Strategic Complementarities in a Dynamic Model of Technology Adoption: P2P Digital Payments

Fernando Alvarez
University of Chicago and NBER

David Argente
Yale University and NBER

Francesco Lippi
EIEF, LUISS, and CEPR

Esteban Méndez
Central Bank of Costa Rica

Diana Van Patten
Yale University and NBER

Technology Diffusion (Griliches, 1957)

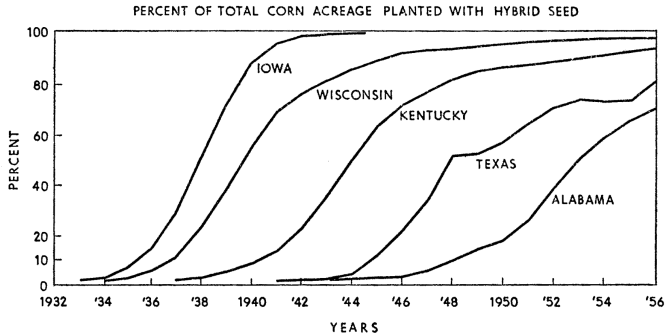


FIGURE 1.—Percentage of Total Corn Acreage Planted with Hybrid Seed.
Source: U.S.D.A., *Agricultural Statistics*, various years.

- Adoption: cost declines over time (e.g. tractors, laundry machines)

- New technologies: social media, payments apps, etc.
  - Adoption: network effects

- New technologies: social media, payments apps, etc.
  - Adoption: network effects
- Dynamic model of technology adoption with strategic complementarities
  - New: Waiting for others to adopt leads to slow adoption

- New technologies: social media, payments apps, etc.
  - Adoption: network effects
- Dynamic model of technology adoption with strategic complementarities
  - New: Waiting for others to adopt leads to slow adoption
- Externality: when agents adopt they benefit others with the technology
  - Optimal time-varying subsidy: large improvements from small changes

- x: Agents differ in potential benefits from using technology
  (e.g. agent's strength of connections)

- x: Agents differ in potential benefits from using technology
  (e.g. agent's strength of connections)
- $N(t)$: share of agents in an agent's network who have adopted
  (e.g. friends, family, co-workers, neighbors)

- x: Agents differ in potential benefits from using technology
  (e.g. agent's strength of connections)
- $N(t)$: share of agents in an agent's network who have adopted
  (e.g. friends, family, co-workers, neighbors)
- Benefits of adopting technology:

$$x \times \Big[\underbrace{\theta_0}_{\text{benefits app}} + \Big]$$

- x: Agents differ in potential benefits from using technology
  (e.g. agent's strength of connections)
- $N(t)$: share of agents in an agent's network who have adopted
  (e.g. friends, family, co-workers, neighbors)
- Benefits of adopting technology:

$$x \times \left[\underbrace{\theta_0}_{\text{benefits app}} + \underbrace{\theta_n}_{\text{complementarity}} N(t) \right]$$

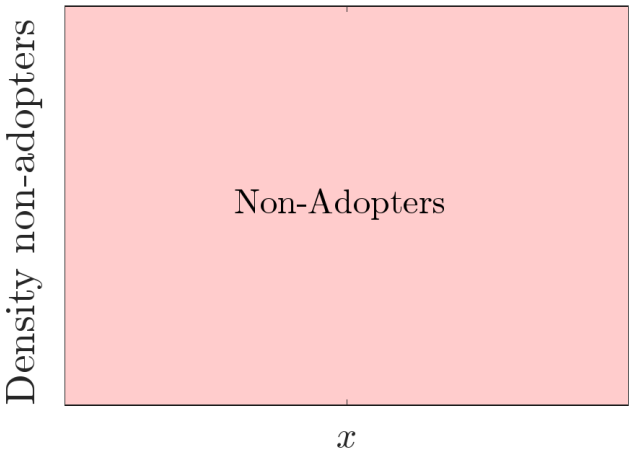
- $c > 0$: fixed cost of adopting the technology (selection)

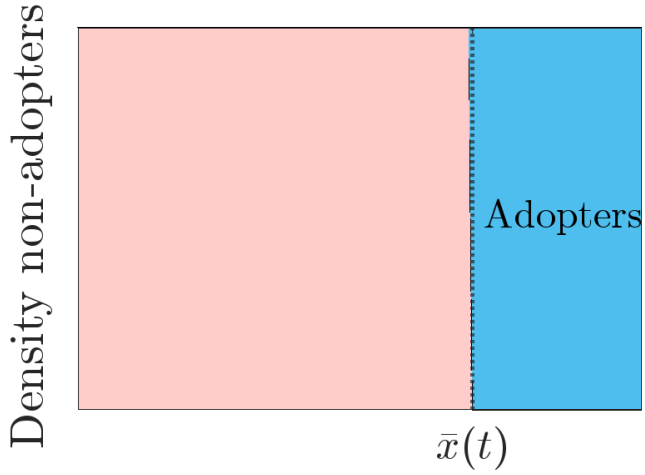
Equilibrium

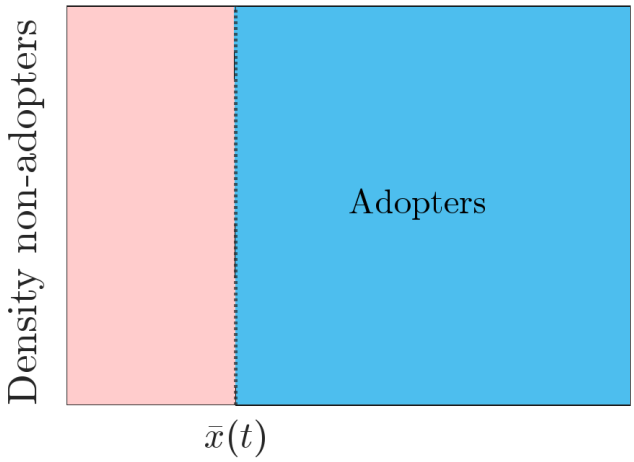
$$\{N(t)\} \xrightarrow{\text{Agents' adoption decision}} \{\bar{x}(t)\}$$

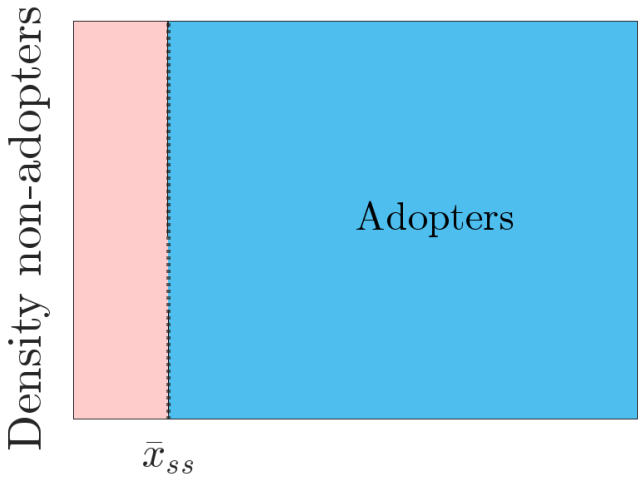
$$\{\bar{x}(t)\} \xrightarrow{\text{Aggregation}} \{N(t)\}$$

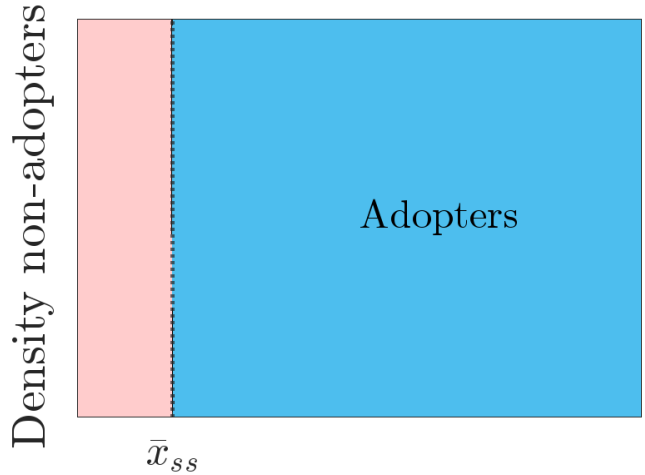
Fixed Point


Density non-adopters
Non-Adopters
x


Density non-adopters
Adopters
$\bar{x}(t)$


Density non-adopters
Adopters
$\bar{x}(t)$


Density non-adopters
Adopters
$\bar{x}_{ss}$



- Dynamics: Model of gradual diffusion!

Solution

- Unique adoption equilibrium: $c < \frac{\theta_0}{\rho}$
  Cost of adopting smaller than idiosyncratic benefits

Solution

- Unique adoption equilibrium: $c < \frac{\theta_0}{\rho}$
  Cost of adopting smaller than idiosyncratic benefits
- Multiple equilibria: $c > \frac{\theta_0}{\rho}$ and θ_n large complementarities
  - High adoption
  - No adoption

Solution

- Unique adoption equilibrium: $c < \frac{\theta_0}{\rho}$
  Cost of adopting smaller than idiosyncratic benefits
- Multiple equilibria: $c > \frac{\theta_0}{\rho}$ and θ_n large complementarities
  - High adoption
  - No adoption
- Same initial conditions different adoption paths!
  - Payments: PIX (Brazil) vs Chivo Wallet (El Salvador)

Optimal Subsidy

$$\text{Subsidy} = \underbrace{\theta_n N(t)}_{\text{Adoption Externality}} \times \underbrace{\mathbb{E}(x|\text{Adopt})}_{\text{Benefits Adopters}}$$

- Additional benefits for agents that adopt the technology
- Easy implementation: time-varying flat subsidy, increasing over time

Application: SINPE Móvil

- Mobile payment app developed by the Central Bank of Costa Rica
  - Launched nationwide in 2015
  - Covers 60% of adult population
  - Transaction value $\approx$ 10% GDP (2021)
  - Design and adoption similar to CBDC
- Data allow to test predictions of theory

From Model to Data

- Main goals:
  - Construct networks (i.e. $N(t)$) for each individual
  - Create individual measures of adoption/use
- In order to:
  - Document selection (i.e. $\bar{x}(t)$)
  - Document strategic complementarities (i.e. θ_n)
  - Calibrate our model

Data

- Pseudonymous identifiers
- Transaction-level data from SINPE Móvil
  Information of senders, receivers, transaction size
- Individual-level data: agents' network
  - Family Networks: Registry of family networkse
  - Networks of Coworkers: Employer-employee data
  - Networks of Neighbors: National registry
- Data can be linked: all sample periods 2015-2022

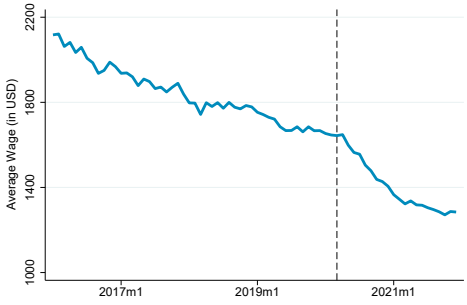
- Technology diffused gradually
  - 5 years to reach 30% of adult population

- Technology diffused gradually
  - 5 years to reach 30% of adult population
- Most transactions are peer-to-peer
  - Account for close to 95% of all transactions

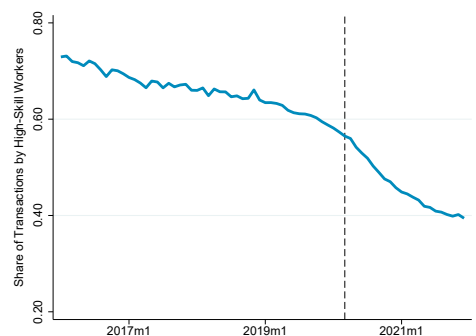
- Technology diffused gradually
  - 5 years to reach 30% of adult population
- Most transactions are peer-to-peer
  - Account for close to 95% of all transactions
- Individuals “belong" to networks
  - 45% transactions among co-workers, 41% family, 50% neighbors, 75% union

- Technology diffused gradually
  - 5 years to reach 30% of adult population
- Most transactions are peer-to-peer
  - Account for close to 95% of all transactions
- Individuals “belong" to networks
  - 45% transactions among co-workers, 41% family, 50% neighbors, 75% union
- Evidence of selection
  - Early adopters (when networks was small) are more intense users

Wages and Skills

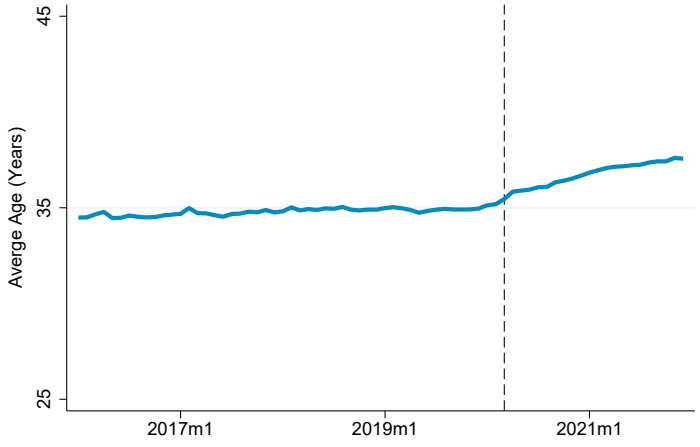


(a) Wages



(b) High Skill

Average Age



- Technology diffusion was not immediate ▸ Adoption
  - 5 years to reach 30% of adult population
- Most transactions are peer-to-peer ▸ P2P
  - Account for close to 95% of all transactions
- Individuals “belong" to networks ▸ Networks
  - 45% transactions among co-workers, 41% family, 50% neighbors, 75% union
- Evidence of selection ▸ Selection
  - Early adopters (when networks was small) are more intense users
- Evidence of strategic complementarities
  - Intensity of use (transactions, value) $\uparrow$ w/share of adopters in user’s network

Evidence of Strategic Complementarities

Transactions positively correlated with $N(t)$

	(1)	(2)	(3)	(4)
Δ Share Neighborhood Adopters	1.008***			0.879***
	(0.022)			(0.031)
Δ Share Coworkers Adopters		0.238***		0.232***
		(0.007)		(0.007)
Δ (Log) Wage		0.044***		0.044***
		(0.001)		(0.001)
Δ Share Relatives Adopters			0.273***	0.308***
			(0.003)	(0.004)
Observations	32,391,602	16,232,003	30,633,379	15,355,945
Time/Cohort FE	Yes	Yes	Yes	Yes

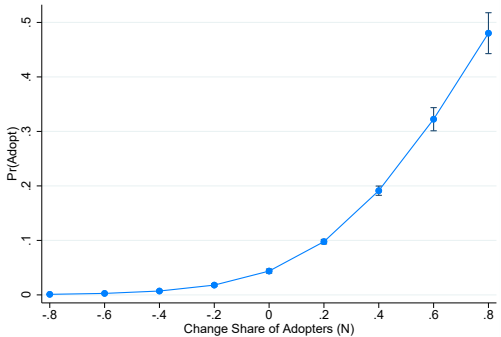
Strategic Complementarities: Mass Layoffs

- Movers design: follow workers fired during *mass layoff*

Strategic Complementarities: Mass Layoffs

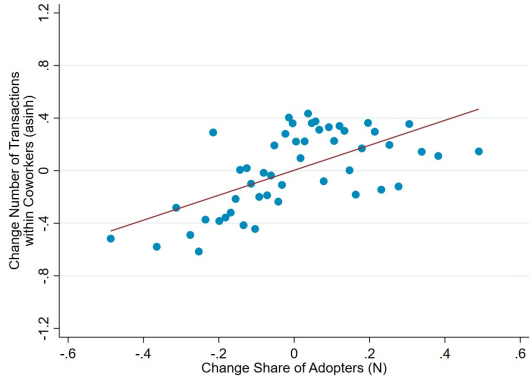
- Movers design: follow workers fired during *mass layoff*

Extensive Margin $\rightarrow$ Workers who had not adopted

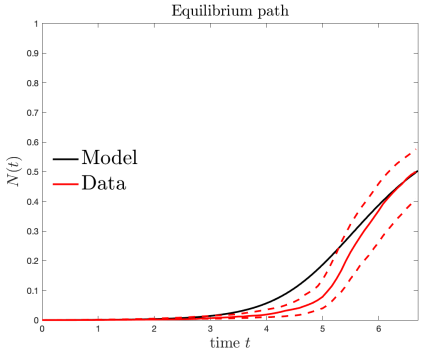


- Controls: Δ wage, Δ firm size, date hired, difference transactions new and old firm, Covid

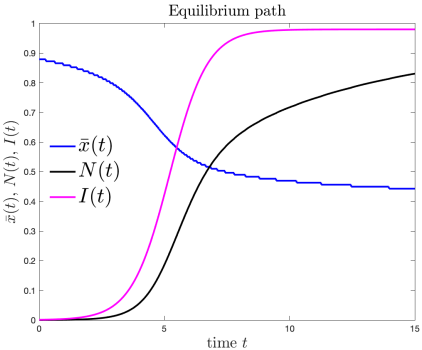
Intensive Margin → Workers who had already adopted



- Effect of network changes on usage (no learning!)
- Controls: tenure in the app, historical transactions, Δ wage, Δ firm size, Covid, difference transactions new and old firm

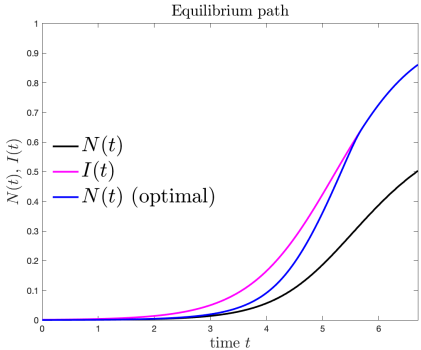


(a) Data vs Model

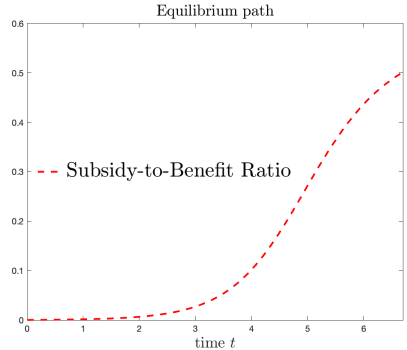


(b) Model: Long-run

- Model replicates empirical patterns
- Path of $\bar{x}(t)$ shows selection
- Approx. 65% of pop. adopt in the median neighborhood in steady state



(a) Optimal Adoption Path



(b) Subsidy

- Externality: higher adoption in efficient equilibrium
- Adoption subsidy: flat (depends on t only) and increasing over time

Conclusion and future work

- Implications for implementation of technologies such as CBDC
  - Large initial subsidy can rule out no-adoption equilibrium
  - Solution for planner and non-linear optimal subsidy

Thank you!

david.argente@yale.edu