Integrating Fragmented Networks: The Value of Interoperability in Money and Payments

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SI 2025 Macro, Money and Financial Frictions

Motivation

- Money: fundamental economic technology, with network effects (Menger 1892, Fisher 1911, Krugman 1984)

- This creates a dilemma for payment system designers:
  - $\Rightarrow$ Maximize network size, but accept limited choice & dominant platforms. . . *or*
  - $\Rightarrow$ Encourage diverse options, but accept market fragmentation

- Dilemma recurs in many contexts:
  - $\Rightarrow$ Domestic payment systems (e.g., Brainard 2019, Yi 2021, Cunliffe 2023, Lane 2025)
  - $\Rightarrow$ Cross-border payment systems (e.g., Duffie 2023, Financial Stability Board 2024)
  - $\Rightarrow$ Multi-polar currency paradigm? (e.g., Lagarde 2025, Pan 2025)

Is it possible to avoid fragmentation without sacrificing choice?

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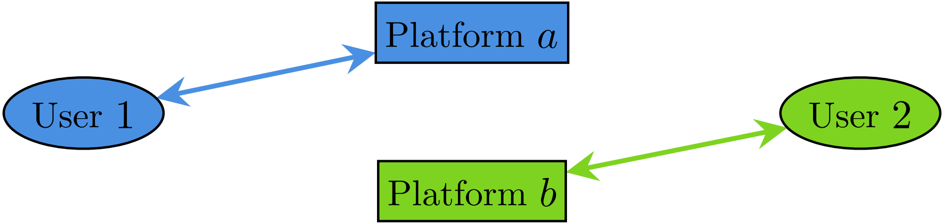

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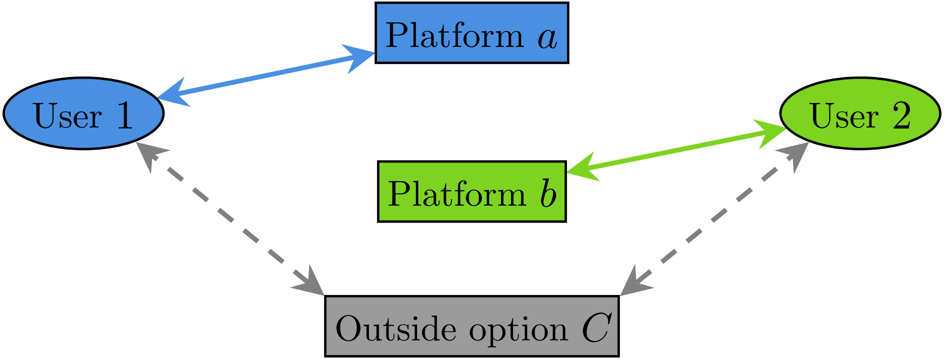

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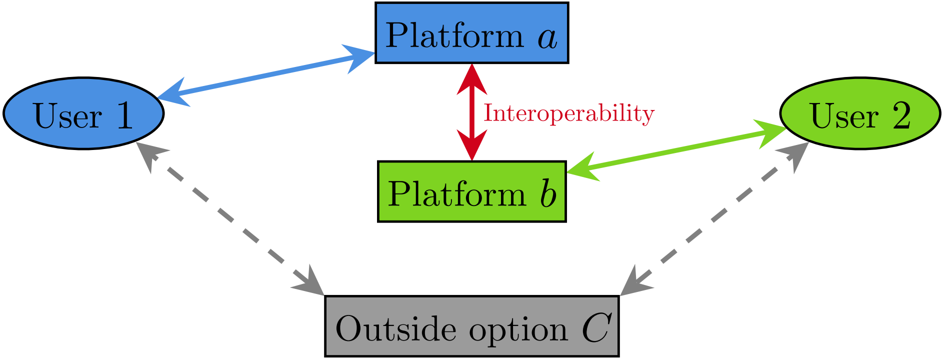


Is it possible to avoid fragmentation without sacrificing choice?

- Conceptual framework:
  - $\Rightarrow$ Interoperability unlocks gains by connecting fragmented networks
  - $\Rightarrow$ Larger benefits where more fragmented ex ante
- Leverage unique data to present causal evidence on interoperability
  - $\Rightarrow$ Observe integration of two large digital payment networks in India
  - $\Rightarrow$ Exploit geographic heterogeneity to construct within-country counterfactual
- Combining theory + data: integration raised total digital payments by 57%

Contributions

1. Show interoperability shapes tradeoffs between network benefits and dominant platforms in money and payments (Krugman 1984, Duffie 2019, Brunnermeier Payne 2022)
2. Show interoperability has large impact on demand with within-country counterfactual (Ferrari Verboven Degryse 2010, Bjorkegren 2022, Brunnermeier Limodio Spadavecchia 2023)
3. Show interoperability amplifies strategic complementarities in adoption of network technologies (Crouzet Gupta Mezzanotti 2023, Alvarez Argente Lippi Mendez Patten 2023)
4. Show interoperability helps explain striking growth, impact of digital payments (Alok Ghosh Kulkarni Puri 2024, Dubey Purnanandam 2023, Crouzet Ghosh Gupta Mezzanotti 2024)

Wider literature ▶

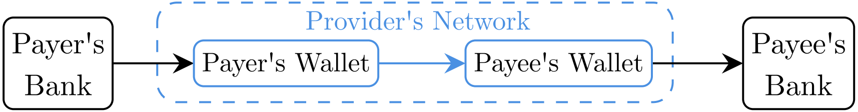
Roadmap

1. Context
2. Conceptual framework
3. Empirical analysis
4. Wider implications

1. Context

Setting: India’s Unified Payments Interface

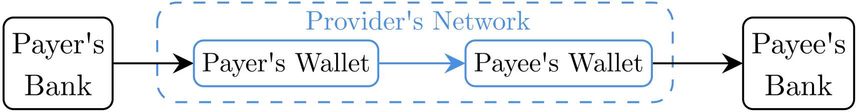
- Prior to launch of UPI in 2016, a closed-loop digital payments provider was dominant



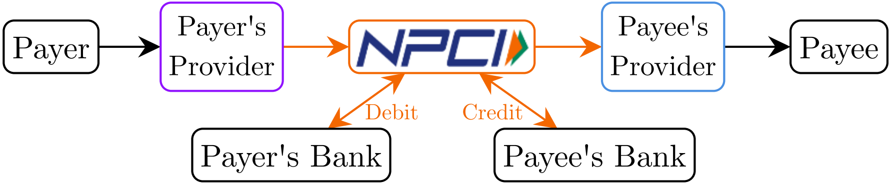
Source: **NPCI, RBI, ACI Worldwide.**

Setting: India's Unified Payments Interface

- Prior to launch of UPI in 2016, a closed-loop digital payments provider was dominant



- UPI offered no-fee transactions between users of any participating payments provider

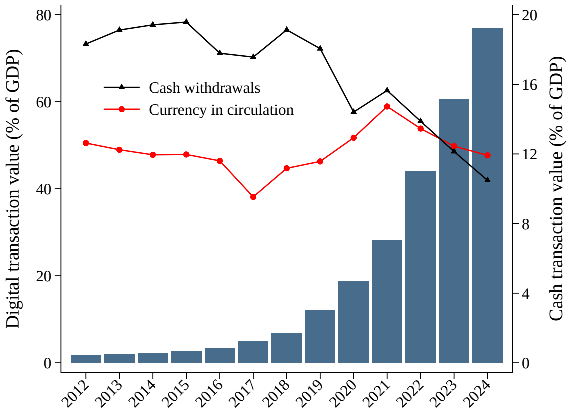


- UPI is now world's largest fast payments system by volume, 18B transactions/month

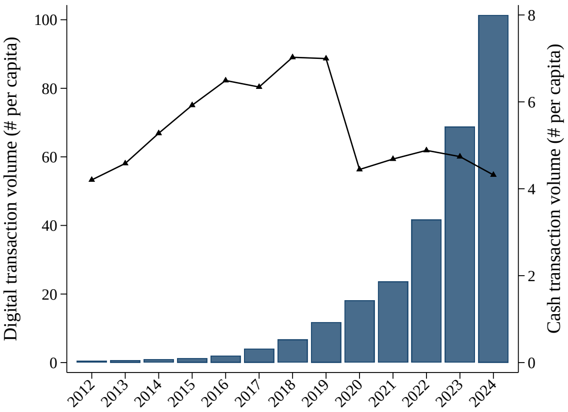
Source: **NPCI, RBI, ACI Worldwide.**

Retail digital payments grew rapidly, cash has begun to decline

Value (percent of GDP)

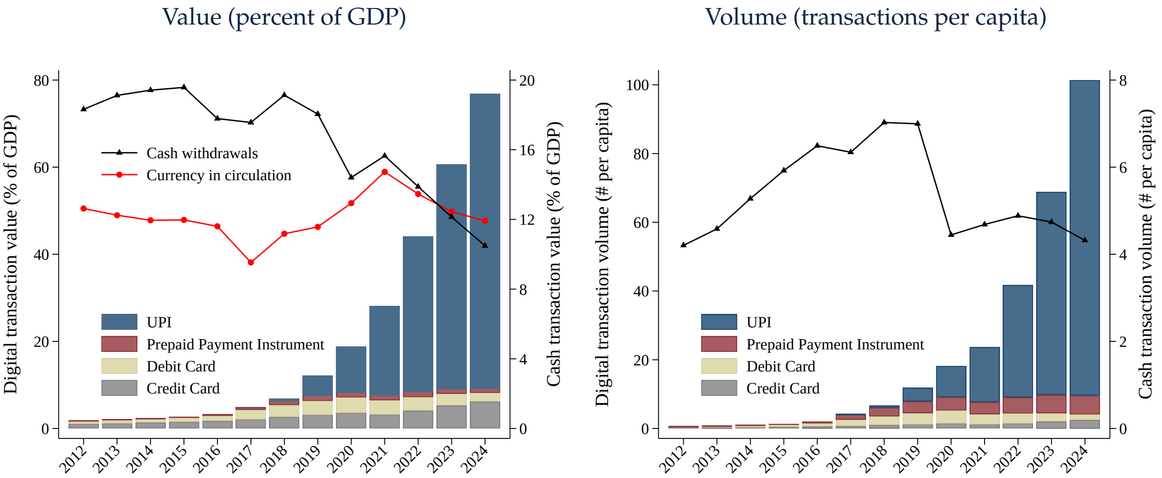


Volume (transactions per capita)



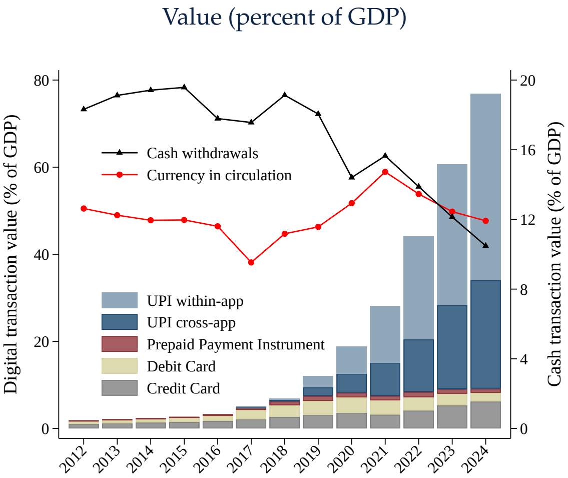
Source: **NPCI, RBI, Haver Analytics, WDI.**

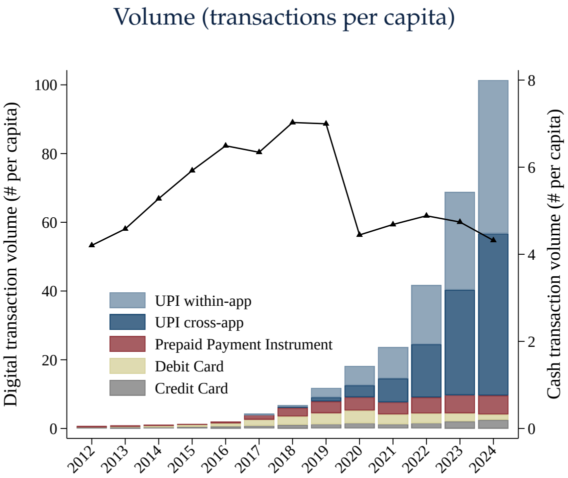
UPI drove most of this growth in digital payments



Source: **NPCI, RBI, Haver Analytics, WDI.**

Interoperability was important in driving UPI's growth





Source: **NPCI, RBI, Haver Analytics, WDI.**

2. Conceptual Framework

Baseline setup

Static model of payment competition highlighting convenience and network effects (inspired by Farhi Maggiori 2018, Coppola Krishnamurthy Xu 2023)

- Users choose from three payment methods: digital platforms a and b, cash C
- Users uniformly distributed across unit squares reflecting two preference dimensions $(x, y) \sim U([0,1] \times [0,1])$ in each district $d \in \{1, \ldots, D\}$
- Each user desires to make a within-district payment
- All users choose their payment method simultaneously

Utility from using cash

$$u^C_{d,x,y} = \gamma y$$

- Utility $u^C_{d,x,y}$ of user (x, y) in district d using cash C depends on:
  1. Cash preference y—reflecting e.g., demographics or informality
  2. Cash benefit parameter $\gamma > 0$
- Utility from using cash does *not* depend on others' adoption: assume all already accept cash, so no network effects

Utility from using digital payments

$$u^a_{d,x,y} = \begin{cases} 1 + \kappa N^*_{d,a} & \text{if } x \leq \hat{x}_d \\ 0 & \text{if } x > \hat{x}_d \end{cases} \qquad u^b_{d,x,y} = \begin{cases} 0 & \text{if } x \leq \hat{x}_d \\ 1 + \kappa N^*_{d,b} & \text{if } x > \hat{x}_d \end{cases}$$

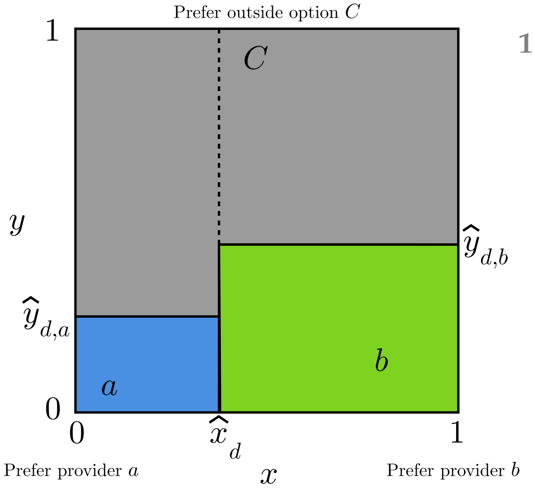
- Utility $u^i_{d,x,y}$ of user (x, y) in district d using platform $i \in \{a, b\}$ depends on:

  1. Preference x relative to exogenous boundary $\hat{x}_d \in (0, \frac{1}{2})$, reflecting e.g., brand familiarity or preferences as in Parlour Rajan Zhu (2022)

  2. Size of the accessible user base $N^*_{d,i}$, which in the absence of interoperability is equal to the number of users $N_{d,i}$ of i in d

  3. Network benefit $\kappa > 0$ each accessible user generates for each other platform user

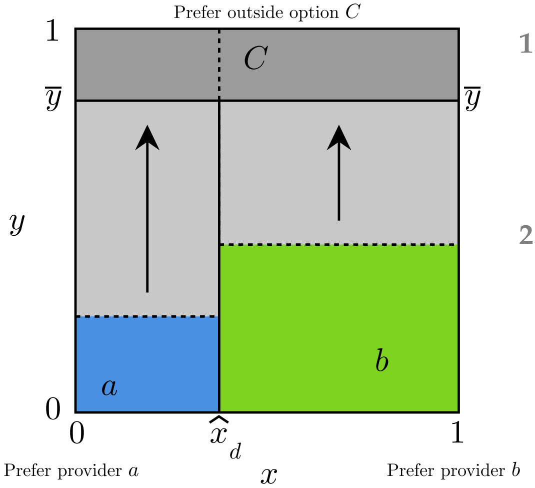
Interoperability ⇒ cross-platform benefits ⇒ higher total adoption



1. Users initially adopt platform $i \in \{a, b\}$ until <u>i-specific</u> network benefits balanced by cash preference of threshold user $\hat{y}_{d,i}$

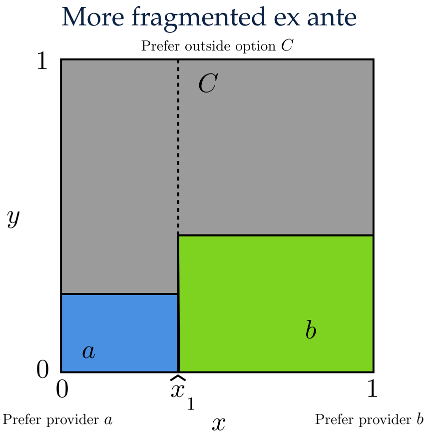
   ⇒ Digital payments users fragmented

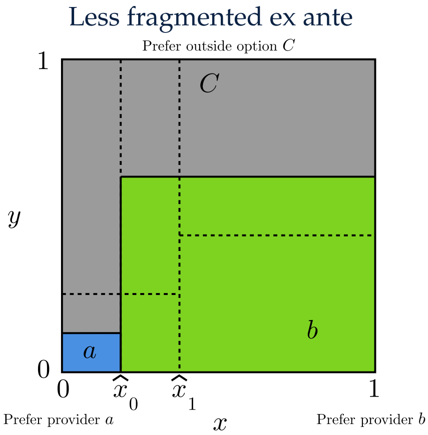
Interoperability ⇒ cross-platform benefits ⇒ higher total adoption



1. Users initially adopt platform $i \in \{a, b\}$ until <u>i-specific</u> network benefits balanced by cash preference of threshold user $\hat{y}_{d,i}$
   - ⇒ Digital payments users fragmented
2. Interoperability gives any platform user access to all such users: $N^*_{d,i} = N_{d,a} + N_{d,b}$
   - ⇒ Unlocks <u>cross-platform</u> network benefits
   - ⇒ Threshold users equalize at $\bar{y}_{d,a} = \bar{y}_{d,b} = \bar{y}$
   - ⇒ Higher adoption of digital payments relative to cash

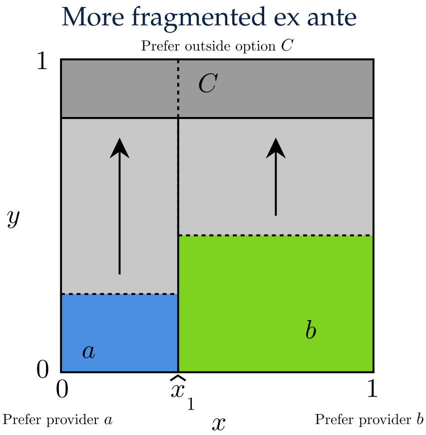
Interoperability ⇒ larger gains where more fragmented ex ante

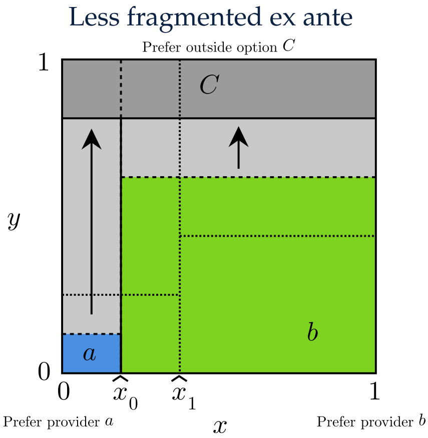




- More fragmented ($\hat{x}_d$ closer to $\frac{1}{2}$) ⇒ higher unrealized network benefits ex-ante

Interoperability ⇒ larger gains where more fragmented ex ante





- More fragmented ($\hat{x}_d$ closer to $\frac{1}{2}$) ⇒ higher unrealized network benefits ex-ante ⇒ larger gains unlocked by interoperability ⇒ larger rise in adoption ex-post

3. Empirical Analysis

Data

We observe two large payment networks before *and* after they became interoperable:

1. **UPI** $\Rightarrow$ aggregated universe of interoperable transactions
   - Value/volume/users by district $\times$ month $\times$ payer app, for all apps
   - Value/volume/users by district $\times$ month $\times$ payer app $\times$ payee app, top four + 'other'

2. **Closed-loop wallet provider** $\Rightarrow$ major fintech incumbent prior to UPI
   - Value/volume/users by district $\times$ month

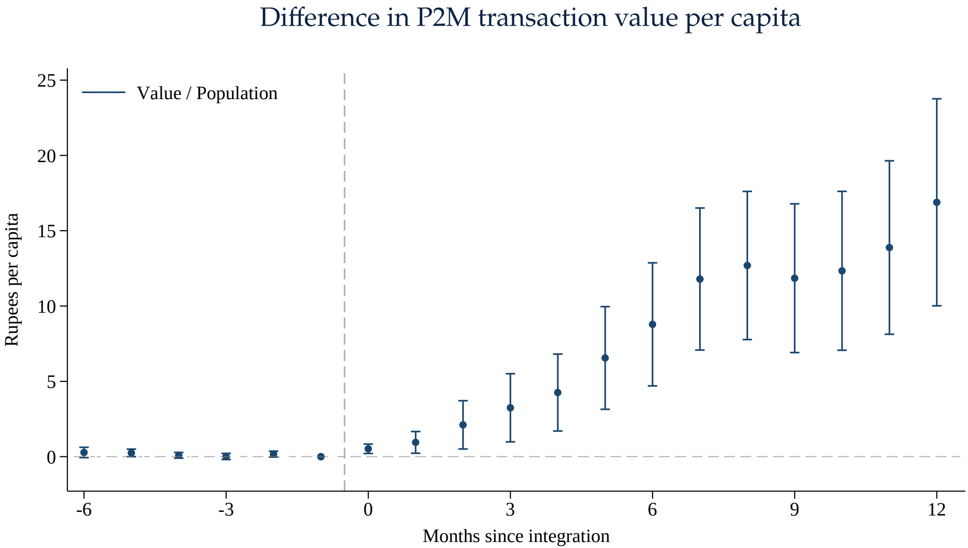
+ **Cash withdrawals**
   - Value/volume by district $\times$ month $\times$ bank

Empirical specification closely aligned with theory

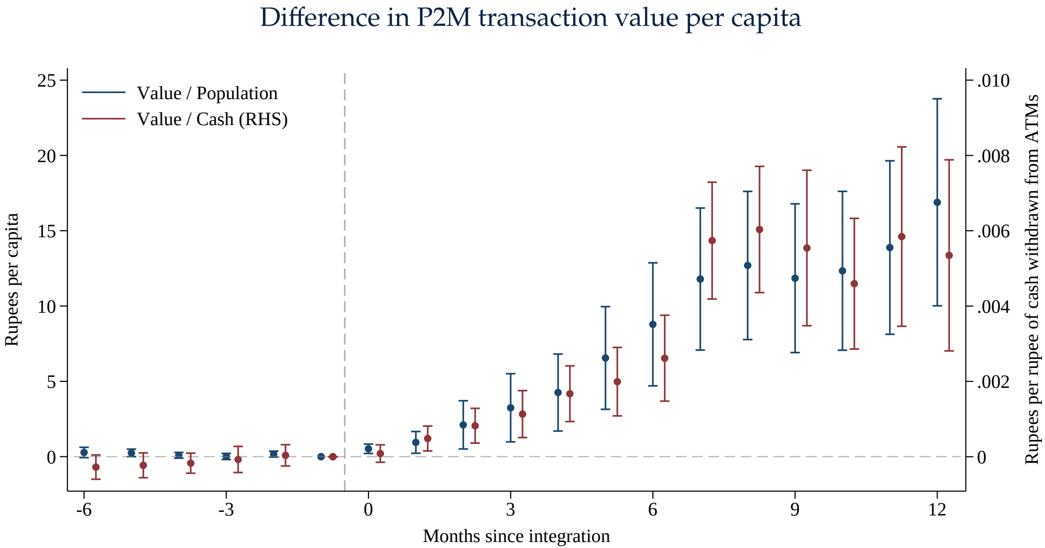
$$y_{dt} = \alpha_d + \alpha_{st} + \beta(P_d^+ \times 1_{\{t \geq t_0\}}) + \beta_Z(Z_d \times 1_{\{t \geq t_0\}}) + e_{dt}$$

- Compare P2M digital payments y_{dt} in districts d with above ($P_d^+ = 1$) vs. below-median share of digital payments on the incumbent prior to integration
- **No anticipation?** Integration followed RBI directive mandating interoperability
- **Parallel trends?**
  - $\Rightarrow$ State-time fixed effects = compare districts within state
  - $\Rightarrow$ Control for differences by ex-ante *level* of digital payments Z_d, use only *composition*
  - $\Rightarrow$ No differential pre-trends

Digital payments grew faster in ‘treated’ districts after integration



‘Treated’ districts also saw faster digital adoption relative to cash



Further results and robustness

- **Drivers of growth**
  - $\Rightarrow$ *Margins:* primarily driven by $\Uparrow$users, plus $\Uparrow$transaction size + $\Uparrow$usage Go ▸
  - $\Rightarrow$ *Channels:* $\Uparrow$transaction value both between and within platforms Go ▸
- **Identification**
  - $\Rightarrow$ *Matching:* pair high-P_d with low-P_d districts on log population Go ▸
  - $\Rightarrow$ *2SLS:* instrument with proximity to incumbent's pre-demonetization hubs Go ▸
  - $\Rightarrow$ *Placebos:* randomized treatment assignment and an alternative t_0 Go ▸

4. Wider Implications

Theory + empirics ⇒ large aggregate impact of interoperability

1. Empirics provide well-identified cross-sectional estimates
2. Aggregating to national level requires solving missing intercept problem (e.g., Wolf 2023, Buera Kaboski Townsend 2023)
3. Theory provides no-fragmentation intercept of zero

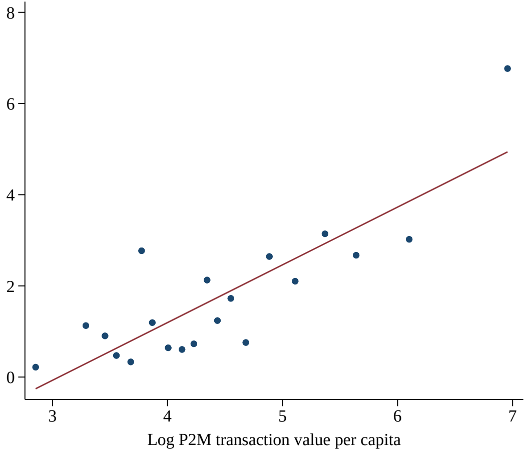
⇒ Construct population-weighted sum of districts' differential adoption relative to places with little ex-ante fragmentation

⇒ Usage of digital payments in India increased by 57% due to networks' integration

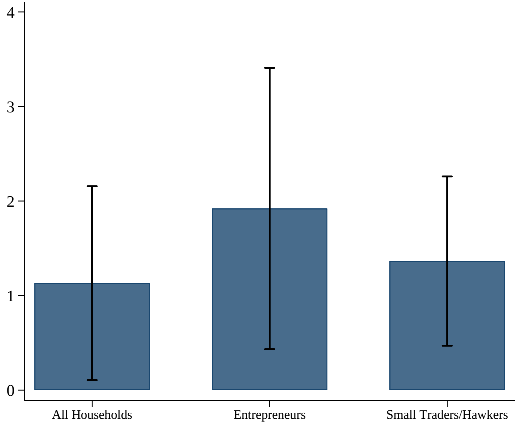
Aggregation details ▶

Positive spillovers from digital payments in 'treated' districts

Households borrowing from NBFCs (2018T3, %)



Difference in P(NBFC borrowing) (p.p.)



Conclusion

Interoperability unlocks gains by unifying fragmented networks

- Money and payments are fundamental network technologies

- Dilemma between network benefits and choice recurs in many settings
  - $\Rightarrow$ Domestic payment systems across a wide range of countries
  - $\Rightarrow$ Multiple competing initiatives to reform cross-border payments
  - $\Rightarrow$ Multi-polar currency paradigm?

- *This paper:* empirical evidence from merger of large existing payment networks that interoperability can help resolve this dilemma

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Appendix

Literature

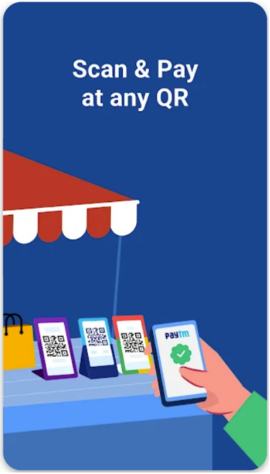
1. Money and payments: Menger (1892), Fisher (1911), Krugman (1984), Kiyotaki Wright (1989), Matsuyama Kiyotaki Matsui (1993), Farhi Maggiori (2018), Coppola Krishnamurthy Xu (2023), Duffie (2019), Benigno Schilling Uhlig (2022), Cong Mayer (2025), Steinsson (2025), Brunnermeier Payne (2022), Goldstein Yang Zeng (2023)

2. Interoperability between networks: Ferrari Verboven Degryse (2010), Bjorkegren (2022), Brunnermeier Limidio Spadavecchia (2023), Bourreau Valletti (2015), Bianchi Bouvard Gomes Rhodes Shreeti (2023)

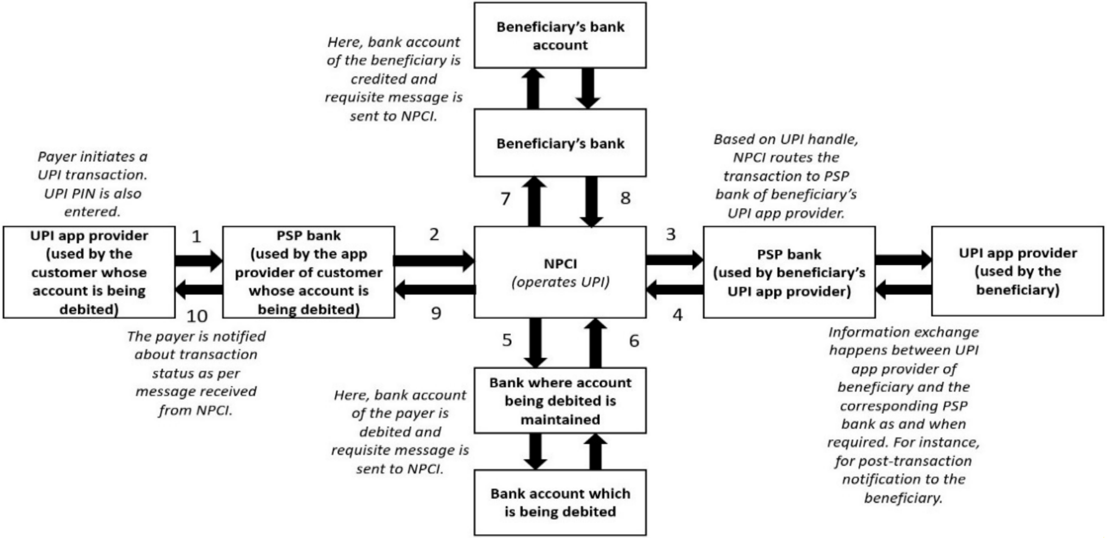
3. Adoption and diffusion of network technologies: Katz Shapiro (1985), Weinberg (1997), Rochet Tirole (2003), Rochet Tirole (2004), Crouzet Gupta Mezzanotti (2023), Alvarez Argente Lippi Mendez Patten (2023), Bjorkegren (2019), Higgins (2024), Wang (2024)

4. Growth of digital payments in India and impact: Alok Ghosh Kulkarni Puri (2024), Crouzet Gupta Mezzanotti (2023), Crouzet Ghosh Gupta Mezzanotti (2024), Ghosh Vallee Zeng (2022), Dubey Purnanandam (2023), Agarwal Ghosh Li Ruan (2024), Di Maggio Ghosh Ghosh Wu (2024)

Multiple apps offer similar services



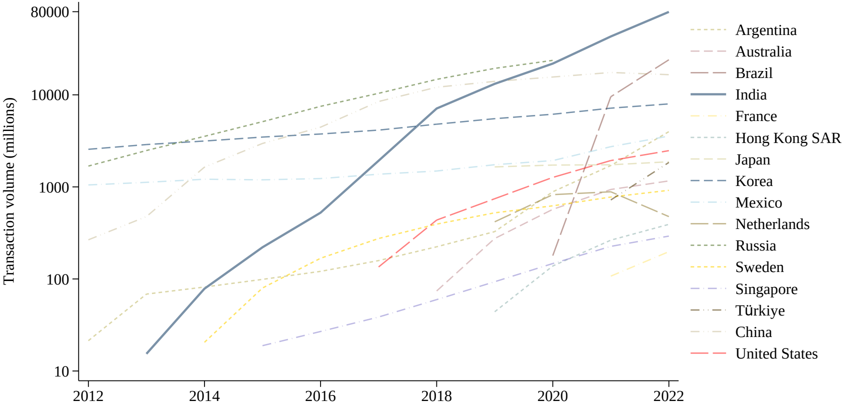
Detailed UPI transaction flow (payer initiated)



Source: RBI.

UPI has become the largest fast payment system by volume

Transaction volume (millions)



Notes: US comprises Zelle from 2017 and RTP from 2020. Fast payments: real-time or near real-time transfers of funds between accounts of end users as close to a 24/7 basis as possible (Frost et al. 2024).

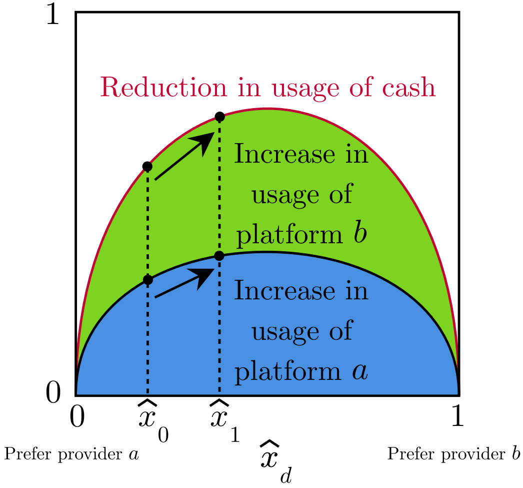
Source: **BIS, Statista, TCH.**

Equilibrium concept and parameter restriction

- We focus on stable, rational equilibria in pure strategies
  - $\Rightarrow$ In equilibrium, users' expectations about the total number of users adopting their chosen payment method are correct
  - $\Rightarrow$ Following a deviation by a small but positive mass of users, choices revert to the same equilibrium

- We impose $\gamma > 1 + \kappa$ for simplicity, ensuring that some users always choose cash

Relative gains by platform



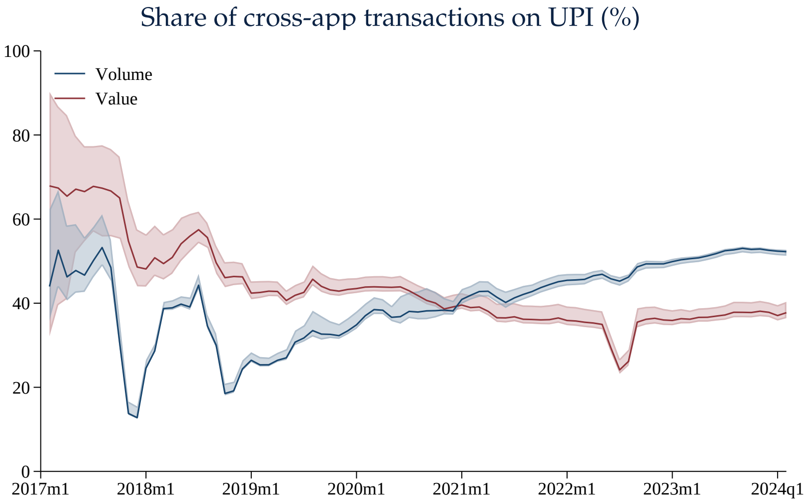
- Interoperability unlocks network gains for, so increases adoption of, both a and b
- Relative impact in more vs. less fragmented districts depends on level of $\hat{x}_d$
  - $\Rightarrow$ Low $\hat{x}_0$ and $\hat{x}_1$: negligible unrealized network benefits when $\hat{x}_0 \to 0$, so gains from interoperability larger for both platforms in $\hat{x}_1$
  - $\Rightarrow$ High $\hat{x}_0$ and $\hat{x}_1$: impact of interoperability on total adoption is flat in vicinity of $\hat{x}_d = \frac{1}{2}$, so if one platform gains more in $\hat{x}_1$ than $\hat{x}_0$, the other must gain less

Model extensions

- **Time-varying external shocks**
  - ⇒ *Intuition*: external shocks occurring at same time as interoperability preclude estimating impact of interoperability by comparing pre vs. post in a single district
  - ⇒ *Implication*: test impact of interoperability by comparing pre vs. post in two districts with different ex ante fragmentation but facing same shock (i.e., parallel trends)

- **Cross-district payments**
  - ⇒ *Intuition*: in polar case where payments flow equally to all districts and $D \to \infty$, only mean fragmentation in destinations matters, no impact of fragmentation at origin
  - ⇒ *Implication*: attenuates our estimates, giving lower bound on true effect

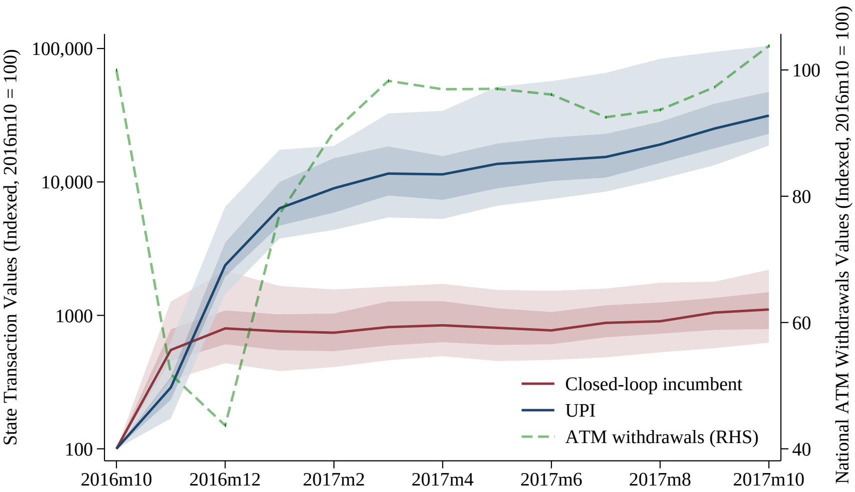
Fact 1: Most UPI transactions occur between users of different apps



⟹ Interoperability necessary for most transactions

Fact 2: After demonetization, UPI kept growing as others plateaued

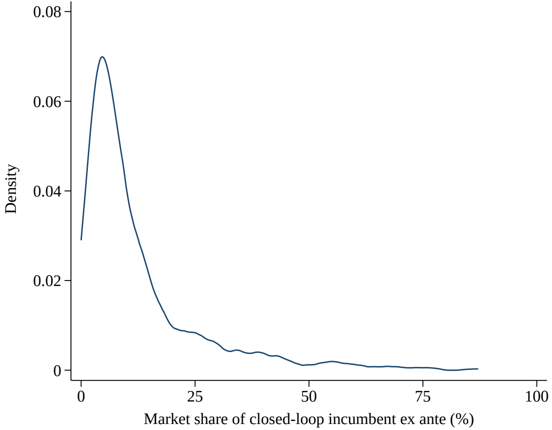
Closed-loop and interoperable digital payments after demonetization (indexed)



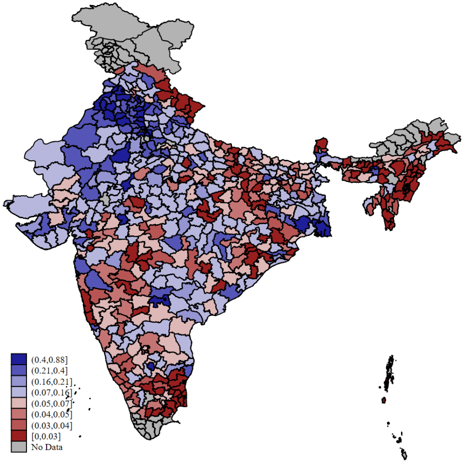
Central lines show the median across states, and inner (outer) shaded regions show 25-75th (10-90th) percentiles.

Presence of the incumbent varied substantially prior to integration

Distribution of P_d

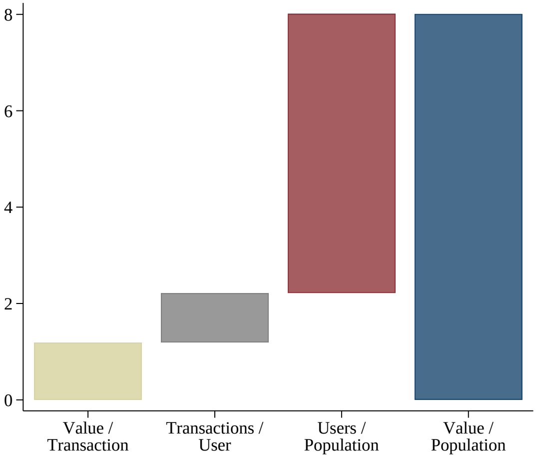


P_d by district

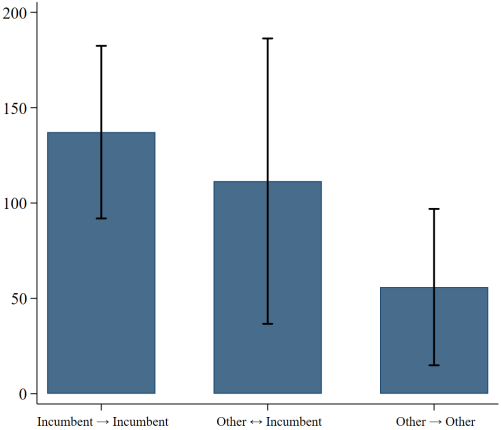


Higher growth across all margins and channels

Growth by margin (Rupees per capita)



Growth by channel (%)



Digital payments grew across all channels

Difference in P2M transaction values

	Total/pop	Total/cash	(Inc→Inc)/pop	(Inc↔Oth)/pop	(Oth→Oth)/pop
	(1)	(2)	(3)	(4)	(5)
$P_d^+ \times 1_{\{t>t_0\}}$	8.010***	0.00334***	11.75***	0.106***	1.989***
	(4.64)	(5.74)	(5.95)	(2.93)	(2.68)
District FEs	✓	✓	✓	✓	✓
State-Time FEs	✓	✓	✓	✓	✓
Control: $Z_d \times 1_{\{t \geq t_0\}}$	✓	✓	✓	✓	✓
N	10,868	10,867	10,868	10,868	10,868
Mean $y_{dt}(P_d^+ = 1, t = t_{-1})$	9.118	0.007	14.365	0	1.936
Mean $y_{dt}(P_d^+ = 0, t \geq t_0)$	6.795	0.012	2.77	0.191	5.179

Notes: t-statistics in parentheses. * p <0.10, ** p <0.05, *** p <0.01. Standard errors clustered at the district level. P_d^+ is a dummy taking value one for districts with above median incumbent market share prior to integration.

Digital payments grew across all margins

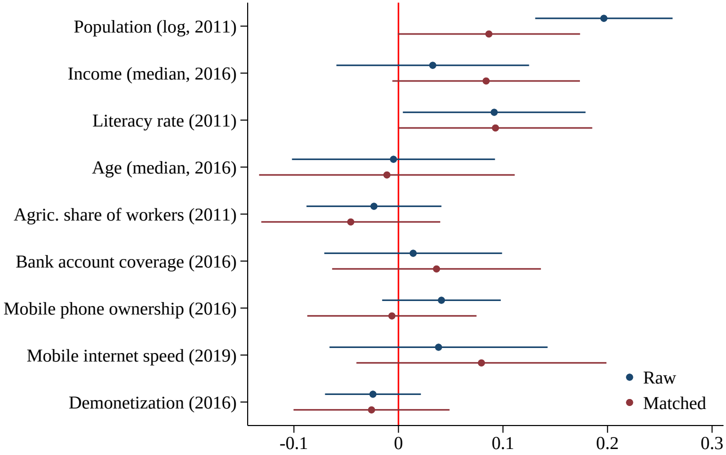
Breakdown of difference in P2M transaction value per capita

	Value / Transaction (₹)	Transactions / User (#)	Users / Population (#)
$P_d^+ \times 1_{\{t>t_0\}}$	9.354**	0.0939**	0.000832*
	(2.11)	(2.48)	(1.93)
District FEs	✓	✓	✓
State-Time FEs	✓	✓	✓
Control: $Z_d \times 1_{\{t \geq t_0\}}$	✓	✓	✓
N	10,868	10,860	10,860
Mean $y_{dt}(P_d^+ = 1, t = t_{-1})$	344.854	3.262	0.002
Mean $y_{dt}(P_d^+ = 0, t \geq t_0)$	309.646	3.625	0.005

Notes: t-statistics in parentheses. * p <0.10, ** p <0.05, *** p <0.01. Standard errors clustered at the district level. P_d^+ is a dummy taking value one for districts with above median incumbent market share prior to integration.

Matched sample is balanced on observables

Association of P_d^+, raw and matched



Observations: 521 / 474. R-squared: 0.406 / 0.398. State FEs, and SEs clustered by state.

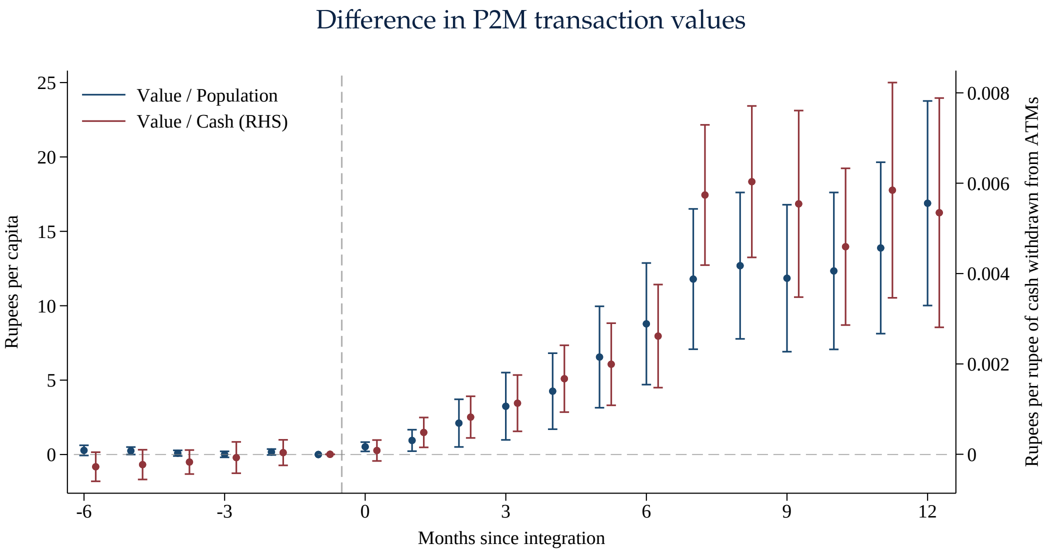
Similar results when matching on log of population

Difference in P2M transaction values

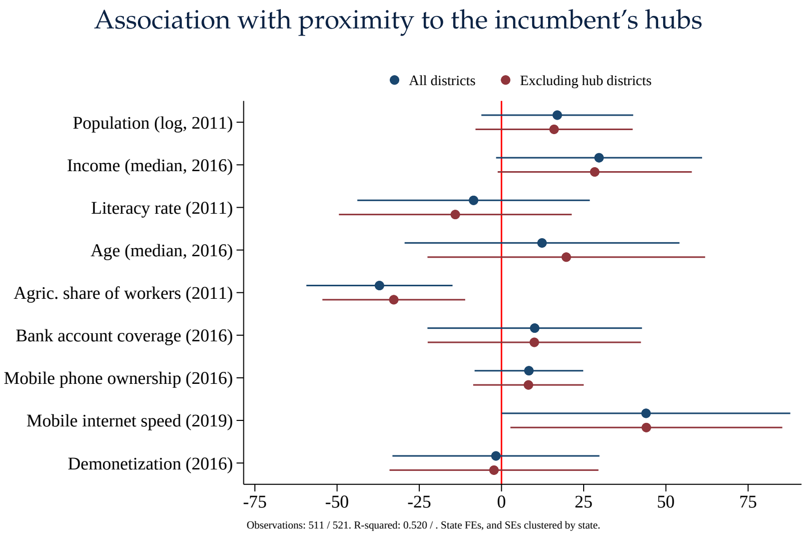
	Total/pop	Total/cash	(Inc→Inc)/pop	(Inc↔Oth)/pop	(Oth→Oth)/pop
	(1)	(2)	(3)	(4)	(5)
$P_d^+ \times 1_{\{t>t_0\}}$	6.777***	0.00336***	9.935***	0.0978***	1.644**
	(4.79)	(4.51)	(6.36)	(2.92)	(2.45)
District FEs	✓	✓	✓	✓	✓
State-Time FEs	✓	✓	✓	✓	✓
Control: $Z_d \times 1_{\{t\geq t_0\}}$	✓	✓	✓	✓	✓
N	10,868	10,867	10,868	10,868	10,868

Notes: t-statistics in parentheses. * p <0.10, ** p <0.05, *** p <0.01. Standard errors clustered at the district level. P_d^+ is a dummy taking value one for districts with above median incumbent market share prior to integration.

Similar results when matching on log of population

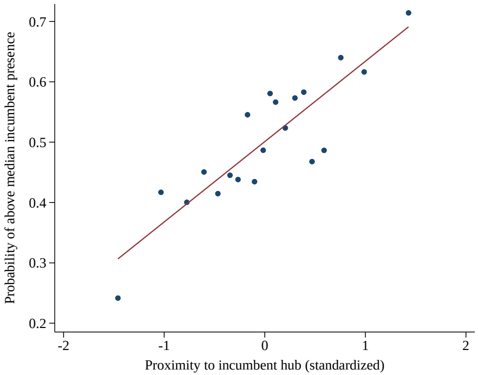


Incumbent hub proximity is largely balanced on observables

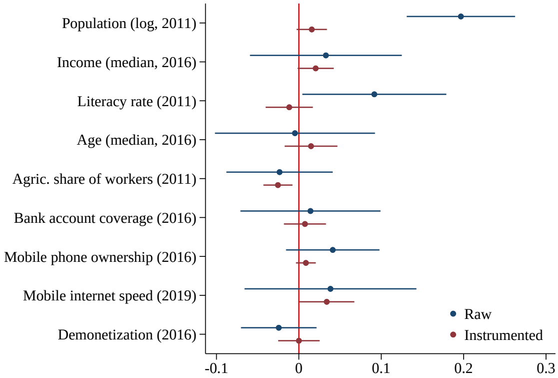


Instrumenting incumbent presence P_d^+ with proximity to its hubs

First stage relationship between H_d and P_d^+



Association with P_d^+, raw and instrumented



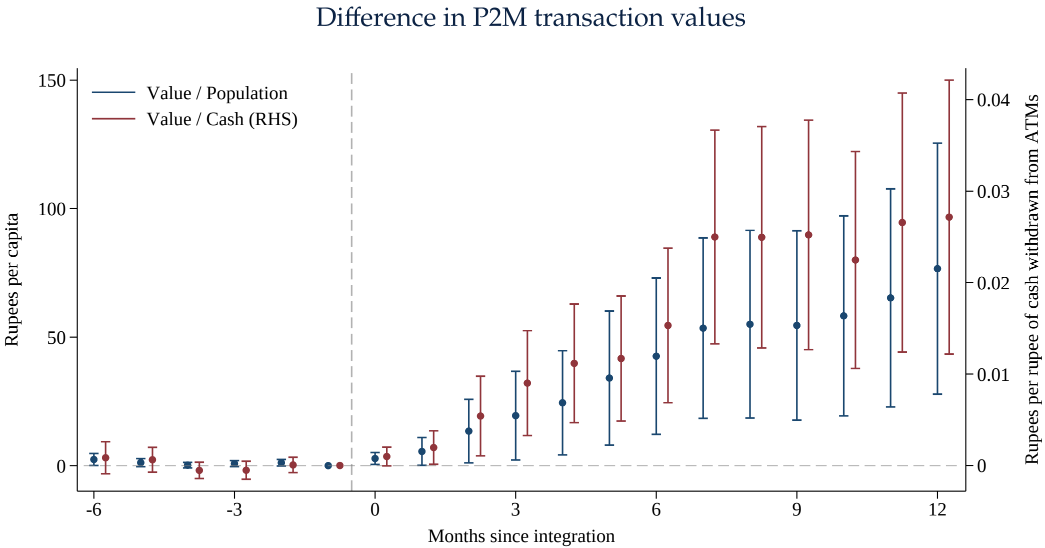
Similar results when instrumenting with hub proximity

Difference in P2M transaction values

	Total/pop	Total/cash	(Inc→Inc)/pop	(Inc↔Oth)/pop	(Oth→Oth)/pop
	(1)	(2)	(3)	(4)	(5)
$P_d^+ \times 1_{\{t>t_0\}}$	17.11***	0.0117***	18.67***	0.299*	5.046*
	(2.71)	(3.30)	(3.03)	(1.78)	(1.90)
District FEs	✓	✓	✓	✓	✓
State-Time FEs	✓	✓	✓	✓	✓
Control: $Z_d \times 1_{\{t \geq t_0\}}$	✓	✓	✓	✓	✓
K-P F-Stat	25.25	25.25	25.25	25.25	25.25
N	10,621	10,620	10,621	10,621	10,621
Mean $y_{dt}(P_d^+ = 1, t = t_{-1})$	6.511	0.007	1.656	0	9.613
Mean $y_{dt}(P_d^+ = 0, t \geq t_0)$	6.729	0.012	5.113	0.188	2.77

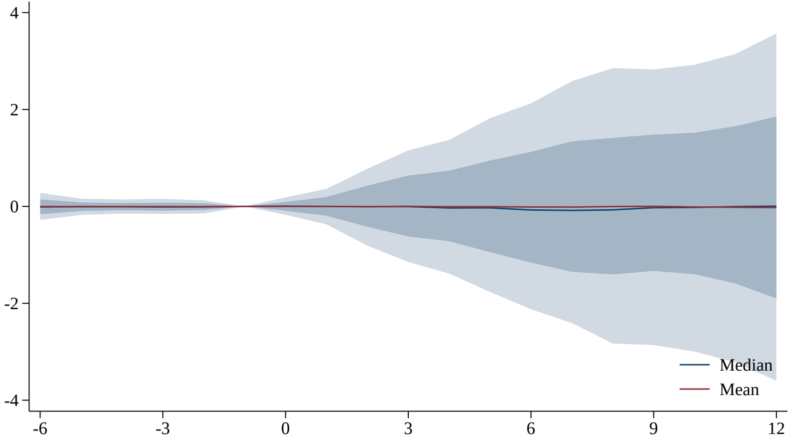
Notes: t-statistics in parentheses. * p <0.10, ** p <0.05, *** p <0.01. Standard errors clustered at the district level. P_d^+ is a dummy taking value one for districts with above median incumbent market share prior to integration.

Similar results when instrumenting with hub proximity



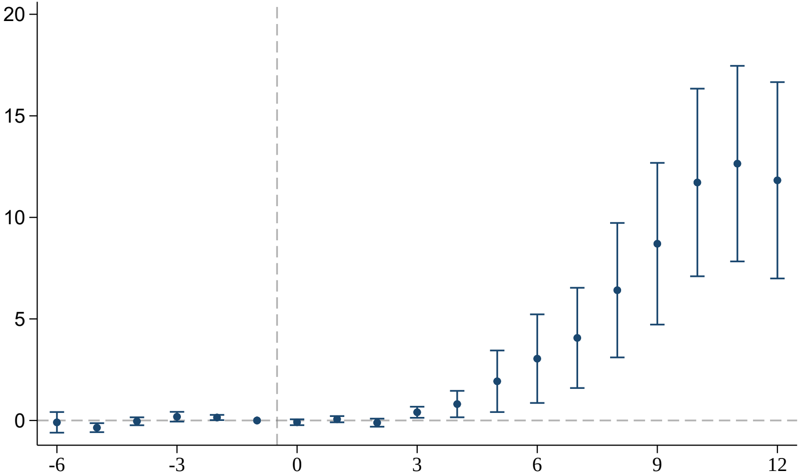
Randomly shuffling P_d^+

Difference in P2M transaction values (Rupees per capita; 1000 random assignments)



Placebo t_0 (three months earlier)

Difference in P2M transaction values (Rupees per capita; $t_0^{placebo} := t_0 - 3$)



Aggregation procedure

1. Estimate impact of interoperability by fragmentation decile, relative to most unified:

$$y_{dt} = \alpha_d + \alpha_{st} + \sum_{n=2}^{10} \beta_n (F_d^n \times 1_{\{t \geq t_0\}}) + \beta_Z (Z_d \times 1_{\{t \geq t_0\}}) + e_{dt}$$

2. Sum estimated differential usage across districts, weighting by population:

$$\Delta y = \frac{\sum_d \sum_{n=2}^{10} \hat{\beta}_n \times F_d^n \times \text{Population}_d}{\sum_d \text{Population}_d}$$

3. Compare to estimated total usage ex-post in absence of interoperability:

$$\frac{\Delta y}{\frac{1}{13} \sum_{t \geq t_0} \left(\frac{\sum_d y_{dt} \times \text{Population}_d}{\sum_d \text{Population}_d} \right) - \Delta y} \times 100 = 57\%.$$

NBFC lending saw growth from platform integration

Response of household level NBFC borrowing to platform integration

	NBFC Borrowing (Y/N)		
	(1)	(2)	(3)
$P_d^+ \times 1_{\{t>t_0\}}$	0.0113**	0.0192**	0.0136***
	(2.17)	(2.54)	(3.00)
Household FEs	✓	✓	✓
State-Wave FEs	✓	✓	✓
Control: $Z_d \times 1_{\{t\geq t_0\}}$	✓	✓	✓
Sample	All	Entrepreneurs	Hawkers
N	898,412	54,161	22,387
Mean $y_{dt}(P_d^+ = 1, t = t_{-1})$	0.0062	0.0118	0.0049
Mean $y_{dt}(P_d^+ = 0, t \geq t_0)$	0.0137	0.0209	0.0153

Notes: Standard errors are clustered at the district level. t-statistics are reported in parentheses.
p <0.10, ** p <0.05, *** p <0.01.