Network Externalities and Technology Adoption: Lessons from Electronic Payments

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The views expressed herein are not those of the Federal Reserve Banks of Boston or San Francisco or of the Federal Reserve System.
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
   - 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

<table>
<thead>
<tr>
<th>Quarter</th>
<th>Number Using ACH</th>
<th>Percent Using ACH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>small</td>
<td>medium</td>
</tr>
<tr>
<td>95:Q2</td>
<td>4208</td>
<td>1811</td>
</tr>
<tr>
<td>95:Q3</td>
<td>4235</td>
<td>1831</td>
</tr>
<tr>
<td>95:Q4</td>
<td>4273</td>
<td>1893</td>
</tr>
<tr>
<td>96:Q1</td>
<td>4383</td>
<td>1911</td>
</tr>
<tr>
<td>96:Q2</td>
<td>4559</td>
<td>1901</td>
</tr>
<tr>
<td>96:Q3</td>
<td>4600</td>
<td>1948</td>
</tr>
<tr>
<td>96:Q4</td>
<td>4732</td>
<td>2032</td>
</tr>
<tr>
<td>97:Q1</td>
<td>4857</td>
<td>2042</td>
</tr>
<tr>
<td>97:Q2</td>
<td>5061</td>
<td>2057</td>
</tr>
<tr>
<td>97:Q3</td>
<td>5138</td>
<td>2057</td>
</tr>
<tr>
<td>97:Q4</td>
<td>5169</td>
<td>2112</td>
</tr>
</tbody>
</table>
Table 2: Entrants and Exiters

<table>
<thead>
<tr>
<th>Quarter</th>
<th>Entrants</th>
<th>Percent of total</th>
<th>Exiters</th>
<th>Percent of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>95:Q2</td>
<td>--</td>
<td>--</td>
<td>407</td>
<td>6.3%</td>
</tr>
<tr>
<td>95:Q3</td>
<td>462</td>
<td>7.1%</td>
<td>414</td>
<td>6.4%</td>
</tr>
<tr>
<td>95:Q4</td>
<td>528</td>
<td>8.0%</td>
<td>397</td>
<td>6.0%</td>
</tr>
<tr>
<td>96:Q1</td>
<td>531</td>
<td>7.9%</td>
<td>388</td>
<td>5.7%</td>
</tr>
<tr>
<td>96:Q2</td>
<td>535</td>
<td>7.7%</td>
<td>493</td>
<td>7.1%</td>
</tr>
<tr>
<td>96:Q3</td>
<td>612</td>
<td>8.7%</td>
<td>319</td>
<td>4.5%</td>
</tr>
<tr>
<td>96:Q4</td>
<td>537</td>
<td>7.4%</td>
<td>328</td>
<td>4.5%</td>
</tr>
<tr>
<td>97:Q1</td>
<td>454</td>
<td>6.2%</td>
<td>256</td>
<td>3.5%</td>
</tr>
<tr>
<td>97:Q2</td>
<td>472</td>
<td>6.2%</td>
<td>266</td>
<td>3.5%</td>
</tr>
<tr>
<td>97:Q3</td>
<td>343</td>
<td>4.5%</td>
<td>254</td>
<td>3.3%</td>
</tr>
<tr>
<td>97:Q4</td>
<td>335</td>
<td>4.3%</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>
Table 3: Fraction adopting in 1997:Q4, by 1995:Q2 adoption

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0-19%</td>
<td>0.376 0.033 0.010 0.005 0.002</td>
</tr>
<tr>
<td>20%-39%</td>
<td>0.105 0.208 0.014 0.019 0.005</td>
</tr>
<tr>
<td>40-59%</td>
<td>0.097 0.136 0.214 0.077 0.028</td>
</tr>
<tr>
<td>60-79%</td>
<td>0.093 0.143 0.221 0.271 0.129</td>
</tr>
<tr>
<td>80-100%</td>
<td>0.329 0.481 0.540 0.629 0.837</td>
</tr>
</tbody>
</table>
Table 4: Fraction adopting, by population and concentration

<table>
<thead>
<tr>
<th>HHI</th>
<th>20,000 - 40,000</th>
<th>100,000 - 200,000</th>
<th>400,000 - 1 million</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>No. of obs.</td>
<td>Mean</td>
</tr>
<tr>
<td>0 - 0.1</td>
<td>0.591</td>
<td>3</td>
<td>0.661</td>
</tr>
<tr>
<td>0.1 - 0.2</td>
<td>0.766</td>
<td>108</td>
<td>0.797</td>
</tr>
<tr>
<td>0.2 - 0.3</td>
<td>0.810</td>
<td>247</td>
<td>0.878</td>
</tr>
<tr>
<td>0.3 - 0.4</td>
<td>0.850</td>
<td>131</td>
<td>0.935</td>
</tr>
<tr>
<td>0.4 - 1.0</td>
<td>0.862</td>
<td>81</td>
<td>0.972</td>
</tr>
</tbody>
</table>
Model of technology adoption

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

- Banks capture all the surplus from adoption, adopt if surplus positive
  \[ A_j = \{ \pi_j(A_{-j}) > 0 \} = \{ \gamma X_j + \beta h(A_{-j}) + \varepsilon_j > 0 \} \]
  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.
  - \( h(A_{-j}) \) is the bank-level network externality, with 2 functional forms:
    - \( \#(j) \) measures the fraction of banks adopting ACH
    - \( \#^Q(j) \) 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: $\text{Corr}[\varepsilon_{1t}, \varepsilon_{2t}] = 0$ (iid errors)

Stylized case with two banks:
\[ A_{1t} = \{ \Pi_{1t} (A_{2t}) > 0 \} = \{ \beta h(A_{2t}) + \delta_t + \alpha_1 + \varepsilon_{1t} > 0 \} \]
\[ A_{2t} = \{ \Pi_{2t} (A_{1t}) > 0 \} = \{ \beta h(A_{1t}) + \delta_t + \alpha_2 + \varepsilon_{2t} > 0 \} \]

- 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>
<thead>
<tr>
<th>Model</th>
<th>Regressor: Fraction adopting [#(j)]</th>
<th>Regressor: ACH volume per [#^Q(j)]</th>
<th>Conditional log like R^2 (within)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1: Adoption on #(j)</td>
<td>1.874*** (0.096)</td>
<td>--</td>
<td>-12,882.9</td>
</tr>
<tr>
<td>Model 2: Adoption on #(j) and #^Q(j)</td>
<td>1.873*** (0.096)</td>
<td>0.142 (0.109)</td>
<td>-12,882.0</td>
</tr>
<tr>
<td>Model 4: Adoption on #(j) with alternate definition of entry/exit</td>
<td>2.073*** (0.135)</td>
<td>--</td>
<td>-9,218.2</td>
</tr>
<tr>
<td>Model 6: Volume per assets on #(j) and #^Q(j)</td>
<td>0.0013 (0.0057)</td>
<td>0.0075 (0.0052)</td>
<td>0.0012</td>
</tr>
</tbody>
</table>
Identifying network externalities from size & concentration

- Idea: \( f(X_{-j}) \) is an excluded exogenous variable in adoption decision:
  \[
  A_j = \{\pi_j(A_{-j}) > 0\} = \{\gamma X_j + \beta h(A_{-j}) + \varepsilon_j > 0\}
  \]
- 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 \( f(X_{-j}) \): concentrated markets can internalize network externalities
- Need to worry about some similar implications of market power
- Reduced-form test of network externalities:
  \[
  A_j = \{\gamma X_j + \alpha HHI_j + \varepsilon_j > 0\}
  \]
- Instrumental variables estimation - linear probability model:
  \[
  A_j = \gamma X_j + \beta h(A_{-j}) + \varepsilon_j
  \]
Table 6: Identification using size and concentration

<table>
<thead>
<tr>
<th>Model</th>
<th>Regressor: MSA/county level concentration [HHI\textsubscript{j}]</th>
<th>Regressor: Fraction adopting ACH [#(j)]</th>
<th>Log likelihood / R\textsuperscript{2} (within)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1: Adoption on HHI\textsubscript{j} and bank size dummies (Logit estimation)</td>
<td>0.392*** (0.046)</td>
<td>--</td>
<td>Log L= -64,392.6</td>
</tr>
<tr>
<td>Model 3: Volume per assets on HHI\textsubscript{j}, for adopting banks (Linear FE estimation)</td>
<td>0.171 (0.053)</td>
<td>--</td>
<td>R\textsuperscript{2}=0.002</td>
</tr>
<tr>
<td>Model 5: Adoption on #(j) and bank fixed effects (Linear IV FE estimation)</td>
<td>--</td>
<td>0.930*** (0.072)</td>
<td>--</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Model</th>
<th>Regression &amp; Estimation</th>
<th>Regressor: Fraction adopting ACH ([#(j)])</th>
<th>Number of observations</th>
<th>Log likelihood / (R^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1: Adoption on (j) (Probit estimation)</td>
<td>1.094 (0.411)<strong>*** Robust: (0.354)</strong>***</td>
<td>237</td>
<td>Log L= -138.4</td>
<td></td>
</tr>
<tr>
<td>Model 2: Adoption on (j) and bank size dummies (Probit estimation)</td>
<td>1.623 (0.679)** Robust: (0.788)**</td>
<td>158</td>
<td>Log L= -84.7</td>
<td></td>
</tr>
<tr>
<td>Model 3: Adoption on (j) (Linear estimation)</td>
<td>0.511 (0.180)***** Robust: (0.291)*</td>
<td>237</td>
<td>(R^2= 0.467)</td>
<td></td>
</tr>
</tbody>
</table>
Table 8: Simulation of network equilibria

<table>
<thead>
<tr>
<th>Number of firms, N</th>
<th>Pareto-worst Nash equilibrium</th>
<th>Pareto-best Nash equilibrium</th>
<th>First-best (perfect cartel) outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.62</td>
<td>0.62</td>
<td>0.62</td>
</tr>
<tr>
<td>2</td>
<td>0.30</td>
<td>0.46</td>
<td>0.66</td>
</tr>
<tr>
<td>3</td>
<td>0.32</td>
<td>0.43</td>
<td>0.67</td>
</tr>
<tr>
<td>4</td>
<td>0.32</td>
<td>0.41</td>
<td>0.67</td>
</tr>
<tr>
<td>5</td>
<td>0.32</td>
<td>0.40</td>
<td>0.67</td>
</tr>
<tr>
<td>6</td>
<td>0.33</td>
<td>0.39</td>
<td>0.67</td>
</tr>
</tbody>
</table>

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 $\theta (1-\theta)$ 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