Network Externalities and Technology Adoption: Lessons from Electronic Payments

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Examine network externalities

Market: automated clearinghouse (ACH)

- ACH is an electronic payment product
- Developed by the Federal Reserve

- Typical usages: paying recurring bills, such as paychecks, mortgages, electricity bills, etc.

What is a network externality?

- Utility from using the good increases when other people use the good
- Must be true after controlling for price and exogenous characteristics

Why should we care about network externalities?

1) Implications for electronic payments

Puzzle: Computers and technology dominant
Why are paper checks so used?

Two explanations:
A) Network externalities
B) Preference for checks
Different policy implications for A and B

2) Implications for other industries

- Many technologically intensive industries may have network aspects
- Examples VCRs, FAX machines, e-mail
- Many theoretical models, little empirical work

Existing empirical work

1) Time series studies

- Park (1997) VCRs
- Economides and Himmelberg (1995) FAXs
- Cabral and Leite (1992) Telex

Central problem:

- Technological advances => falling prices
- Is the rising quantity movement along a demand curve or network externalities?

2) Cross-sectional studies

- Goolsbee and Klenow (1998) Computer use
- Rysman (2000) Yellow pages

- Correlations in preferences leads to “reflection problem”
- X variables can be used as a source of variation, i.e. instruments

Goals of this study

We want to understand:

- Are there network effects in electronic payments?
- What causes these effects (informational problems, or more users)?
- Economic magnitudes of the effects

Innovation of our methodology

- Use panel data with geographic variation
- Simple theoretical model with testable implications
- Develop three different methods to identify network externalities:
  1) Clustering of adoption
  2) Externalities internalized in concentrated markets
  3) Quasi-experimental variation from small branches
- Compute economic impact using estimated parameters

Data

We merge several sources of data

1) ACH Billing data from the Federal Reserve
- Volume and usage of transaction origination for each ABA bank/quarter

2) FDIC Call Reports database
- Assets, deposits, location
- HQ zip code, quarterly

3) Summary of Deposits database
- Deposits, branch locations
- Branch zip code, annual

4) Geographical data
- Use to determine network

Table 1: ACH usage by bank size

Quarter	Number Using ACH			Percent Using ACH		
	small	medium	large	small	medium	large
95:Q2	4208	1811	440	53.1%	75.1%	73.8%
95:Q3	4235	1831	448	53.7%	75.3%	73.9%
95:Q4	4273	1893	462	54.5%	76.9%	75.1%
96:Q1	4383	1911	468	55.8%	77.9%	75.2%
96:Q2	4559	1901	449	57.7%	78.0%	76.1%
96:Q3	4600	1948	480	58.3%	79.8%	81.8%
96:Q4	4732	2032	482	60.5%	81.1%	80.3%
97:Q1	4857	2042	473	62.0%	81.8%	79.4%
97:Q2	5061	2057	470	64.1%	83.8%	82.0%
97:Q3	5138	2057	470	65.1%	83.3%	82.6%
97:Q4	5169	2112	465	65.9%	83.9%	81.9%

Table 2: Entrants and Exiters

Quarter	Entrants	Percent of total	Exiters	Percent of total
95:Q2	--	--	407	6.3%
95:Q3	462	7.1%	414	6.4%
95:Q4	528	8.0%	397	6.0%
96:Q1	531	7.9%	388	5.7%
96:Q2	535	7.7%	493	7.1%
96:Q3	612	8.7%	319	4.5%
96:Q4	537	7.4%	328	4.5%
97:Q1	454	6.2%	256	3.5%
97:Q2	472	6.2%	266	3.5%
97:Q3	343	4.5%	254	3.3%
97:Q4	335	4.3%	--	--

Table 3: Fraction adopting in 1997:Q4, by 1995:Q2 adoption

		Fraction of banks adopting in 1995:Q2				
		0-19%	20%-39%	40-59%	60-79%	80-100%
Fraction of banks adopting in 1997:Q4 given 1995:Q2 level	0-19%	0.376	0.033	0.010	0.005	0.002
	20%-39%	0.105	0.208	0.014	0.019	0.005
	40-59%	0.097	0.136	0.214	0.077	0.028
	60-79%	0.093	0.143	0.221	0.271	0.129
	80-100%	0.329	0.481	0.540	0.629	0.837

Table 4: Fraction adopting, by population and concentration

	Population of MSA/county					
HHI	20,000 - 40,000		100,000 - 200,000		400,000 - 1 million	
	Mean	No. of obs.	Mean	No. of obs.	Mean	No. of obs.
0 - 0.1	0.591	3	0.661	11	0.679	4
0.1 - 0.2	0.766	108	0.797	67	0.912	34
0.2 - 0.3	0.810	247	0.878	38	0.828	8
0.3 - 0.4	0.850	131	0.935	6	--	0
0.4 - 1.0	0.862	81	0.972	1	--	0

Model of technology adoption

- Set of customers i of banks j
- Discrete choice between ACH and checks:
  $u_{i,j}\left(\text{Usage}_{-i,j}\right) = \gamma^C X_{i,j} + f\left(\beta^C, \text{Usage}_{-i,j}\right)$
- Consumers use ACH if utility is positive and their bank adopts
- Networks extend 30 kilometers, static model
- Network externality:
  $\partial u_{i,j} / \partial \text{Usage}_{-i,j} > 0$
- Two stage game: banks choose adoption, then consumers choose usage
- Consumer game has unique Pareto-dominating Nash equilibrium, given adoption
- For this equilibrium, $\text{Usage}^P\left(\text{Adoption}\right)$ is increasing in Adoption

Model (continued)

- Banks capture all the surplus from adoption, adopt if surplus positive

$$A_j = \left\{ \pi_j \left(A_{-j} \right) > 0 \right\} = \left\{ \gamma X_j + \beta h \left(A_{-j} \right) + \varepsilon_j > 0 \right\}$$

where:

- { } is the indicator function
- A_{-j} is the adoption decisions of other banks
- X_j are the banks' own characteristics, such as size, fixed effects, etc.
- $h\left(A_{-j}\right)$ is the bank-level network externality, with 2 functional forms:
  - $\#\left(j\right)$ measures the fraction of banks adopting ACH
  - $\#^{Q}\left(j\right)$ measures the number of ACH transactions per dollar assets

- Consumer network externality leads to bank-level network externality
- Overall game has unique Pareto-dominating subgame perfect equilibrium

Identifying network externalities from clustering

- Find network externalities if adoption is correlated within a network
- Bank and time fixed effects control for technological differences and advancements
- Main identifying assumption: $\mathrm{Corr}\left[\varepsilon_{1t}, \varepsilon_{2t}\right] = 0$ (iid errors)

Stylized case with two banks:

$$A_{1t} = \left\{\Pi_{1t}\left(A_{2t}\right) > 0\right\} = \left\{\beta h\left(A_{2t}\right) + \delta_t + \alpha_1 + \varepsilon_{1t} > 0\right\}$$

$$A_{2t} = \left\{\Pi_{2t}\left(A_{1t}\right) > 0\right\} = \left\{\beta h\left(A_{1t}\right) + \delta_t + \alpha_2 + \varepsilon_{2t} > 0\right\}$$

- Use Chamberlain's fixed effects logit
- Method can test for positive network externality
- More structural methods can identify magnitudes (see Ackerberg and Gowrisankaran)
- Using quantity and adoption, can distinguish from other phenomena

Table 5: Identification using clustering

	Regressor: Fraction adopting $[\#(j)]$	Regressor: ACH volume per $[\#^{Q}(j)]$	Conditional log like R^2 (within)
Model 1: Adoption on $\#(j)$	1.874*** (0.096)	--	-12,882.9
Model 2: Adoption on $\#(j)$ and $\#^{Q}(j)$	1.873*** (0.096)	0.142 (0.109)	-12,882.0
Model 4: Adoption on $\#(j)$ with alternate definition of entry/exit	2.073*** (0.135)	--	-9,218.2
Model 6: Volume per assets on $\#(j)$ and $\#^{Q}(j)$	0.0013 (0.0057)	0.0075 (0.0052)	0.0012

Identifying network externalities from size & concentration

- Idea: $f\left(X_{-j}\right)$ is an excluded exogenous variable in adoption decision:
  $$A_j = \left\{\pi_j\left(A_{-j}\right) > 0\right\} = \left\{\gamma X_j + \beta h\left(A_{-j}\right) + \varepsilon_j > 0\right\}$$
- Adoption will be correlated with other banks' sizes, but other banks' sizes do not directly enter into adoption decision
- Concentration is a nice way of encapsulating $f\left(X_{-j}\right)$: concentrated markets can internalize network externalities
- Need to worry about some similar implications of market power
- Reduced-form test of network externalities:
  $$A_j = \left\{\gamma X_j + \alpha HHI_j + \varepsilon_j > 0\right\}$$
- Instrumental variables estimation - linear probability model:
  $$A_j = \gamma X_j + \beta h\left(A_{-j}\right) + \varepsilon_j$$

Table 6: Identification using size and concentration

	Regressor: MSA/county level concentration [HHI_j]	Regressor: Fraction adopting ACH [$\#(j)$]	Log likelihood / R^2 (within)
Model 1: Adoption on HHI_j and bank size dummies (Logit estimation)	0.392*** (0.046)	--	Log L= -64,392.6
Model 3: Volume per assets on HHI_j, for adopting banks (Linear FE estimation)	0.171 (0.053)	--	R^2=0.002
Model 5: Adoption on $\#(j)$ and bank fixed effects (Linear IV FE estimation)	--	0.930*** (0.072)	--

Identification from quasi-experimental variation in adoption

- Idea: Want to observe exogenous variation in adoption $(\#(j))$
- Natural experiment: multi-branch banks adopt ACH system-wide
- Small branch adoption of large bank is exogenous
- These decisions trace out structural parameter for local bank

We create a sample of networks with:
- Exactly one local bank
- One or more small branches of large bank
- "Small" defined by $< 5\%$ of deposits

- Identification assumption: deposits and presence of large banks are exogenous

Using estimated structural parameters:
- Compute Pareto-best and -worst equilibria
- Compute first-best solution

Table 7: Identification using quasi-experimental variation

	Regressor: Fraction adopting ACH [#(j)]	Number of observations	Log likelihood / R^2
Model 1: Adoption on #(j) (Probit estimation)	1.094 (0.411)*** Robust: (0.354)***	237	Log L= -138.4
Model 2: Adoption on #(j) and bank size dummies (Probit estimation)	1.623 (0.679)** Robust: (0.788)**	158	Log L= -84.7
Model 3: Adoption on #(j) (Linear estimation)	0.511 (0.180)*** Robust: (0.291)*	237	R^2= 0.467

Table 8: Simulation of network equilibria

Number of firms, N	Pareto-worst Nash equilibrium	Pareto-best Nash equilibrium	First-best (perfect cartel) outcome
1	0.62	0.62	0.62
2	0.30	0.46	0.66
3	0.32	0.43	0.67
4	0.32	0.41	0.67
5	0.32	0.40	0.67
6	0.33	0.39	0.67

Cell gives expected percent of banks adopting
N symmetric firms, deposits=$34 Million

Extension: Structural estimation

(See Ackerberg and Gowrisankaran, in progress)

- Structural estimation to can combine three methods of identification
- More realistic functional forms for consumers and banks
- Need to model multiple equilibria
- Frequency θ ($1-\theta$) of best (worst) equilibrium
- Use maximum likelihood
- Allow for random effects, not fixed effects

Structural estimation algorithm:

1) Construct mutually exclusive networks
2) Draw vector of unobservables
3) Search over parameter vector to maximize likelihood:
   A) Solve N.E. by network given unobservables
   B) Evaluate implied density for draw
   C) Sum over simulation draws to get likelihood

Conclusions

- Detailed panel data helps separate network externalities from other implications

- Significant evidence of network externalities:
  1) Testing from clustering
  2) Identification from size and concentration
  3) Natural experiment from small branches

- Can distinguish network externalities from market power and other explanations

- We find moderately large network externalities, at bank level