginal effect of $\%R_{jt}$ is significant and positive for the origination decision, suggesting that there are large complementarities between the decision to adopt origination technology and existing levels of ACH receipt. A bank is more likely to adopt ACH origination when a large proportion of banks within the local network offer ACH receipt services. The positive coefficient for RELSIZE suggests

Table 3: ACH Receipt adoption

Variable	Sunk Cost: Marginal Effect	Sunk Cost (IV): Marginal Effect	Repeated Nash: Marginal Effect
$\%O_{jt}$	0.0050	0.0020	0.0889
	(0.0001)	(0.0001)	(0.0018)
$RELSIZE_r$	0.0000	0.0002	0.0033
	(0.0001)	(0.00024)	(0.0007)
$GOVEMP_{jt}$	0.0001	0.0003	0.0001
	(0.0001)	(0.0002)	(0.0001)
$DEPOSITS_{it}$ (\$10m)	-0.0154	-0.0166	-0.0651
	(0.0898)	(0.0865)	(0.0031)
$DEPOSITS2_{it}$ (\$10m)	0.0200	0.0202	0.0132
	(0.0175)	(0.0171)	(0.0008)
$DEPOSITS3_{it}$ (\$10m)	-0.0071	-0.0071	-0.0005
	(0.0068)	(0.0042)	(0.0001)
Log-likelihood	-6,405	-9,158	-261,231
Observations	168,848	163,142	451,602
Model Description	Sample excludes institutions who adopted ACH receipt previously.	$\%O_{jt}$ is instrumented, using $BIGFIRM_j$. Sample excludes institutions who adopted ACH receipt previously.	Sample is all financial institutions including those who have received in previous periods.

There were dummy variables for each of the regional networks and 34 time periods
Dependent variable r_{ijt} =1 if bank i adopts ACH receipt technology in month t, r_{ijt} =0 otherwise.

that the dominant bank in a network is far likelier to adopt ACH origination than less dominant banks. The coefficients for the various deposit variables suggest that origination adoption increases with deposits, but that the relationship is non-linear. The positive coefficient on BIGFIRM implies that banks are more likely to originate ACH in the presence of firms with large payroll commitments.

Table 3 displays probit estimates of marginal effects, evaluated at the mean value of the variable, for equation (4), the decision to adopt receipt technology. The estimated coefficient on $\%O_{ijt}$ is significant and positive for the decision to act as a receiver. Banks are more likely to receive ACH if there are already many originators in the network.

The positive and significant coefficient for number of federal employees, suggests that the 1996 DCIA Act encouraged banks with a large number of federal employees in the local network to adopt ACH receipt. It appears that RELSIZE is more important than the absolute size of the bank, since the coefficients on absolute deposits are not significant at conventional levels.

The results in Table 2 for the network effect for $\%R_{jt}$ are similar for whether $\%R_{jt}$ is assumed to be exogenous or endogenous. This suggests that tastes for ACH origination within different regions did not change at different rates during the period, perhaps because of the short time span of the data. By contrast the estimate of network effects on $\%O_{jt}$ for the decision to receive, is lower when instrumental variables are used.

For both origination and receipt, the model where entry is irreversible has lower estimated network effects, than the model where costs are not sunk and firms are free to enter and exit. This suggests that not taking into account the irreversibility of the decision to adopt a technology can lead to an overestimation of the magnitude of network effects.

The positive estimates for network effects on both the receipt and origination sides of the ACH adoption equation suggest that the system is explosive, and that a low origination/low receipt adoption is not a stable equilibrium. An exogenous increase in adoption on one side of the industry (for example due to the arrival of a large firm in the local network) could trigger an iterative process of successive network effects encouraging adoption of receipt and then origination, until the network reaches a new high origination/high receipt equilibrium. Consequently these estimates suggest that there is a positive feedback mechanism inherent in the ACH system which means that a low origination/low receipt equilibrium is temporary, and that the network is likely to progress to a stable high origination/high receipt equilibrium in the future.

7 Extension: Exploiting indeterminacy in the initial setting.

In the above estimates, exogenous changes lead to a positive feedback loop for adoption For example, an exogenous event such as the arrival of a new large corporate client encourages banks to adopt ACH origination. This in turn encourages banks to adopt ACH receipt on the other side of the network, and so on.

However, this model cannot explain why in 1995 ACH adoption decisions are different in different regions, despite identical exogenous conditions. This can only be explained with a more sophisticated model of multiple equilibria. If there is no coordination between the potential receiver and originator, either both adopting or neither adopting can be an equilibrium. (Gandal, Kende, and Rob 2000) dismiss this region of indeterminacy, since the "don't adopt/don't adopt" equilibrium is unstable. As the evidence presented above suggest, if perturbed just a little, then the network will cross to an "adopt/adopt" equilibrium. Whilst in the long run this may be the case, in the initial distribution, the potential for don't adopt/don't adopt equilibria exists.

To illustrate the issues arising from simultaneity, consider the case where there is one potential originator and one potential receiver within the region. Here some vector of exogenous variables x,z maps into regions for ϵ where the model predicts a non-unique outcome vector. Equations (1) and (2) can be simplified to

$$o = \begin{cases} 1 & \text{if } \beta x + \Delta r + \epsilon_o > 0, \\ 0 & \text{otherwise.} \end{cases} \tag{5}$$

$$r = \begin{cases} 1 & \text{if } \beta z + \Delta o + \epsilon_r > 0, \\ 0 & \text{otherwise.} \end{cases} \tag{6}$$

If these decisions are treated as simultaneous, the endogenous variables are ((0,0)

(0,1) (1,0) (1,1)).

In Figure 1, the box in the center represents an area of uncertainty, where the model could predict either an outcome where both adopt, or neither adopts. The area of indeterminacy means we cannot get exact probabilities for $Pr((1,1) \mid x, z)$ and $Pr((0,0) \mid x, z)$. However (Tamer 2001) and (Tamer 2002) show it is possible to derive likelihood bounds on the probabilities. I suppress the dependence of the bounds on (x, z, θ), where $\theta = (\beta_o, \beta_r, \Delta_o, \Delta_r, \Omega)$ for simplicity.

We can see in Figure 1 that the probability of the two banks lying in the region of uncertainty is

$$H_{uncertain} = Pr(-\beta_o x - \Delta_o < \epsilon_o < -\beta_o x; -\beta_r z - \Delta_r < \epsilon_r < -\beta_r z)$$

If both banks are in the region of uncertainty, the probability that they always both adopt ACH is:

$$H_{11} = Pr(-\beta_o x - \Delta_o < \epsilon_o; -\beta_r z - \Delta_r < \epsilon_r)$$

If both banks are in the region of uncertainty, the probability that neither ever adopt ACH is:

$$H_{00} = Pr(\epsilon_o < -\beta_o x - \Delta_o; \epsilon_r < -\beta_r z - \Delta_r)$$

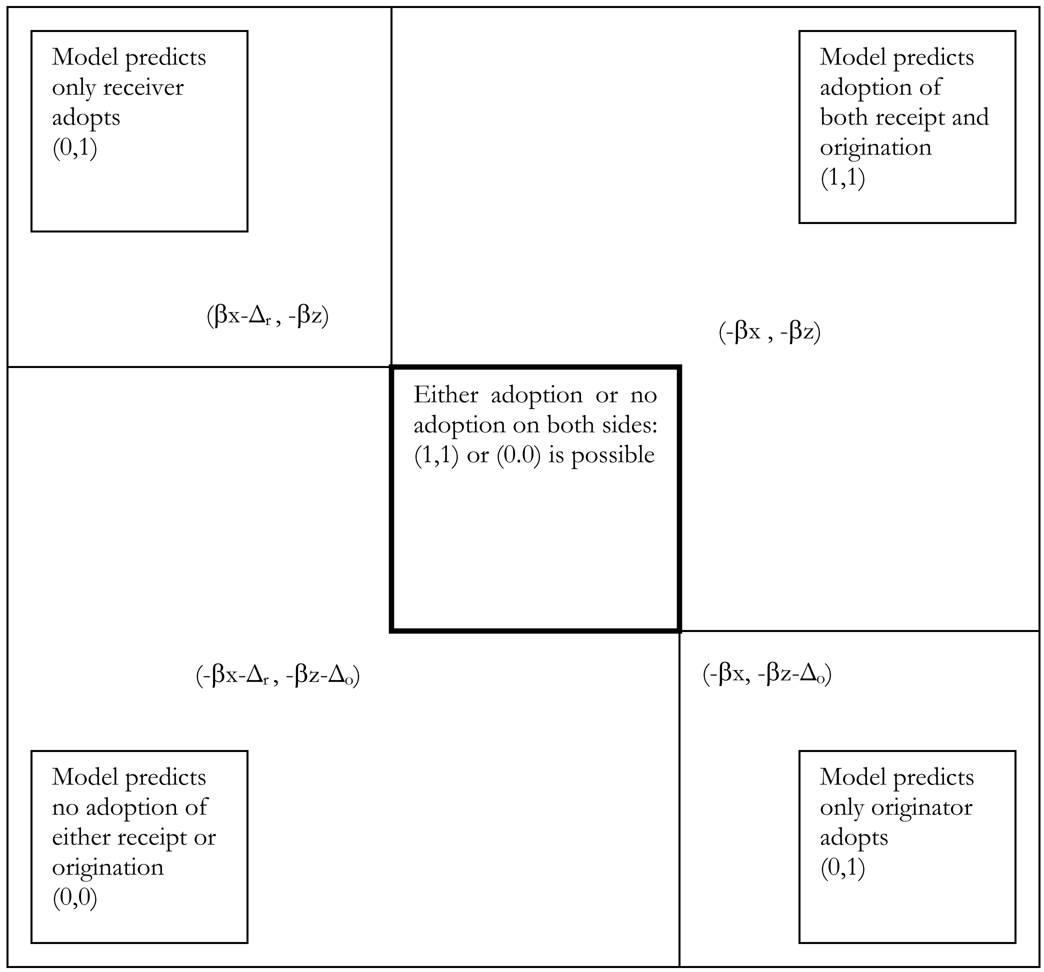
We can use these bounds for the probability of both banks adopting

$$H_{L11} = H_{H11} - H_{uncertain} < Pr((1,1) \mid x, z) < H_{H11}$$

And we can use these bounds for the probability of neither bank adopting.

$$H_{L00} = H_{H00} - H_{uncertain} < Pr((0,0) \mid x, z) < H_{H00}$$

Returning to the diagram, since network effects are positive, there is no indeterminacy for the probability that the potential originator adopts, and the potential receiver


Model predicts only receiver adopts (0,1)
Model predicts adoption of both receipt and origination (1,1)
(βx-Δr , -βz)
(-βx , -βz)
Either adoption or no adoption on both sides: (1,1) or (0.0) is possible
(-βx-Δr , -βz-Δo)
(-βx, -βz-Δo)
Model predicts no adoption of either receipt or origination (0,0)
Model predicts only originator adopts (0,1)

doesn't adopt

$$H_{10}(x,z,\theta) = Pr(-\beta x < \epsilon_o; \epsilon_r < -\beta z - \Delta) = Pr((1,0)|x,z)$$

Similarly, there is no indeterminacy for the probability that the potential originator doesn't adopt, and that the potential receiver adopts

$$H_{01}(x,z,\theta) = Pr(\epsilon_o < -\beta x - \Delta; -\beta z < \epsilon_r) = Pr((0,1)|x,z)$$

We can use these bounds to construct log likelihoods. Given an i.i.d. sample, the likelihood of an observation [(o,r),X,Z] can be bounded from below by

$$LL(x,z,t) = H_{L00}1[(o,r) = (1,1)] + H_{10}1[(o,r) = (1,0)] + H_{01}1[(o,r) = (0,1)] + H_{L11}1[(o,r) = (0,0)]$$

and from above by

$$LH(x,z,t) = H_{H00}1[(o,r) = (1,1)] + H_{10}1[(o,r) = (1,0)] + H_{01}1[(o,r) = (0,1)] + H_{H11}1[(o,r) = (0,0)]$$

These bounds can be estimated using maximum likelihood techniques. (Tamer 2002) provides a proof that because the unobserved likelihood L(t) lies between the two observed functions LL and LH, the maximum of the unobserved likelihood must lie between t_L and t_H, which means we can get bounds on the coefficients of interest. The advantage of using likelihood bounds techniques is that they don't require strict assumptions about distributional form. The disadvantage of likelihood bounds techniques is that the estimates are less sharp. To explore the indeterminacy in the initial setting, this model was applied to the initial distribution of ACH adoption in March 1995, in regions where there were only two financial institutions. Computation constraints dictated this restriction to cases where there was one potential originator and one potential receiver for each region. The potential originator was the largest (in

Table 4: Using indeterminacy for estimation in the two bank case

Variable Description	Lower Bound Marginal effect	Upper Bound Marginal effect	95% Estimated Confidence Interval
Δ_o	0.0003	0.0362	[0.0000, 0.0068]
$DEPOSIT_0$	0.0253	0.0262	[-0.0086, 0.0659]
$DEPOSIT2_0$	0.0000	0.0502	[-0.0021, 0.0007]
$DEPOSIT3_0$	0.0006	0.0012	[-0.0043, 0.0911]
BIGFIRM	0.0419	0.0484	[0.0001, 0.0925]
Δ_r	0.0003	0.0008	[-0.0083, 0.0007]
$DEPOSIT_R$	0.0007	0.0009	[-0.0005, 0.0019]
$DEPOSIT2_R$	0.0000	0.0000	[-0.004, 0.0002]
$DEPOSIT3_R$	0.0000	0.0000	[-0.0001, 0.0001]
EMPLOYEES	0.0005	0.0008	[0.0001, 0.0034]
Dependent variable are ((0,0),(0,1),(1,0),(0,0)) depending on entry decisions of potential originator (largest bank), and potential receiver (second largest bank) in region, in March 1995, 335 observations.			

terms of deposits) non-multi-region bank within the region. The potential receiver was the second largest non-multi-region bank. For the potential originator, the exogenous variables in the vector x the number of large firms within the region, and the potential originator's total deposits, deposits squared, and deposits cubed. For a bank's decision to adopt receipt, the vector z contains the number of employees on payroll in the region and the individual's bank's total deposits, deposits squared, and deposits cubed.[2] Table 4 presents estimates for this likelihood bounds approach to the incomplete technology adoption game. I computed 95% confidence intervals using bootstrap methodology, sub-sampling the data 1000 times. As before, the network effects represented by Δ_o and Δ_r are positive. These estimates confirm the previous findings. Network effects are present, and they are larger for the decision to originate than to receive. The effects are smaller in magnitude at the margin, than in the earlier estimation, but that could be because the estimates were limited to two banks for each region.

[2] It is not appropriate to use government employees in this period, because the legislation mandating them to use ACH had not yet been passed in March 1995.

8 Conclusion

The link between network effects and a positive feedback mechanism in two-sided networks has been receiving increased theoretical attention. This paper provides the first empirical study of a two-sided positive feedback mechanism in an industry where there is a multitude of identifiable potential participants on both sides of the networks. In addition to using time and place effects to identify network in local regions, this paper also exploited the potential for multiple equilibria in the initial static setting to provide further estimates of network effects. Future empirical work needs to find ways of resolving the potential for multiple equilibria with a dynamic setting, and multiple players.

Both the probit and likelihood bound estimates suggest that significant network effects exist for both origination and receipt for this time period. This is suggestive about government policy towards encouraging ACH use. Since the decision to join an ACH network is taken by an isolated financial institution, without reference to the effect that their joining the network has on other network users, the positive network externalities identified could have policy implications: namely, the government might have to intervene because banks fail to recognize the beneficial effect that their decision to adopt has on others. However my estimates imply that there is an iterative positive feedback mechanism inherent in the process of adoption of ACH. Therefore it is not clear that the incidence of a low origination/low receipt equilibrium persists long enough, or is costly enough in terms of welfare, to warrant government intervention.

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