Costs of Technological Frictions: Evidence from EHR (Non-)Interoperability

Rebekah Dix
Yale

Kelsey Moran
Miami

Thi Mai Anh Nguyen
NYU

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Electronic Health Records and Interoperability

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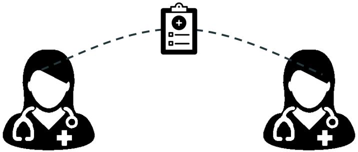
What are effects of EHR (non-)interoperability on patients?

Channels: (1) direct, (2) allocative

How Interoperability Could Affect Patients



(1) Direct Effect

- Influence health information exchange

  $\Rightarrow$ hassle costs

  $\Rightarrow$ care coordination/continuity failures

  $\Rightarrow$ wasteful spending, patient harm

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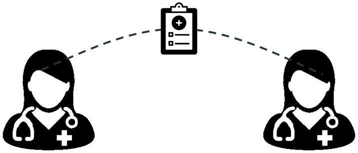

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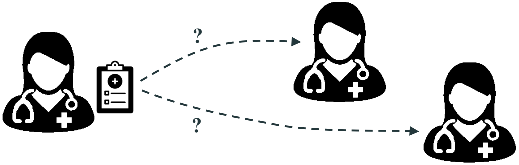
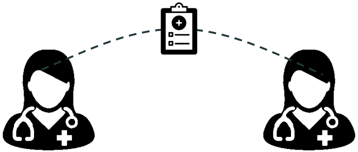


(2) Allocative Effect

- Shift flow of patients across providers
  - – prefer sending to compatible providers
  - ⇒ Δ patient allocations
  - ⇒ Δ distance, cost, quality of care

How Interoperability Could Affect Patients



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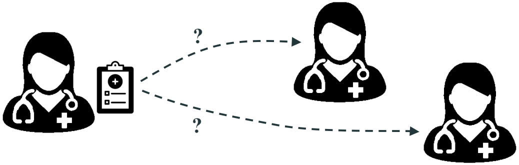

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Setting: Medicare patients shared between hospitals

Outline

1. Data and Setting
2. Direct Effect
3. Allocative Effect
4. Model Estimation and Counterfactuals
5. Conclusion

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Data

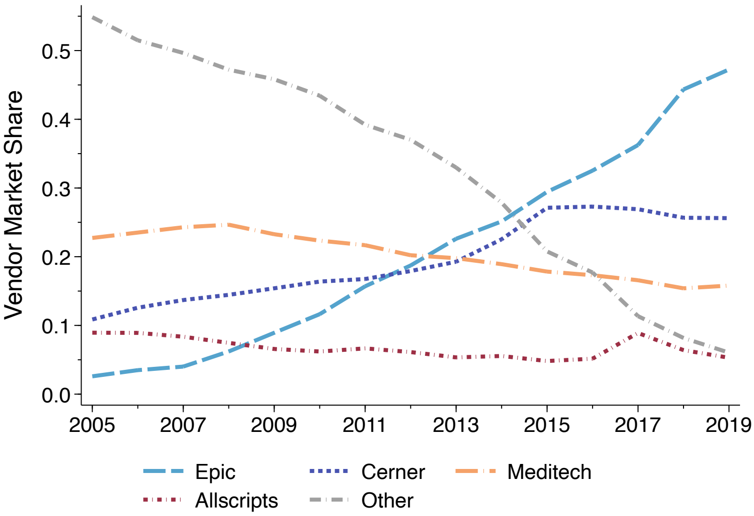
1. **Hospitals:** hospital surveys
   - American Hospital Association (AHA) Annual Survey (2005-2019)
   - American Hospital Association (AHA) IT Survey (2009-2019)
   - Healthcare Information and Management Systems Society (HIMSS) (2005-2017)

   ⇒ hospital characteristics, **EHR vendor, interoperability**

2. **Patients:** CMS Medicare Claims
   - MedPAR (2005-2019): inpatient facility claims, 100% sample
   - Carrier (2008-2019): provider service claims, 20% random sample
   - diagnosis/procedure codes, charge amounts, admission/discharge dates, providers involved

   ⇒ cross-hospital **patient flows, outcomes**

EHR Market Dominated by Epic, Cerner, Meditech



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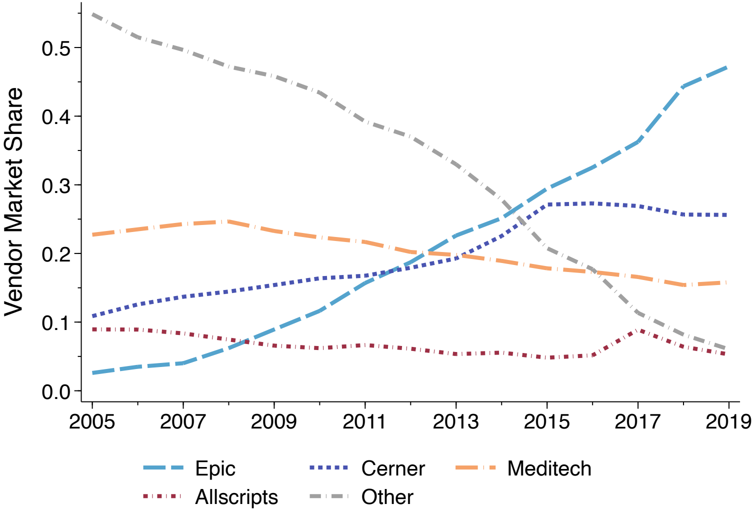
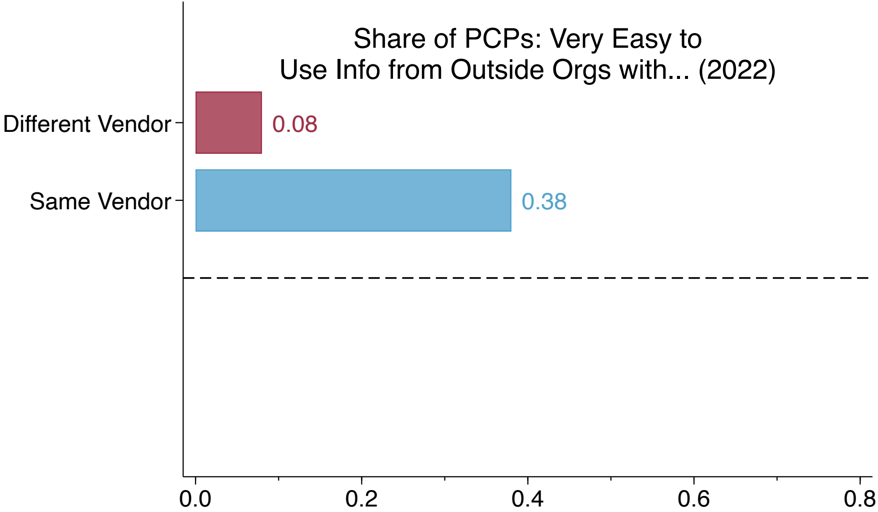


8% hospitals switch vendors annually

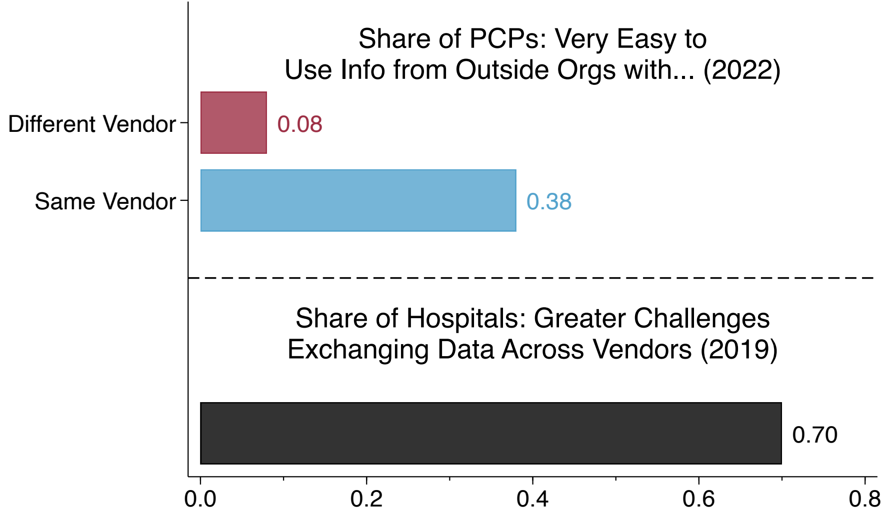
Within-Vendor > Across-Vendor Interoperability



Exchanging patient data across different EHR vendors is challenging

Within-Vendor > Across-Vendor Interoperability

domains evidence persistence awareness



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Direct Effect on Patient Outcomes

- Does interoperability directly affect patients shared between hospitals?

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- Analyze changes in whether hospital-pair has **same EHR vendor** using event study:

$$Y_{i(hh')t} = \left(\sum_{r=-6}^{6} \beta_r \mathbf{1}_{\{t=switch_{(hh')}+r\}} \right) + \alpha_{(hh')} + \gamma_t + \delta X_{it,(hh')t,mt} + \epsilon_{i(hh')t}$$

- $Y_{i(hh')t}$: outcomes for two types of cross-hospital patients:
  (1) **inpatient transfers**: discharged from one hospital & admitted to another within 1 day
  (2) **referrals**: referred from one physician to another for a service that takes place at a hospital & main hospital affiliations of the two physicians differ

Direct Effect on Patient Outcomes

definitions specification sum stats

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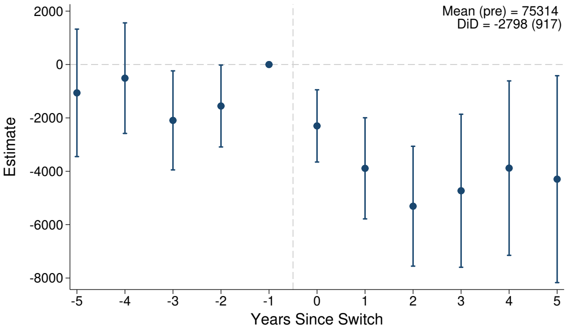
- Endogeneity? threats & robustness

Costs ↓ and health ↑ after pair switches to same vendor

more

low-quality, high-risk largest



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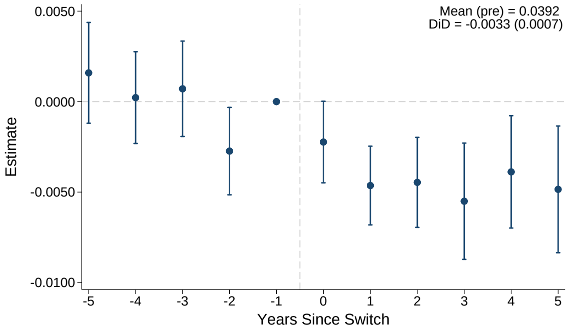

B. Referrals, 60-Day Readmit

4% ↓ charges, 2% ↓ images for transfers

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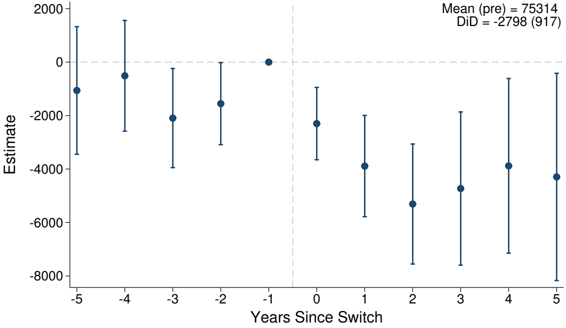

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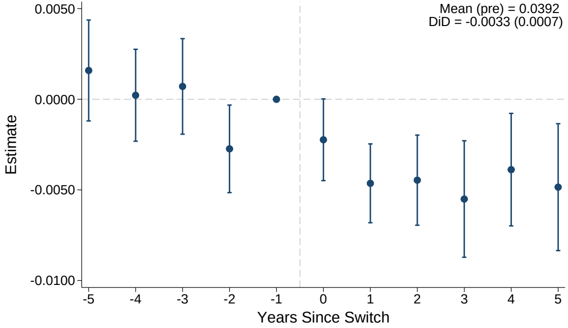

B. Referrals, 60-Day Readmit

4% ↓ charges, 2% ↓ images for transfers; 3% ↓ tests, 11% ↓ admissions for referrals

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Allocative Effect on Patient Flows

sum stats opposite reallocation? magnitudes hetero
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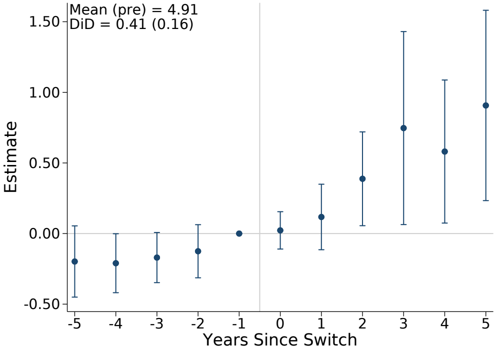

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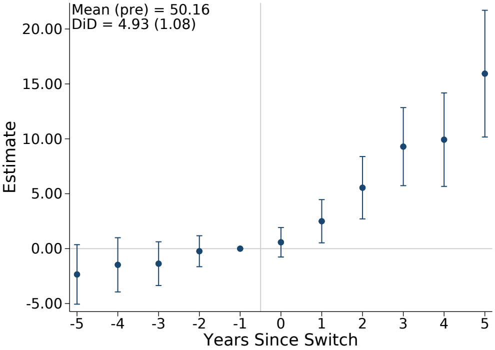


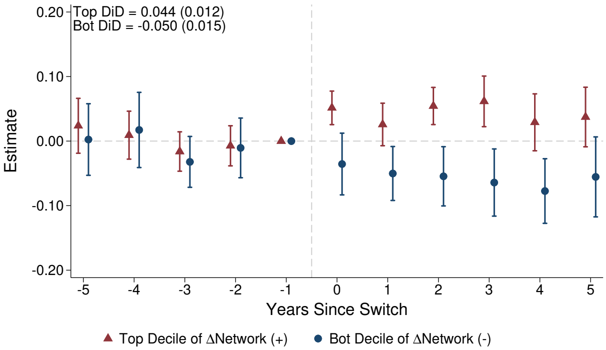
B. # Referrals

8% ↑ transfers, 10% ↑ referrals; symmetric ⇒ reallocation

Allocative Effect on Patient Outcomes

details & full sample

- Does this reallocation of patients across hospitals also affect patient outcomes?
- Switching to EHR vendors used by higher-quality hospitals (●) ⇒ outcomes improve
- Switching to EHR vendors used by lower-quality hospitals (▲) ⇒ outcomes worsen



Transfers, 60-Day Mortality

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Model of Patient Flows

details

- Hospital h in market m has a patient p whom it must transfer
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  $\Rightarrow$ **interoperability elasticity positive, 34-56% of distance elasticity** more

Welfare Gains from Improving Interoperability

intensive patients extensive patients

Counterfactual	%Δ Total Welfare	Δ Total Welfare (-km)	=	Δ Direct Welfare (-km)	+	Δ Allocative Welfare (-km)	Share Switch
First-Best Full Interop. (All = 1)	21.2%	56.5		53.8		2.7	0.075

- **First-Best Full Interoperability:** max. direct gains & eliminates allocative distortion
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Epic Monopoly (All Epic)	12.9%	34.4		33.1		1.4	0.053

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- **Epic Monopoly:** achieves 61% of first-best
  - eliminates allocative distortion but potential consequences: ↑ prices, ↓ innovation incentives

Progress from 2013 to 2019

- **Achieved 34%** of first-best welfare gains
  - 70% due to technological improvements ($\uparrow$ levels)
  - 30% due to EHR choices ($\uparrow$ vendor concentration)

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  - coordination effects in move to interoperable systems

	(1) ΔWelfare (-km)	(2) %ΔTransfers Received
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	(0.455)	(0.00520)
ΔEpic Share	-1.722***	-0.0944***
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- Public policies (TEFCA) enforcing **min. quality standard** may capture gains w/o concentration

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Conclusion

- In markets where consumers move between products, technological frictions have both **direct** and **allocative** effects on consumer welfare
- Find evidence of both channels in context of EHR system interoperability:
    1. directly decreases cost of care, hospital readmissions
    2. changes direction of patient flows between providers $\implies$ changes outcomes
- Eliminating such frictions yields large welfare gains
    - due to both **maximizing positive direct effects** & **eliminating allocative distortion**
    - so far, achieved only 34% of possible gains with **uneven distribution** across hospitals
- Lays groundwork for future research on consumer choices, firm incentives for compatibility

Thank you!

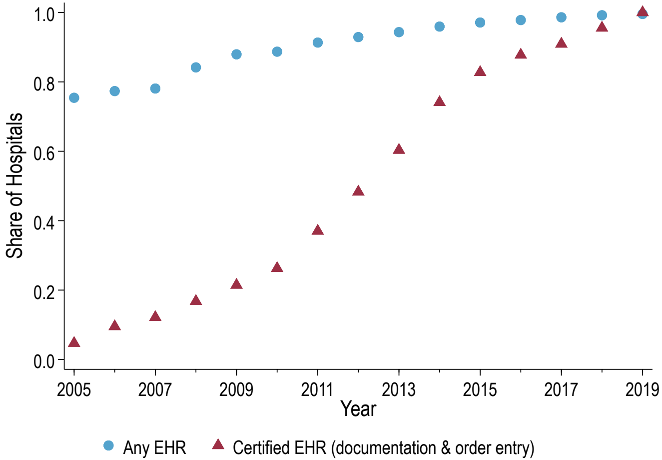
kcmoran@miami.edu

Outline

6. Appendix

EHR Adoption

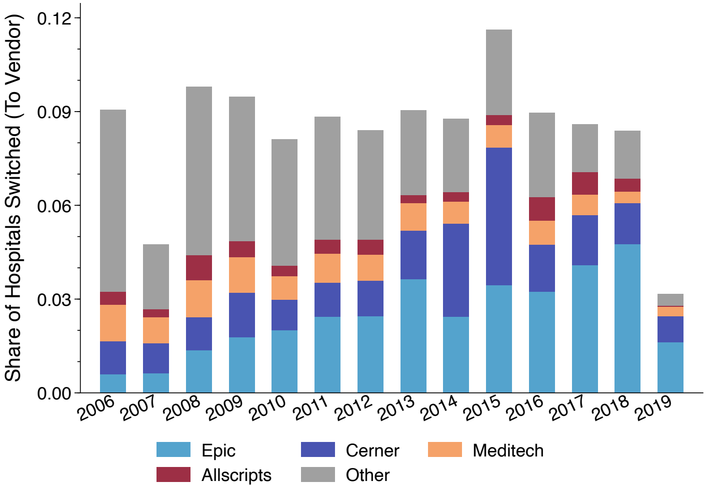
Back



While EHRs always prominent, their capabilities have increased

EHR Switches Over Time

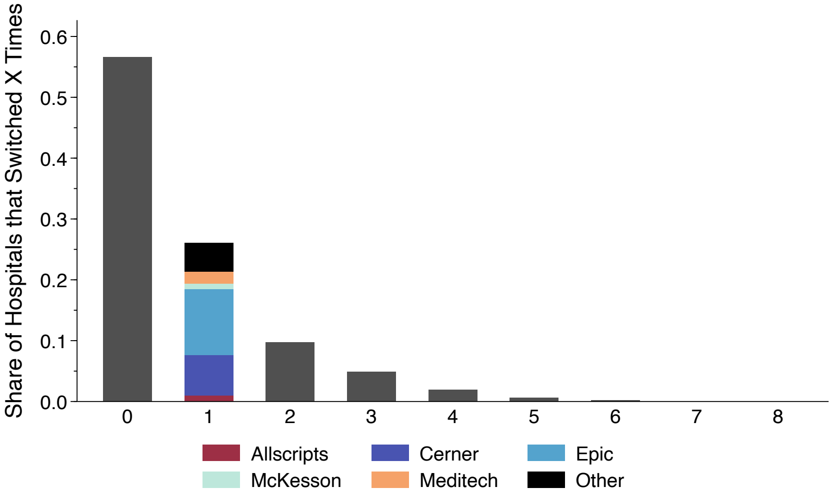
Back



8% hospitals switch vendors annually

EHR Switches per Hospital

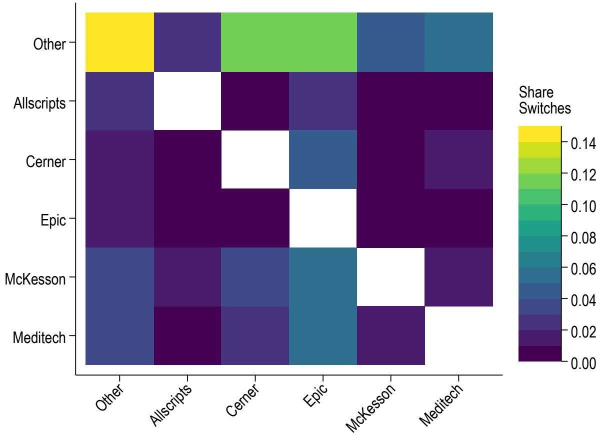
Back



43% hospitals switch at least once; 26% switch exactly once (2005-2017)

EHR Switches: Vendor Switched From/To Heatmap

Back



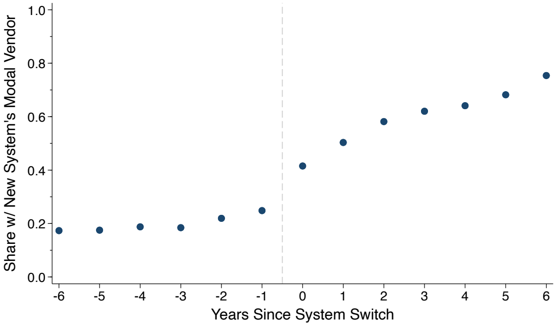
Descriptive Evidence of Role of Interoperability in EHR Choice

Back

Of hospitals that switch vendors once during our sample period:

- 39% switch to modal vendor in their local market (vs. 9% switch away)
- 69% switch to the modal vendor in their hospital system (vs. 13% switch away)

Of hospitals that switch hospital systems once during our sample period:



Market-Level Modal Vendor (2019)

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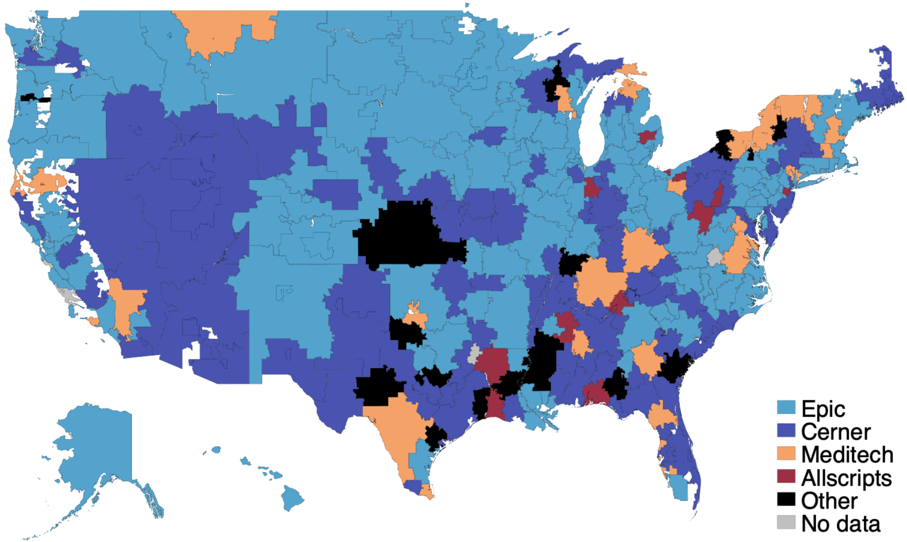

Market-Level Change in Vendor Concentration

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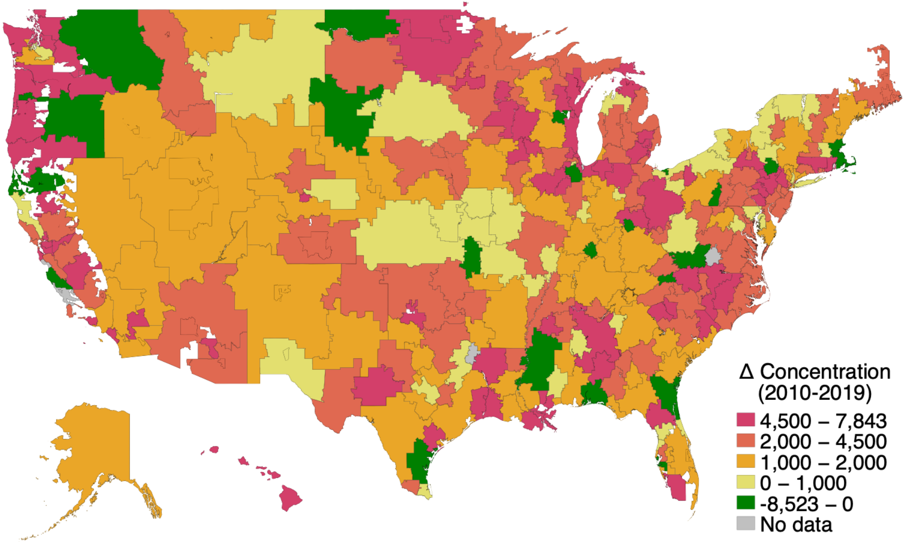
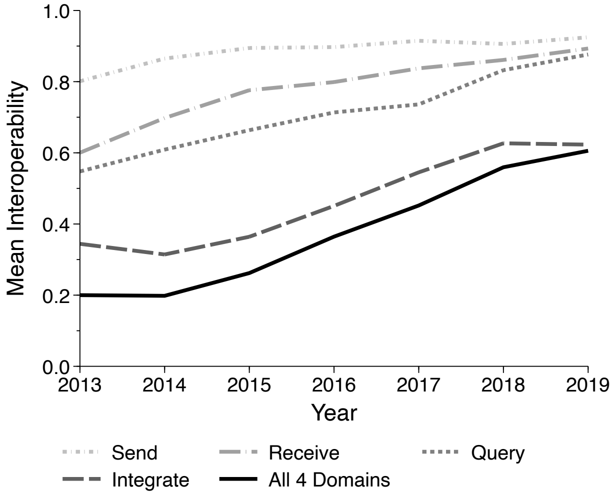


State of Interoperability: Imperfect

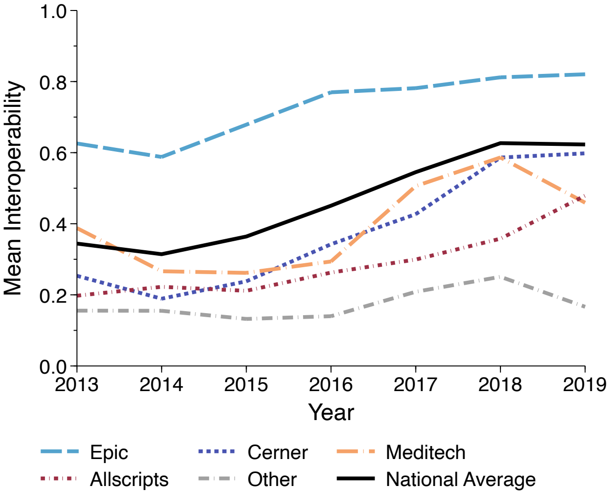
back



Progress over time but integration remains difficult

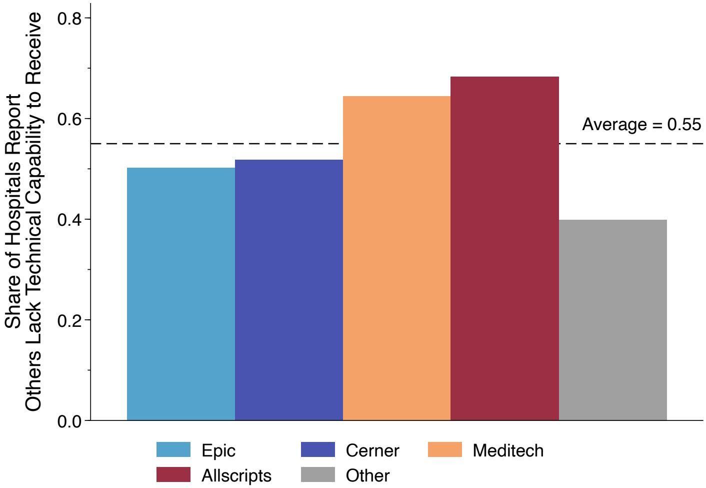
State of Interoperability by Vendor

Back



National average integration level low, substantial heterogeneity by vendor

(Sad) State of Interoperability



55% hospitals report others lack technical capability to receive their data (2017-2019)

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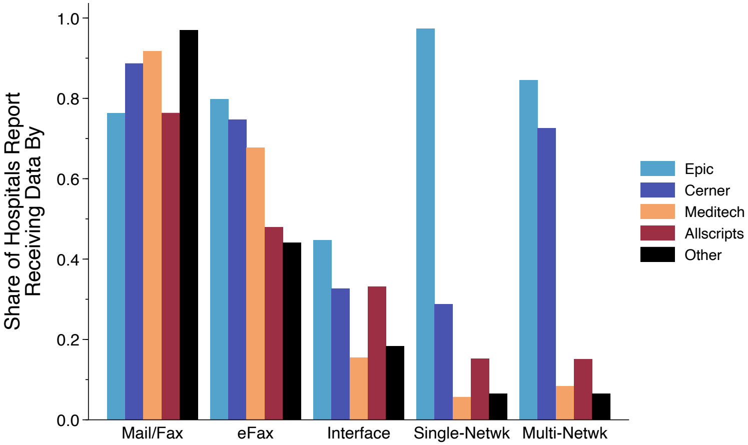

Receiving by mail/Fax/eFax incredibly common; only Epic has single-vendor network (2019)

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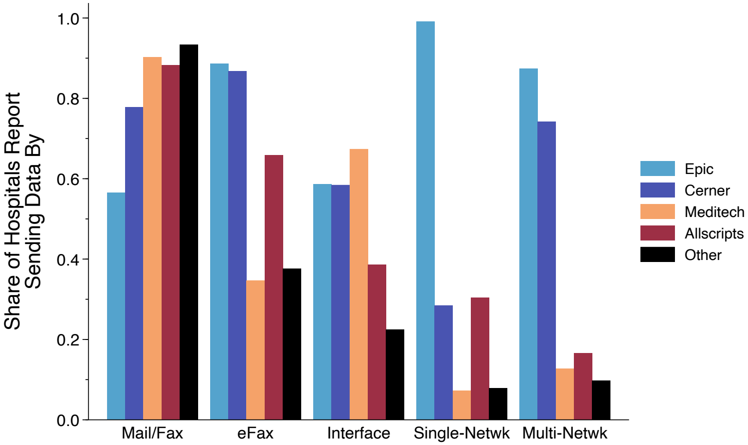

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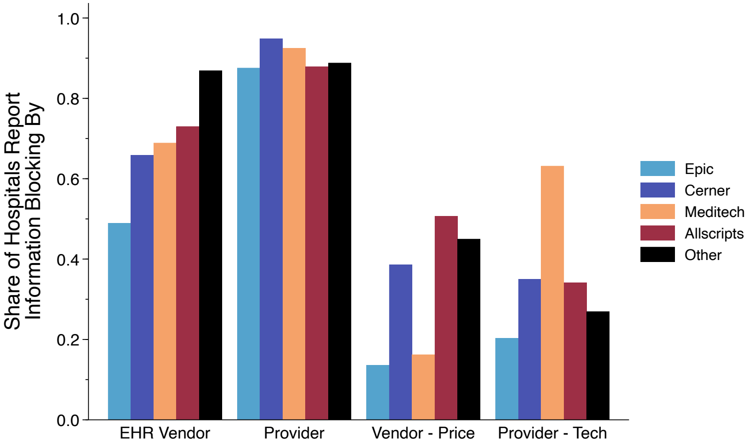

Rampant information blocking by both EHR vendors and healthcare providers (2019)

(Sad) State of Interoperability

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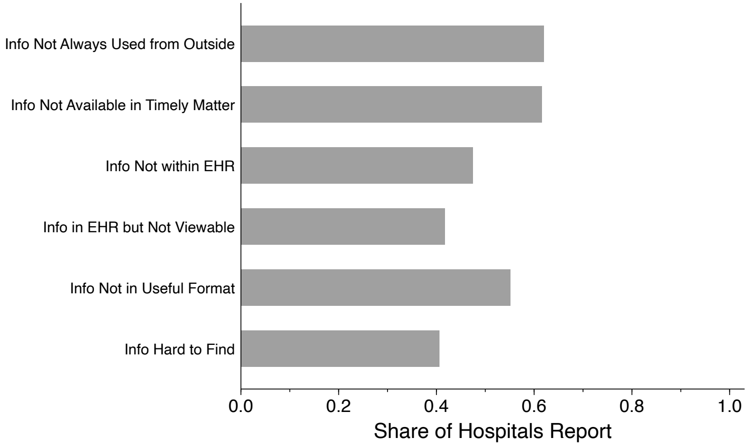

62% hospitals do not always use info from outside providers due to... (2017-2019)

Why Low Interoperability Persists

Back

"Epic's CEO Judy Faulkner is the single biggest obstacle to EHR interoperability."
—Ken Glueck, VP Oracle Cerner, May 2024

- Various proprietary software
  - incompatible data structures, workflow processes, & coding terminology across vendors necessitate complex data mapping & transformation processes
  - concerns regarding data integrity, security, & compliance add technical complexity
  - push for all vendors to use same standard of exchange (e.g., FHIR), but different implementations of standards $\Rightarrow$ inconsistencies in data representation
- Policy efforts ongoing
  - HITECH Act of 2009 promoted adoption, but not interoperability
  - 21^{st} Century Cures Act of 2016 prohibited info blocking, but not enforced until 2020, 2024
  - public/private RHIOs exist, but quality, services, participation varies widely
  - TEFCA to establish national "network of networks," but ongoing

Awareness of Low Interoperability

Back

Patients, providers are very aware of imperfect EHR interoperability, consequences:

- 32% patients encounter gaps in info exchange when visiting provider (ONC 2019)
- 64% physicians lack outside patient records at point of care (ONC 2022)
- 85% physicians struggle exchanging info across different EHR systems (ONC 2022)
- 38% PCPs find same-EHR-vendor info easy to use vs. 8% for different-vendor (Everson 2024)
- 5% patients redo tests due to unavailable prior data (ONC 2019)
- ≥80% physicians report HIE ↑ care quality, coordination, ↓ duplicate testing (ONC 2022)

"It's like opening a book to page 200 and being asked to write page 201... the middle of the book may be mysteriously ripped out, pages 75 to 95 shuffled, and several chapters don't even seem to be part of the same story. Meanwhile, everyone is urging me to write now."
—Dr. Yurkiewicz, *Fragmented* (2023)

Definitions of Cross-Hospital Patient Flows

Back

1. Inpatient Transfers: discharged from one hospital and admitted to another within 1 day
   - 5.1% (600K per year) of hospital inpatient stays result in a cross-hospital transfer
   - limit to hospital pairs in same HRR (average 18.3 other hospitals)
   - on average, each bed-weighted hospital pair exchanges 4.4 transfers annually

2. Referrals: referred from one physician to another for a service that takes place at a hospital & main hospital affiliations of the two physicians differ more details
   - 35.5% (95M per year) of physician claim lines in hospitals are cross-hospital referrals
   - limit to hospital pairs that share patients at baseline (average 73.9 other hospitals)
   - on average, each bed-weighted hospital pair exchanges 65.8 referrals annually

- *limit to 2005-2017 due to drop in share of hospitals reporting vendor post-HIMSS*

Definition of Cross-Hospital Referrals

Back

Steps for identifying cross-hospital referrals:

1. Using 20% Carrier files, restrict to services that take place at a hospital
2. Identify that hospital using either:
   - Crosswalk between the Inpatient, Outpatient files (list facility) and Carrier files
     - Possible when patient is inpatient/outpatient at a single facility on day of carrier claim
   - Primary hospital affiliation of the providing clinician
     - Affiliation determined by counting number of Inpatient, Outpatient claims the provider has at each hospital; top affiliation is hospital with largest number
     - Average provider has 86% of their claims take place at their top affiliation
     - 40% of providers have only 1 affiliation
3. Assume the place of service for the event that led to each referral is also a hospital
4. Assign identity of first hospital as primary hospital affiliation of the referring clinician

Patient Summary Statistics

Back

A. Transfers

	Transfer Patients	
	Mean	SD
Patient to 1st Hospital (km)	34.2	78.9
Patient to 2nd Hospital (km)	52.7	86.5
Days, 1st Hospital	7.88	24.6
Days, 2nd Hospital	13.5	15.4
Charges, 1st Hospital ($)	65049.7	113152.6
Charges, 2nd Hospital ($)	67589.5	106904.5
Died within 30 days	0.10	
Diagnosis Codes		
Aftercare	0.24	
Circulatory	0.22	
Respiratory	0.12	
Injury	0.096	
Infection	0.051	
Other	0.28	
N	7,804,147	

B. Referrals

	Referrals	
	Mean	SD
Total Allowable Charge ($)	67.0	134.5
Diagnosis Codes		
Circulatory	0.20	
Respiratory	0.12	
Musculoskeletal	0.11	
Aftercare	0.091	
Genitourinary	0.073	
Other	0.42	
BETOS Codes		
Eval. & Manag.	0.28	
Imaging	0.45	
Procedures	0.11	
Tests	0.100	
Other	0.065	
N	46,818,072	

Hospital-Pair Summary Statistics

Back

A. Transfers

	Hospital Pairs	
	Mean	SD
# of Transfers	4.50	20.1
Fraction of Sender Transfers	0.052	0.15
Sender Total Transfers within HRR	145.7	201.3
Same EHR Vendor	0.21	
Same System	0.079	
Same EHR Vendor — Different Systems	0.17	
Distance between Hospitals (km)	41.9	48.8
Big to Big*	0.55	
Big to Small*	0.23	
Small to Big*	0.20	
Small to Small*	0.020	
N	1,377,473	

B. Referrals

	Hospital Pairs	
	Mean	SD
# of Referrals	54.1	293.4
Fraction of Sender Referrals	0.019	0.074
Sender Total Referrals within Base Pairs	5094.6	5270.8
Same EHR Vendor	0.22	
Same System	0.039	
Same EHR Vendor — Different Systems	0.20	
Distance between Hospitals (km)	216.8	
Big to Big*	0.75	
Big to Small*	0.10	
Small to Big*	0.13	
Small to Small*	0.019	
N	2,067,664	

Notes: Hospital pair observations weighted by combined baseline beds (* weighted by referrals).
Fraction of flows = (# flows sent from h to h') / (total # flows sent from h).

Event Study Strategy

back

$$Y_{i(hh')t} = \left(\sum_{r=-6}^{6} \beta_r \mathbf{1}_{\{t=switch_{(hh')}+r\}} \right) + \alpha_{(hh')} + \gamma_t + \delta X_{it,(hh')t,mt} + \epsilon_{i(hh')t}$$

- $Y_{i(hh')t}$: **outcome of patient** i sent from h to h' in year t
  - charges, # tests, # images, readmitted within 30/60 days
- r: relative year since h, h' switched to having **same EHR vendor**
  - exclude $r = -1$, bin endpoints ($r \leq -6$, $r \geq 6$)
- controls: patient age, sex, race, chronic conditions, Charlson score, diagnosis category
- cluster SEs by hh'
- sample: hospital pairs that start with different vendors, switch to same max. once

- **Patient composition Δs:** with or without controls, including patient FEs $\Rightarrow$ **similar results**

Potential Identification Threats

- **Patient composition Δs:** with or without controls, including patient FEs $\Rightarrow$ **similar results**
- **Other hospital, market Δs** (coinciding with vendor switches):
  - add controls for h, h' chars.: beds, employees, ownership, capabilities
  - add $h \times t$, $h' \times t$ FEs, estimate using PPML (i.e., gravity model)
  - drop if either h or h' ever changes hospital systems (owners)
  - separately estimate by whether h or h' switches vendors

  $\Rightarrow$ **similar results**

Potential Identification Threats

back | patient comp Δs | other h, m Δs | placebo | 2SLS | opposite

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- $+$**:** Callaway, Sant'Anna (2021); cluster SEs by market $\Rightarrow$ **similar results**

Direct Effects on Transfers: Robustness to Patient Controls

	(1)	(2)	(3)	(4)	(5)	(6)
			Panel A: Charges			
Same EHR Vendor	-2653.3***	-2634.1***	-2664.9***	-2797.7***	-5810.7***	-2797.7**
	(882.8)	(888.0)	(892.0)	(917.2)	(1667.4)	(1249.3)
Observations	2406466	2394951	2347783	2347783	821655	2347783
Mean of Outcome	75314	75314	75314	75314	75314	75314
	Charges	Charges	Charges	Charges	Charges	Charges
			Panel B: # Images			
Same EHR Vendor	-0.0238**	-0.0235**	-0.0244***	-0.0305***	-0.0135	-0.0305***
	(0.00924)	(0.00927)	(0.00923)	(0.00934)	(0.0158)	(0.0111)
Observations	2406466	2394951	2347783	2347783	821655	2347783
Mean of Outcome	1.425	1.425	1.425	1.425	1.425	1.425
Patient Demographics		X	X	X		X
Patient Health			X	X		X
Patient Diagnosis				X		X
Patient FEs					X	
Level of Cluster	Pair	Pair	Pair	Pair	Pair	HRR

Direct Effects on Referrals: Robustness to Patient Controls

Back

	(1)	(2)	(3)	(4)	(5)
Panel A: # Tests					
Same EHR Vendor	-0.0188**	-0.0198**	-0.0188**	-0.00649	-0.0188*
	(0.00786)	(0.00783)	(0.00778)	(0.00532)	(0.00984)
Observations	26535742	26393950	26393910	25113303	26393910
Mean of Outcome	0.659	0.659	0.659	0.659	0.659
Panel B: 60-Day Readmit					
Same EHR Vendor	-0.00484***	-0.00498***	-0.00440***	-0.00332***	-0.00440***
	(0.000995)	(0.000995)	(0.000956)	(0.000733)	(0.00107)
Observations	22164926	22048799	22048773	20785265	22048773
Mean of Outcome	0.0392	0.0392	0.0392	0.0392	0.0392
Patient Demographics		X	X		X
Patient Health			X		X
Patient FEs				X	
Level of Cluster	Pair	Pair	Pair	Pair	HRR

Direct Effects on Transfers: Robustness to Hospital Controls

	(1)	(2)	(3)	(4)	(5)	(6)
			Panel A: Charges			
Same EHR Vendor	-2797.7***	-2637.9***	-2571.0***	-2533.2***	-2532.0***	-4138.8***
	(917.2)	(906.8)	(888.4)	(878.1)	(875.8)	(1152.8)
Observations	2347783	2347783	2300977	2300977	2300977	2076227
Mean of Outcome	75314	75314	75314	75314	75314	75314
	Charges	Charges	Charges	Charges	Charges	Charges
			Panel B: # Images			
Same EHR Vendor	-0.0305***	-0.0308***	-0.0325***	-0.0327***	-0.0333***	-0.0170
	(0.00934)	(0.00932)	(0.00935)	(0.00926)	(0.00923)	(0.0119)
Observations	2347783	2347783	2300977	2300977	2300977	2076227
Mean of Outcome	1.425	1.425	1.425	1.425	1.425	1.425
Hospital Beds		X	X	X	X	
Hospital Employees			X	X	X	
Hospital Ownership				X	X	
Hospital Capabilities					X	
Never Same System						X

Direct Effects on Referrals: Robustness to Hospital Controls

Back

	(1)	(2)	(3)	(4)	(5)	(6)
	Panel A: # Tests					
Same EHR Vendor	-0.0188**	-0.0189**	-0.0197**	-0.0190**	-0.0186**	-0.0307***
	(0.00778)	(0.00777)	(0.00777)	(0.00773)	(0.00768)	(0.0101)
Observations	26393910	26393910	26393910	26393910	26393910	23163190
Mean of Outcome	0.659	0.659	0.659	0.659	0.659	0.659
	Panel B: 60-Day Readmit					
Same EHR Vendor	-0.00440***	-0.00439***	-0.00423***	-0.00421***	-0.00425***	-0.00422***
	(0.000956)	(0.000954)	(0.000956)	(0.000957)	(0.000960)	(0.00116)
Observations	22048773	22048773	22048773	22048773	22048773	19365725
Mean of Outcome	0.0392	0.0392	0.0392	0.0392	0.0392	0.0392
Hospital Beds		X	X	X	X	
Hospital Employees			X	X	X	
Hospital Ownership				X	X	
Hospital Capabilities					X	
Never Same System						X

Direct Outcomes Placebo Test

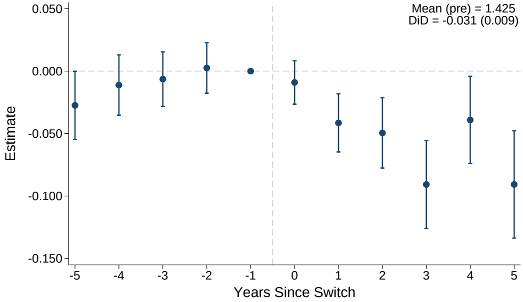
Back

Test: among control hospital pairs, any effect of either sending or receiving hospital switching EHR vendors but without the pair gaining the same vendor from said switch?

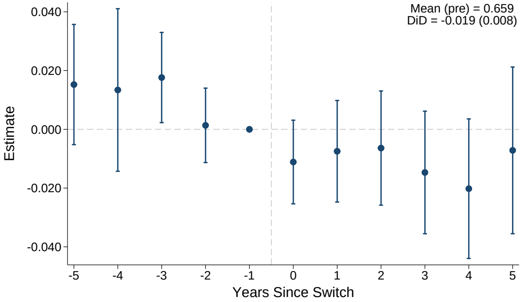
	Patient Outcomes			
	(1) Charges	(2) # Images	(3) # Tests	(4) 30 Day Readmit
A. Transfer Patients				
Post-Placebo Switch	-233.5	0.0190**	0.0518*	-0.00391
	(1049.7)	(0.00933)	(0.0311)	(0.00273)
Mean of Outcome	86159	1.403	3.811	0.3345
B. Referral Patients				
Post-Placebo Switch	0.140	-0.00670	-0.00219	-0.000651
	(1.170)	(0.0107)	(0.00823)	(0.00166)
Mean of Outcome	150	1.253	0.625	0.0648

Event studies noisy but show no significant pre-trends

Back



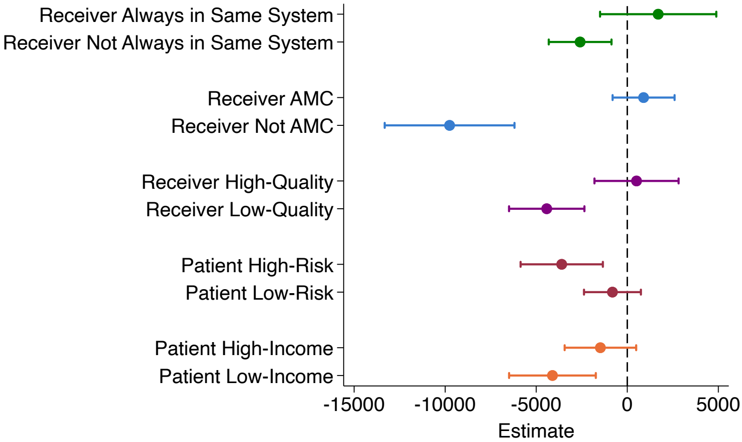
A. Transfers, # Images



B. Referrals, # Tests

Largest effects when receiver hospital low-quality, patient high-risk

Back

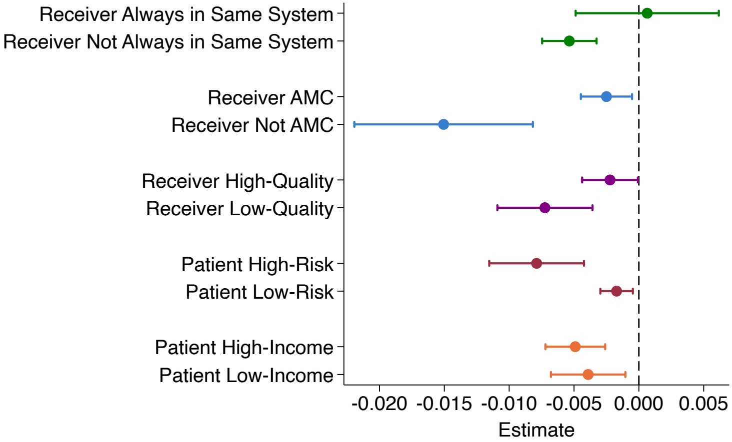


A. Transfers, Charges

more outcomes

Largest effects when receiver hospital low-quality, patient high-risk

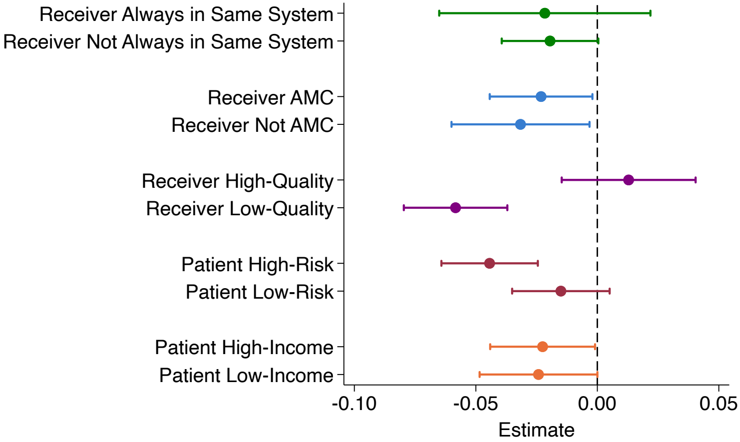
Back



Referrals, 60-Day Readmit

Largest effects when receiver hospital low-quality, patient high-risk

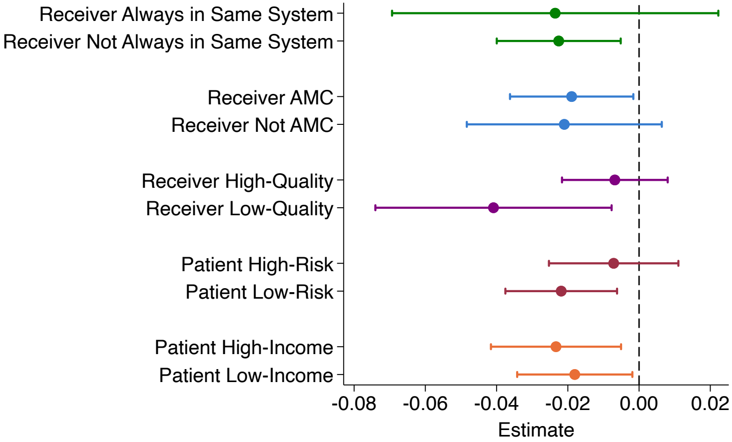
Back



Transfers, # Images

Largest effects when receiver hospital low-quality, patient high-risk

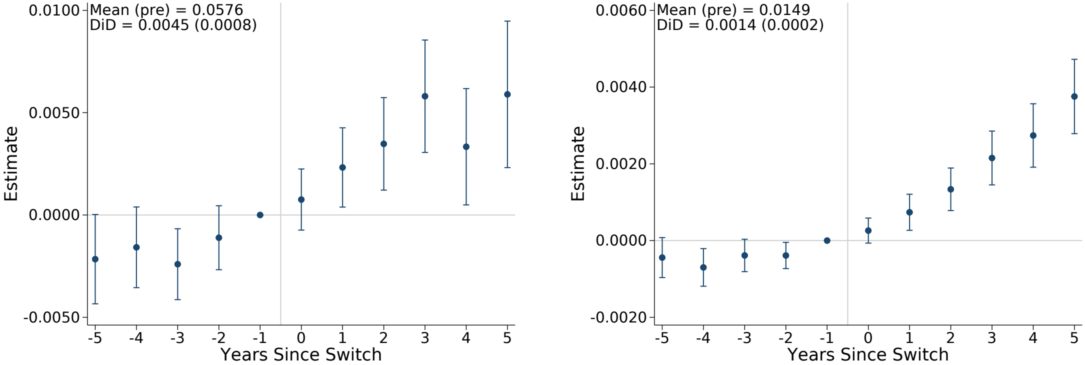
Back



Referrals, # Tests

8% (9%) ↑ fraction transfers (referrals) after pair switches to same vendor

Back



A. Fraction of Transfers **B. Fraction of Referrals**

Similar for fraction flows = (# flows sent from h to h') / (total # flows sent from h)

Flows Robustness: Additional Controls

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
				Panel A: # of Transfers					
Same EHR Vendor	0.431***	0.424***	0.415***	0.503***	0.499***	0.434**	0.429***	0.415**	-0.215
	(0.151)	(0.156)	(0.156)	(0.163)	(0.163)	(0.185)	(0.138)	(0.176)	(0.286)
Observations	957657	957656	957656	912995	912995	626938	955832	957656	342336
Mean of Outcome	4.91	4.91	4.91	4.91	4.91	4.91	4.91	4.91	4.91
				Panel B: Fraction of Transfers					
Same EHR Vendor	0.00395***	0.00459***	0.00449***	0.00461***	0.00456***	0.00484***	0.00503***	0.00449***	0.00241*
	(0.000880)	(0.000827)	(0.000824)	(0.000836)	(0.000835)	(0.000954)	(0.000829)	(0.00108)	(0.00141)
Observations	901423	901414	901414	880662	880662	606206	899411	901414	318930
Mean of Outcome	0.0576	0.0576	0.0576	0.0576	0.0576	0.0576	0.0576	0.0576	0.0576
Market x Year FEs		X	X	X	X	X		X	X
Hospital Beds			X	X	X	X		X	X
Hospital Employees				X	X	X			
Hospital Ownership					X	X			
Hospital Capabilities						X			
Hospital x Year FEs							X		
Drop System Switchers									X
Level of Cluster	Pair	Pair	Pair	Pair	Pair	Pair	Pair	HRR	Pair

Flows Robustness: Additional Controls

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Panel A: # of Referrals								
Same EHR Vendor	5.996***	4.985***	4.926***	4.783***	4.697***	3.931***	2.606**	4.926***	3.991**
	(1.150)	(1.080)	(1.081)	(1.088)	(1.087)	(1.149)	(1.178)	(1.467)	(1.992)
Observations	1450814	1425179	1425179	1401970	1401970	1064102	1448065	1425179	433454
Mean of Outcome	50.16	50.16	50.16	50.16	50.16	50.16	50.16	50.16	50.16
	Panel B: Fraction of Referrals								
Same EHR Vendor	0.00132***	0.00137***	0.00135***	0.00127***	0.00126***	0.00120***	0.00140***	0.00135***	0.00131***
	(0.000191)	(0.000192)	(0.000192)	(0.000192)	(0.000192)	(0.000209)	(0.000215)	(0.000273)	(0.000380)
Observations	1431659	1406422	1406422	1396069	1396069	1060813	1429309	1406422	427298
Mean of Outcome	0.0149	0.0149	0.0149	0.0149	0.0149	0.0149	0.0149	0.0149	0.0149
Market x Year FEs		X	X	X	X	X		X	X
Hospital Beds			X	X	X	X		X	X
Hospital Employees				X	X	X			
Hospital Ownership					X	X			
Hospital Capabilities						X			
Hospital x Year FEs							X		
Drop System Switchers									X
Level of Cluster	Pair	Pair	Pair	Pair	Pair	Pair	Pair	HRR	Pair

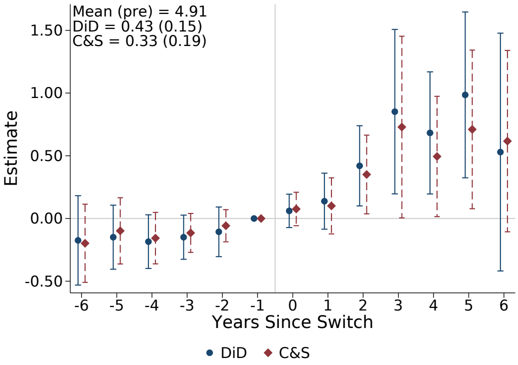
Flows Robustness: PPML

	(1)	(2)	(3)	(4)	(5)	(6)
			Panel A: # of Transfers			
Same EHR Vendor	0.120***	0.113***	0.158***	0.120***	0.113***	0.158***
	(0.0321)	(0.0264)	(0.0220)	(0.0321)	(0.0264)	(0.0220)
Observations	390458	390399	342308	390458	390399	342308
Mean of Outcome	4.91	4.91	4.91	4.91	4.91	4.91
			Panel B: Fraction of Transfers			
Same EHR Vendor	0.0737***	0.0885***	0.152***	0.0737***	0.0885***	0.152***
	(0.0148)	(0.0149)	(0.0226)	(0.0148)	(0.0149)	(0.0226)
Observations	380831	380773	342308	380831	380773	342308
Mean of Outcome	0.0576	0.0576	0.0576	0.0576	0.0576	0.0576
Market x Year FEs		X			X	
Hospital x Year FEs			X			X
Level of Cluster	Pair	Pair	Pair	Pair	Pair	Pair
Separation	FE, Simplex, IR	FE, Simplex, IR	FE, Simplex, IR	FE, Simplex	FE, Simplex	FE, Simplex

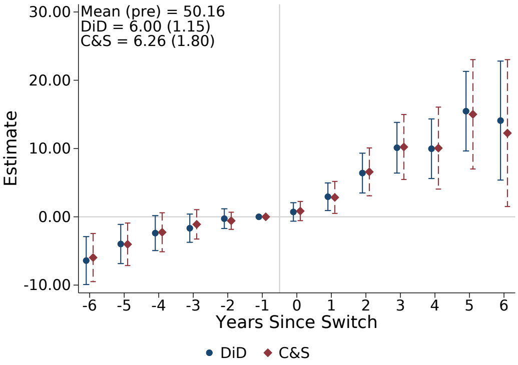
Flows Robustness: PPML

	(1)	(2)	(3)	(4)	(5)	(6)
			Panel A: # of Referrals			
Same EHR Vendor	0.137***	0.143***	0.132***	0.137***	0.143***	0.132***
	(0.0209)	(0.0167)	(0.0126)	(0.0209)	(0.0167)	(0.0126)
Observations	1374119	1349101	1337024	1374119	1349101	1337024
Mean of Outcome	50.16	50.16	50.16	50.16	50.16	50.16
			Panel B: Fraction of Referrals			
Same EHR Vendor	0.0779***	0.0853***	0.137***	0.0779***	0.0853***	0.137***
	(0.0111)	(0.0113)	(0.0133)	(0.0111)	(0.0113)	(0.0133)
Observations	1358747	1334102	1337024	1358747	1334102	1337024
Mean of Outcome	0.0149	0.0149	0.0149	0.0149	0.0149	0.0149
Market x Year FEs		X			X	
Hospital x Year FEs			X			X
Level of Cluster	Pair	Pair	Pair	Pair	Pair	Pair
Separation	FE, Simplex, IR	FE, Simplex, IR	FE, Simplex, IR	FE, Simplex	FE, Simplex	FE, Simplex

Flows Robustness: Callaway & Sant'Anna (2021) Estimates



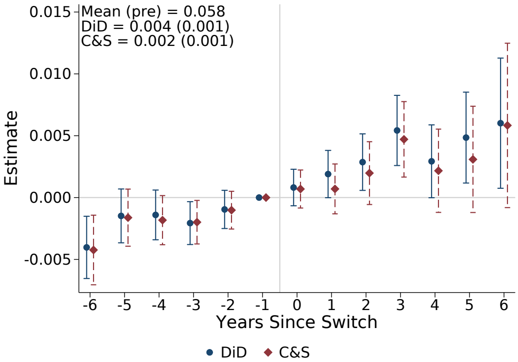
A. # Transfers



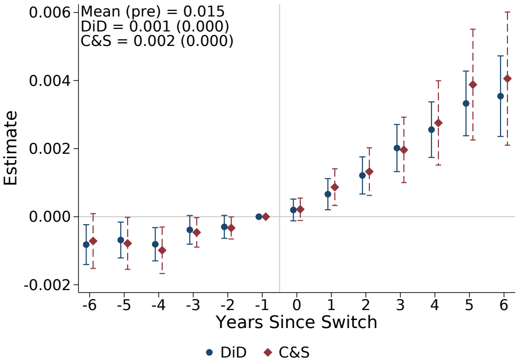
B. # Referrals

Flows Robustness: Callaway & Sant'Anna (2021) Estimates

Back



A. Fraction of Transfers



B. Fraction of Referrals

Flows Robustness: Whether Sender or Receiver Switches Vendors

Back

	# of Transfers			Fraction of Transfers		
	(1)	(2)	(3)	(4)	(5)	(6)
	All	Senders	Receivers	All	Senders	Receivers
Same EHR Vendor	0.311**	0.377***	0.250	0.00413***	0.00592***	0.00241**
	(0.147)	(0.144)	(0.254)	(0.000854)	(0.00135)	(0.00104)
Observations	941645	874216	873869	887041	822978	822579

	# of Referrals			Fraction of Referrals		
	(1)	(2)	(3)	(4)	(5)	(6)
	All	Senders	Receivers	All	Senders	Receivers
Same EHR Vendor	5.106***	3.904***	6.485***	0.00141***	0.00232***	0.000644***
	(1.077)	(1.436)	(1.739)	(0.000192)	(0.000294)	(0.000239)
Observations	1505121	1328893	1320468	1486142	1310924	1303404

Flows Placebo Test

Back

Test: among control hospital pairs, any effect of either sending or receiving hospital switching EHR vendors but without the pair gaining the same vendor from said switch?

	(1) # of Transfers	(2) Fraction of Transfers	(3) # of Referrals	(4) Fraction of Referrals
Post-Placebo Switch	-0.000970	0.000118	-0.000970	0.000118
	(0.0760)	(0.000579)	(0.0760)	(0.000579)
Observations	418498	392291	418498	392291
Mean of Outcome	4.31	0.0441	45.90	0.0175

Notes: Each regression includes pair fixed effects and year fixed effects. Weighted by combined baseline bed size. SEs clustered at hospital sender-receiver level, in parentheses. * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

OLS Concerns & 2SLS

Back to Direct Back to Flows Back to Model

- Potential problems with OLS:
  (1) hospitals choose whether to switch EHR vendors $\implies \mathbf{1}_{e_{ht}=e_{h't}}$ potentially endogenous
  (2) classical measurement error evidence

$\Rightarrow$ Instrument for $\mathbf{1}_{e_{ht}=e_{h't}}$ using "System Pressure" visualization

- Hospitals in multi-hospital systems face pressure to use same EHR vendor as other hospitals in their systems
  - ex: St. John Medical Center—largest hospital in Ascension—switches to Epic $\implies \uparrow$ pressure for other Ascension hospitals, even those located in different markets, to also switch to Epic
  - label share of other hospital beds in own system but different market that use Epic the "System Pressure" a hospital faces to use Epic; not endogenous to local market factors
- Limit to pairs where neither hospital is largest in own system ($\downarrow$ FS reverse causality)
- Ex: instrument for both having Epic with product of both System Pressures for Epic

2SLS transfer charges estimates $\approx 3 \times$ OLS estimates

Back to Direct

	Same EHR Vendor	Charges		
	(1)	(2)	(3)	(4)
	FS	RF	2SLS	OLS
Instrument Same Epic	0.797***	-22274.0***		
	(0.0595)	(3627.0)		
Instrument Same Cerner	0.626***	-18410.8***		
	(0.0989)	(3776.4)		
Instrument Same Meditech	0.299***	1772.5		
	(0.0772)	(4368.9)		
Instrument Same Allscripts	0.237	11478.8		
	(0.160)	(15066.2)		
Same EHR Vendor			-27660.3***	-8883.4***
			(4164.1)	(1910.7)
Observations	348939	348939	348939	348939
Mean of Outcome	0.113	9.1e+04		
First Stage F-Stat	66.1			

2SLS transfer flows estimates ≈ 2.5 × OLS estimates

Back to Flows Back to Model

	Same EHR Vendor	Fraction of Transfers		
	(1)	(2)	(3)	(4)
	FS	RF	2SLS	OLS
Instrument Same Epic	0.510***	0.000578		
	(0.0143)	(0.00173)		
Instrument Same Cerner	0.545***	0.00665***		
	(0.0169)	(0.00240)		
Instrument Same Meditech	0.435***	0.00326*		
	(0.0157)	(0.00174)		
Instrument Same Allscripts	0.149***	-0.0152**		
	(0.0230)	(0.00642)		
Same EHR Vendor			0.00547**	0.00228***
			(0.00238)	(0.000672)
Observations	218632	218632	218632	218632
Mean of Outcome	0.257	0.062		
First Stage F-Stat	683.8			

2SLS referral flows estimates ≈ 3.5 × OLS estimates

Back to Flows Back to Model

	Same EHR Vendor	Fraction of Referrals		
	(1)	(2)	(3)	(4)
	FS	RF	2SLS	OLS
Instrument Same Epic	0.592***	0.00294***		
	(0.0112)	(0.00102)		
Instrument Same Cerner	0.603***	0.00231**		
	(0.0132)	(0.000947)		
Instrument Same Meditech	0.390***	0.000524		
	(0.0134)	(0.000946)		
Instrument Same Allscripts	0.170***	-0.0149***		
	(0.0389)	(0.00387)		
Same EHR Vendor			0.00402***	0.00110***
			(0.00112)	(0.000345)
Observations	260033	260033	260033	260033
Mean of Outcome	0.243	0.021		
First Stage F-Stat	1348.4			

Evidence of Classical Measurement Error

Instrument for whether hospital pair has same vendor in one survey with whether hospital pair has same vendor in other survey $\implies$ 2SLS estimates $\approx$ 1.5 - 4 $\times$ OLS estimates

	Fraction of Transfers					
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) 2SLS	(6) 2SLS
Same EHR Vendor - HIMSS	0.00182***		0.00145*		0.00598***	
	(0.000497)		(0.000833)		(0.00206)	
Same EHR Vendor - AHA IT		0.00291***		0.00238***		0.00365*
		(0.000745)		(0.000818)		(0.00209)
Observations	1057046	477713	375796	375796	375796	375796
Mean of Outcome	0.0511	0.0511	0.0511	0.0511	0.0511	0.0511
Restrict to Non-Miss			X	X	X	X
First Stage F-Stat					7138.2	6800.8

Notes: Each regression includes pair fixed effects and year fixed effects. Weighted by combined baseline bed size. SEs clustered at hospital sender-receiver level, in parentheses. * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Evidence of Classical Measurement Error

Back

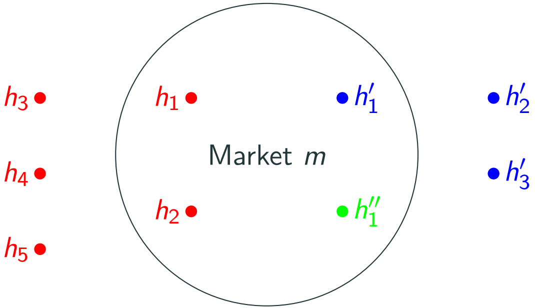
Instrument for whether hospital pair has same vendor in one survey with whether hospital pair has same vendor in other survey $\implies$ 2SLS estimates $\approx$ 2 - 2.5 $\times$ OLS estimates

	Fraction of Referrals					
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) 2SLS	(6) 2SLS
Same EHR Vendor - HIMSS	0.000956***		0.000634***		0.00127***	
	(0.000135)		(0.000162)		(0.000358)	
Same EHR Vendor - AHA IT		0.000707***		0.000569***		0.00145***
		(0.000164)		(0.000160)		(0.000371)
Observations	1741987	924141	855012	855012	855012	855012
Mean of Outcome	0.0184	0.0184	0.0184	0.0184	0.0184	0.0184
Restrict to Non-Miss			X	X	X	X
First Stage F-Stat					32714.8	30462.7

Notes: Each regression includes pair fixed effects and year fixed effects. Weighted by combined baseline bed size. SEs clustered at hospital sender-receiver level, in parentheses. * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Illustration of System Pressure Instrument Calculation

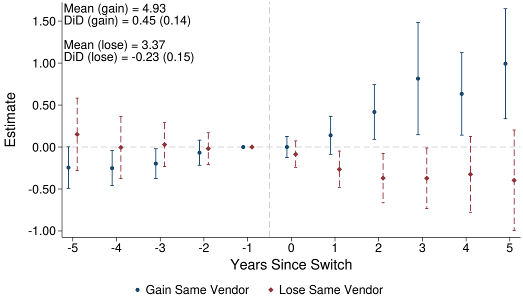
Back



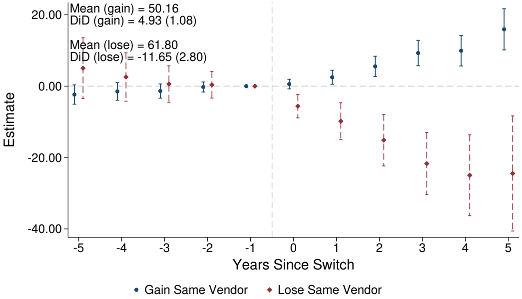
Notes: Hospitals in the same hospital system have the same color. Hospitals inside of the circle are located in the same market (HRR) m. Hospitals outside of the circle are located in different markets. In this example, system pressure for hospital h_1 to have vendor e in year t, $SP(ht, e)$, is calculated as the share of beds among hospitals $\{h_3, h_4, h_5\}$ that use vendor e in year t. System pressure for h'_1 is similarly based on the vendors used by $\{h'_2, h'_3\}$. Hospital h''_1 does not belong to a multi-hospital system containing hospitals outside of its own market and is therefore discarded from the instrumental variables sample.

Opposite Treatment: Lose Same Vendor

Back



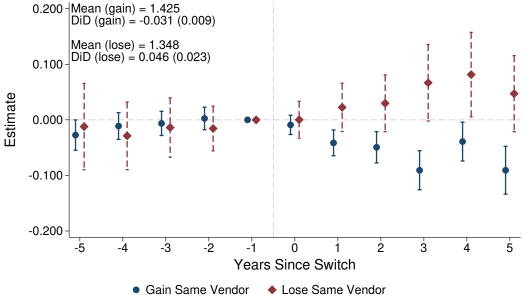
A. # Transfers



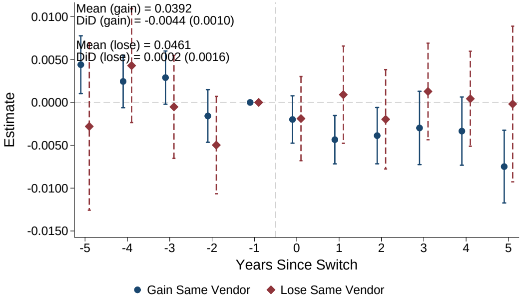
B. # Referrals

Opposite Treatment: Lose Same Vendor

Back



A. Transfers, # Images



B. Referrals, 60-Day Readmit

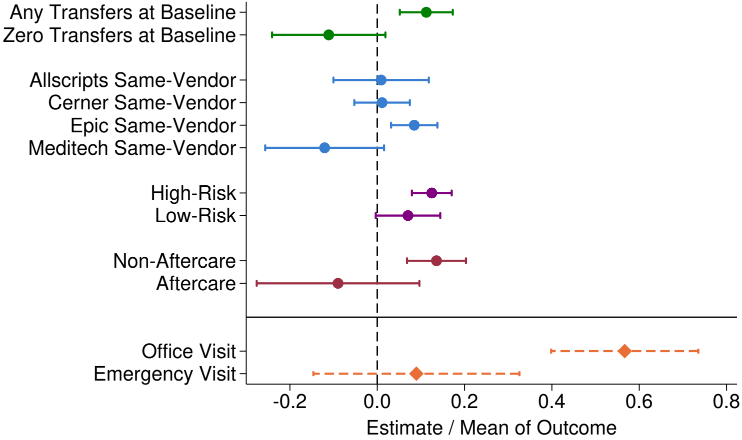
Magnitudes

Back to Flows Back to Model

- Estimate that hospital pairs increase shared inpatient transfers by 8% and referrals by 9-10% when they switch to same EHR vendor
- 40% of hospitals switch vendors at least once; these on average have 7.3 other hospitals with same vendor within its HRR and 21.7 hospitals with which it interacts at baseline
- With 7.8M Medicare inpatient transfers and 930M Medicare cross-hospital referrals over sample period, estimates imply:
  - 100,000 Medicare inpatient transfers are reallocated across hospitals from 2005-2017
  - 15M Medicare patient referrals are reallocated across hospitals from 2008-2017
- Given average costs of cross-hospital flows, changes in patient flows reallocated \$7.3B of Medicare spending across hospitals over sample period (\$0.5B each year)

Flows Heterogeneity by Hospital, Vendor, Patient Characteristics

Back



Transfers, Referrals

Reallocation across hospitals or change in total flows?

Back

	Total Patient Flows			
	(1) Transfers Sent	(2) Transfers Received	(3) Referrals Sent	(4) Referrals Received
Post-EHR Switch	0.793	-2.314	14.33	425.2*
	(4.461)	(4.205)	(101.8)	(239.3)
Observations	34,542	34,542	29,805	29,805
Mean of Outcome	249.08	210.64	4,587.27	4,839.17

(1) no Δ total transfers, referrals sent, (2) small $\uparrow$ referrals received (Epic)

empirical strategy details | no change in patient characteristics | increase in referrals for epic only | no market/system share heterogeneity

Total Flows: Empirical Strategy

Back

$$Y_{ht} = \beta * \mathbf{1}_{(\text{Post-Switch}_{ht})} + \alpha_h + \gamma_t + X_{ht,mt} + \epsilon_{ht}$$

- Y_{ht} total patient flows to/from hospital h in year t
- $\mathbf{1}_{(\text{Post-Switch}_{ht})}$ indicator for whether h has yet switched EHR vendors in t
- $X_{ht,mt}$ characteristics of hospital and market in year t (e.g., bed size, market by year FEs)
- cluster SEs at hospital level
- weight by number of beds at baseline

Total Flows: No Change in Transfer Patient Characteristics

	Characteristics for Transfer Patients					
	(1)	(2)	(3)	(4)	(5)	(6)
	Age	Medicaid Dual	# Chronic Conditions	# Cancers	# Heart Conditions	Charlson Score
Post-EHR Switch	0.124	-0.00272	-0.00529	0.000661	0.00166	0.00686
	(0.0935)	(0.00310)	(0.0173)	(0.000996)	(0.00425)	(0.0127)
Observations	32091	29080	32068	32068	32068	32091
Mean of Outcome	70.41	0.33	4.70	0.09	0.85	4.69

Notes: Each column is a separate regression with standard errors clustered at the hospital level and includes hospital and market-year fixed effects. Outcomes are hospital-level average characteristics of transfer patients sent from that hospital.

Total Flows: No Change in Referral Patient Characteristics

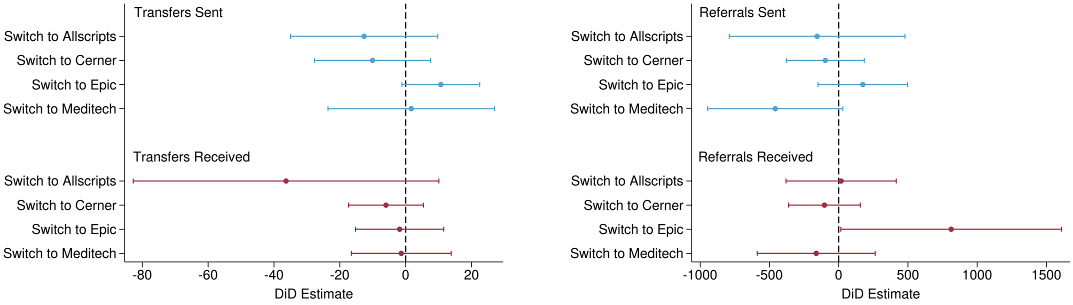
Back

	Characteristics for Referral Patients					
	(1) Age	(2) Medicaid Dual	(3) # Chronic Conditions	(4) # Cancers	(5) # Heart Conditions	(6) Charlson Score
Post-EHR Switch	0.0523	0.00166	-0.00495	0.000229	-0.00328	0.00792
	(0.0732)	(0.00270)	(0.0228)	(0.00199)	(0.00675)	(0.0168)
Observations	26948	26948	26948	26948	26948	26948
Mean of Outcome	71.62	0.33	5.97	0.17	1.06	5.54

Notes: Each column is a separate regression with standard errors clustered at the hospital level and includes hospital and market-year fixed effects. Outcomes are hospital-level average characteristics of referral patients sent from that hospital.

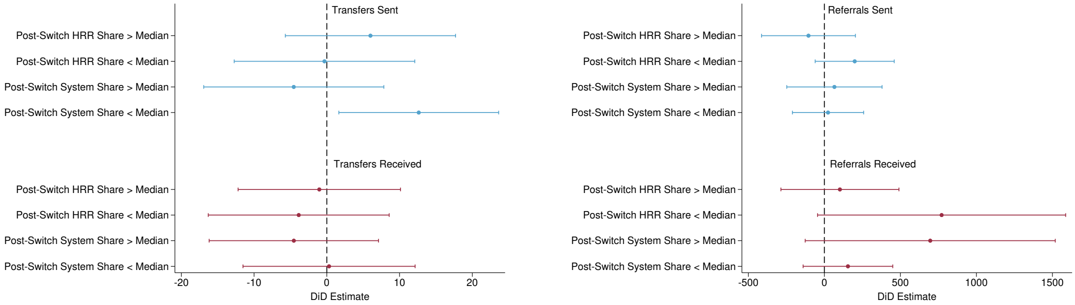
Total Flows: Heterogeneity by Vendor

Back



Total Flows: Heterogeneity by Vendor Market/System Share

Back



Allocative Effect on Patient Outcomes

- Does reallocation of patients across hospitals affect outcomes?
  - may depend on **comparison** of hospitals gain vs. lose patients

$\Rightarrow$ Do changes in EHR network **pass through** into changes in patient outcomes?

$$Y_{iht} = \beta_1 \mathbf{1}_{\text{Post-Switch}_{ht}} + \beta_2 \left(\mathbf{1}_{\text{Post-Switch}_{ht}} \times \Delta\text{Network}_{Yh} \right) + \alpha_h + \gamma_t + \delta X_{it,ht,mt} + \epsilon_{iht}$$

- Y_{iht}: outcome of patient i sent from hospital h in year t
- $\Delta\text{Network}_{Yh}$: change in average baseline Y of other local same-vendor hospitals after switch
- sample: patients sent to other same-vendor hospitals

more details on $\Delta\text{Network}_{Yh}$ more details on sample

Δ Local EHR Network Characteristics predict Δ Patient Outcomes

back

	Outcomes for Same-Vendor Transfer Patients			
	(1) Distance (km)	(2) Mean Charges	(3) 30 Day Readmit	(4) 60 Day Death
Post-EHR Switch	4.440***	1106.4	0.00129	0.00295
	(1.664)	(5981.7)	(0.00634)	(0.00545)
$\times$ ΔNetwork	0.255**	0.425***	0.156**	0.222***
	(0.106)	(0.0987)	(0.0622)	(0.0573)
Observations	571377	620903	512363	620903
Mean of Outcome	35.94	78190.73	0.30	0.14

similar for referrals | robust to patient-level controls | largest when switch to vendor w/ higher market/system vendor share | no interaction

Δ Local EHR Network Characteristics predict Δ Patient Outcomes

back

	Outcomes for Same-Vendor Transfer Patients			
	(1) Distance (km)	(2) Mean Charges	(3) 30 Day Readmit	(4) 60 Day Death
Post-EHR Switch	4.440***	1106.4	0.00129	0.00295
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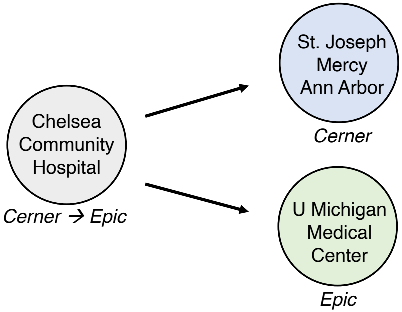
similar for referrals | robust to patient-level controls | largest when switch to vendor w/ higher market/system vendor share | no interaction

Changes in Local EHR Network Characteristics

- $\Delta\textbf{Network}_{Yh}$ = when hospital h switches vendors, how do baseline characteristics (Y) of other hospitals in its market with same vendor change?

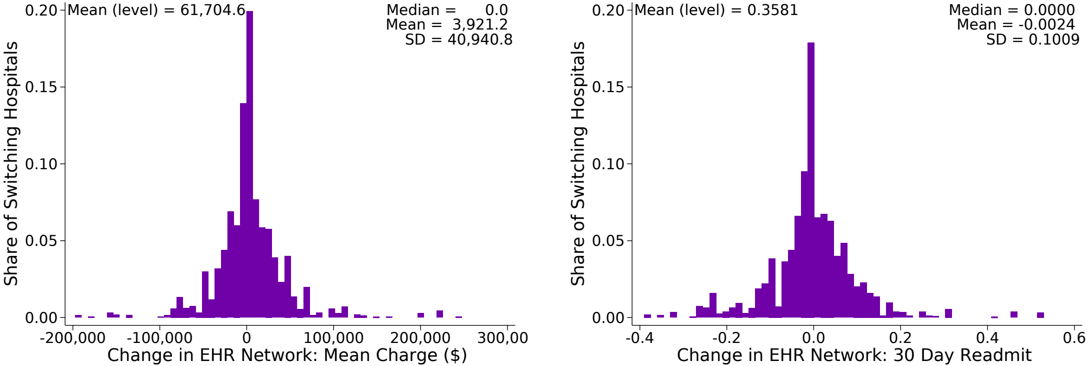


$= \mathbb{E}(Y \mid \text{Same Vendor Post}) - \mathbb{E}(Y \mid \text{Same Vendor Pre})$

- Y: distance to focal hospital, charges, readmit./mortality rates for all received transfer/referral patients
- weight other hospitals by beds
- restrict to other hospitals that share patients with focal hospital at baseline (risk set)

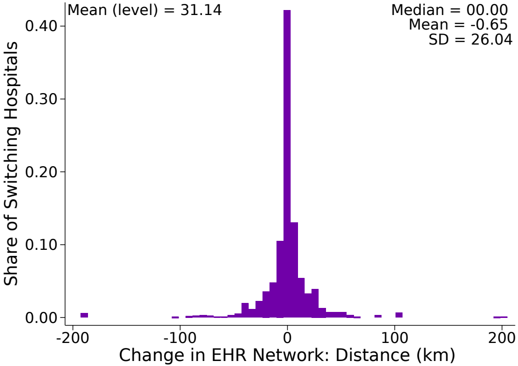
Changes in Local EHR Network Characteristics - Transfers

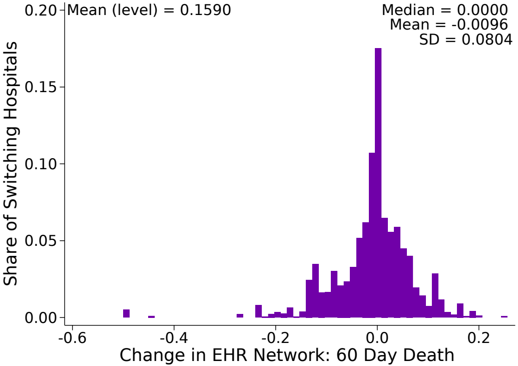
On average, hospitals switch to EHR vendors whose local networks include more expensive but closer and slightly better hospitals; wide distributions



Changes in Local EHR Network Characteristics - Transfers

On average, hospitals switch to EHR vendors whose local networks include more expensive but closer and slightly better hospitals; wide distributions





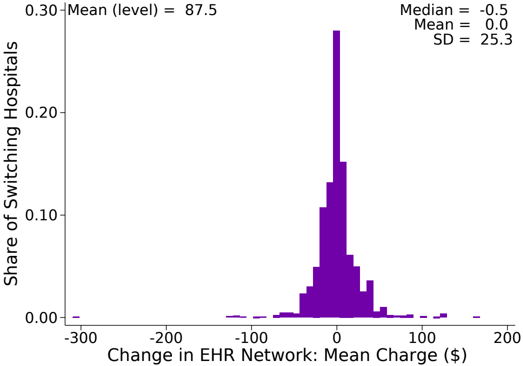
Changes in Local EHR Network Characteristics - Transfers

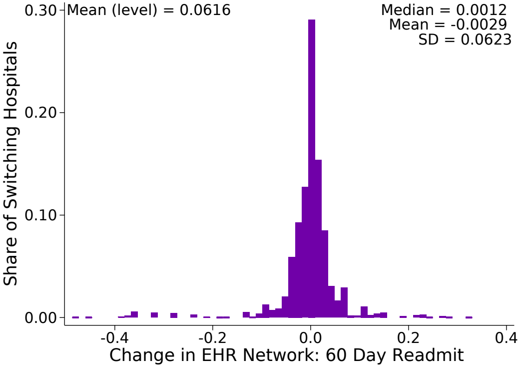
	Baseline Characteristics of Local EHR Network						
	(1) Hosps	(2) Beds	(3) Traumas	(4) Trauma 1s	(5) AMCs	(6) System Hosps	(7) System Beds
Post-EHR Switch	1.053***	562.1***	1.375***	0.562***	1.195***	0.436***	118.5***
	(0.278)	(67.09)	(0.169)	(0.0521)	(0.197)	(0.0738)	(16.89)
Observations	28311	28311	28311	28311	28311	28311	28311
Mean of Outcome (Lvl)	6.45	1264.75	3.74	0.59	3.68	1.65	322.33

Notes: Each column is a separate regression with standard errors clustered at the hospital level and includes hospital and market-year fixed effects. Hospitals weighted by baseline beds. Outcomes are average baseline characteristics of other hospitals in the same HRR with the same EHR vendor as the switching hospital in any given year. * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Changes in Local EHR Network Characteristics - Referrals

On average, hospitals switch to EHR vendors whose local networks include more expensive but closer and slightly better hospitals; wide distributions

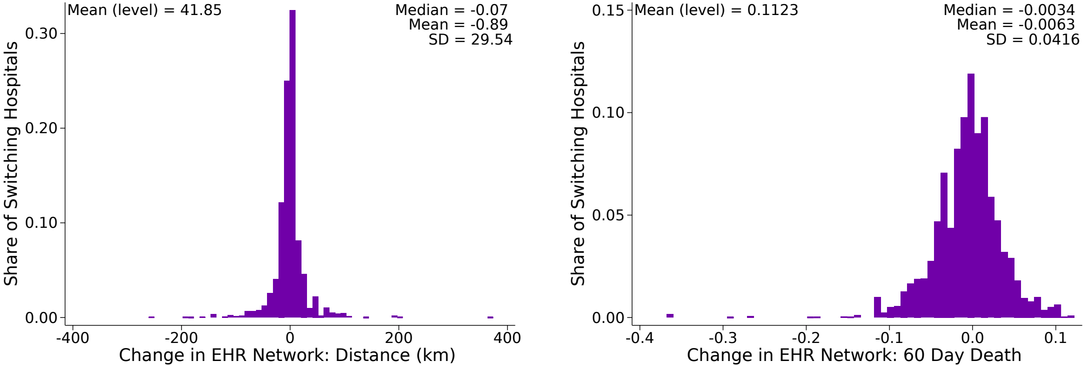




Changes in Local EHR Network Characteristics - Referrals

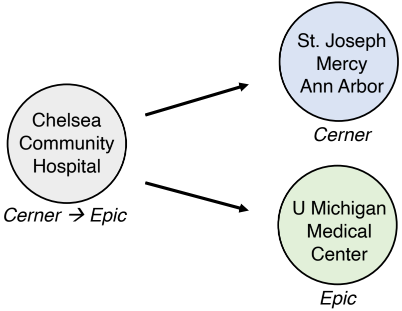
Back

On average, hospitals switch to EHR vendors whose local networks include more expensive but closer and slightly better hospitals; wide distributions



Changes in Patient Outcomes

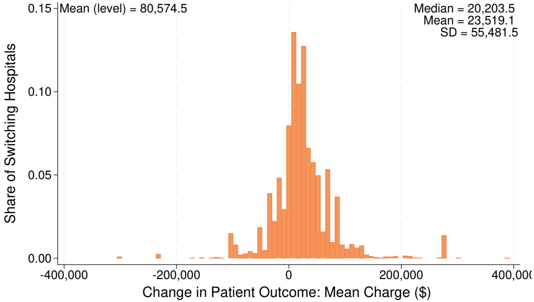
- When hospital h switches vendors, how do outcomes (Y) change for patients that h sends to other hospitals?



  - Y: sent patients' average distance traveled, charges, readmit./mortality rates
  - not all patients reallocated $\Rightarrow$ narrow into relevant sample: patients sent to same-vendor hospitals pre vs. post-switch
  - $\Delta Y = \mathbb{E}(Y \mid \text{Sent Post}) - \mathbb{E}(Y \mid \text{Sent Pre})$

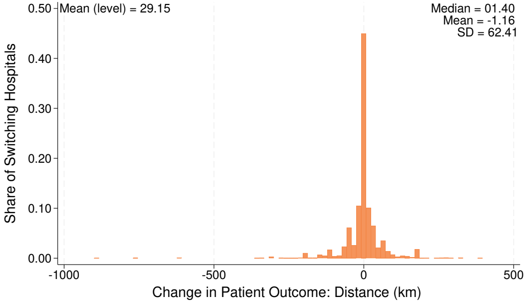
Changes in Patient Outcomes - Transfers

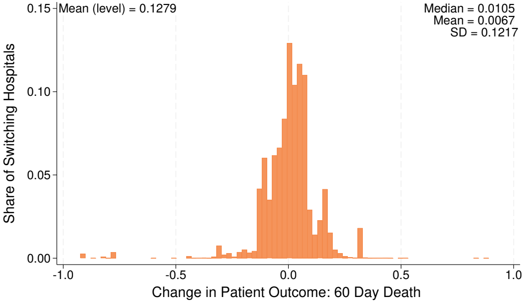
Wide distributions in change in sent patient outcomes after switch



Changes in Patient Outcomes - Transfers

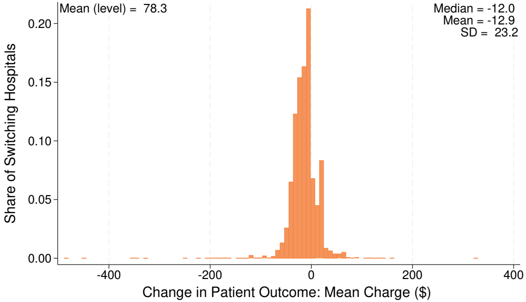
Wide distributions in change in sent patient outcomes after switch

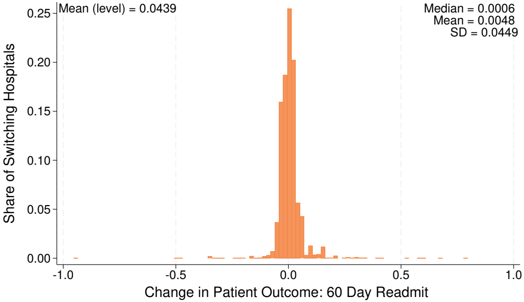




Changes in Patient Outcomes - Referrals

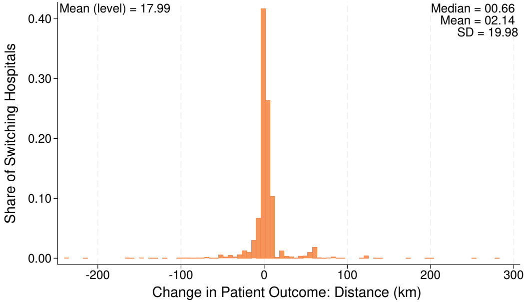
Wide distributions in change in sent patient outcomes after switch

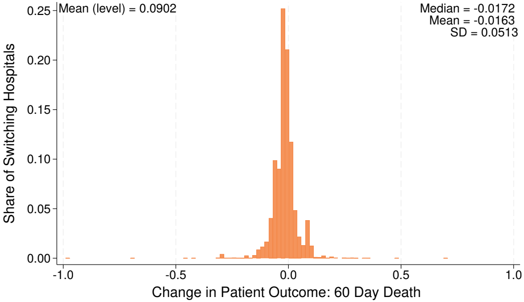




Changes in Patient Outcomes - Referrals

Wide distributions in change in sent patient outcomes after switch





Same-Vendor Transfer Patients Slightly Healthier After Switch

Back

	Characteristics for Transfer Patients					
	(1) Age	(2) Medicaid Dual	(3) # Chronic Conditions	(4) # Cancers	(5) # Heart Conditions	(6) Charlson Score
Post-EHR Switch	-0.485	-0.0142*	-0.173***	-0.0119*	-0.000178	-0.130**
	(0.333)	(0.00855)	(0.0659)	(0.00670)	(0.0200)	(0.0581)
Observations	21583	21583	21583	21583	21583	21583
Mean of Outcome	69.98	0.39	6.99	0.16	1.28	5.93

Notes: Each column is a separate regression with standard errors clustered at the hospital level and includes hospital and market-year fixed effects. Outcomes are hospital-level average characteristics of transfer patients sent from that hospital.

Allocative: Δ Local EHR Network Predicts Δ Patient Outcomes

Back

Similar results for referrals

	Outcomes for Same-Vendor Referral Patients			
	(1)	(2)	(3)	(4)
	Distance (km)	Mean Charges	60 Day Readmit	60 Day Death
Post-EHR Switch	-0.443	0.606	0.00535**	-0.00381
	(0.988)	(1.339)	(0.00242)	(0.00255)
$\times$ ΔNetwork	0.313***	0.297***	0.104*	0.189***
	(0.0518)	(0.0725)	(0.0568)	(0.0697)
Observations	12739822	13994311	11632215	13994311
Mean of Outcome	22.82	80.27	0.05	0.09

Allocative Effect Robustness

Back

Robust to adding controls for 27 chronic conditions, age, Charlson score

	Outcomes for Same-Vendor Transfer Patients			
	(1)	(2)	(3)	(4)
	Distance (km)	Mean Charges	30 Day Readmit	60 Day Death
Post-EHR Switch	4.359***	409.8	0.00344	0.00231
	(1.647)	(5833.0)	(0.00574)	(0.00547)
x Change in Network	0.255**	0.421***	0.122**	0.218***
	(0.106)	(0.0973)	(0.0571)	(0.0572)
Observations	559433	607807	501664	607807
Mean of Outcome	35.94	78190.73	0.30	0.14

Back

Allocative Effect Robustness

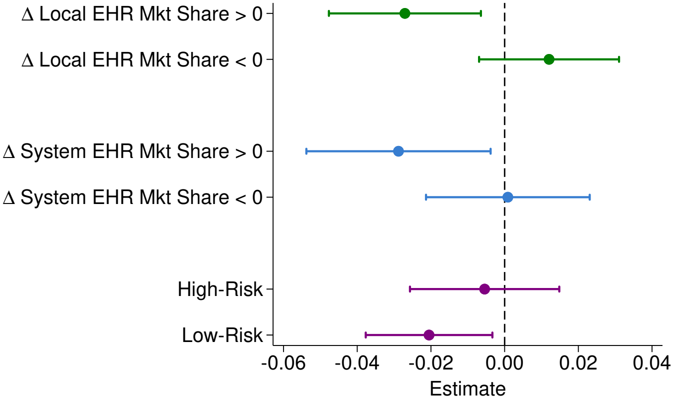
Back

Robust to adding controls for 27 chronic conditions, age, Charlson score

	Outcomes for Same-Vendor Referral Patients			
	(1)	(2)	(3)	(4)
	Distance (km)	Mean Charges	60 Day Readmit	60 Day Death
Post-EHR Switch	-0.442	0.573	0.00606***	-0.00291
	(0.987)	(1.326)	(0.00220)	(0.00205)
x Change in Network	0.313***	0.284***	0.0878*	0.141***
	(0.0518)	(0.0707)	(0.0497)	(0.0532)
Observations	12739106	13993531	11631497	13993531
Mean of Outcome	22.82	80.27	0.05	0.09

Allocative Effects Heterogeneity

Back



A. Transfer Patient 30 Day Readmit

Switching to better local vendor network with higher market/system vendor share yields greatest patient benefits

Allocative Effect: No Interaction

Back

On average, same-vendor transfer patients are sent farther away, experience slight increase in readmission rates

	Outcomes for Same-Vendor Transfer Patients			
	(1)	(2)	(3)	(4)
	Distance (km)	Mean Charges	30 Day Readmit	60 Day Death
Post-EHR Switch	6.589***	2723.5	0.00823*	0.00512
	(1.596)	(4592.2)	(0.00478)	(0.00467)
Observations	714532	781421	644864	781421
Mean of Outcome	35.94	78190.73	0.30	0.14

Allocative Effect: No Interaction

Back

On average, same-vendor referral patients experience slight increase in readmission rates, slight decrease in death rates

	Outcomes for Same-Vendor Referral Patients			
	(1)	(2)	(3)	(4)
	Distance (km)	Mean Charges	60 Day Readmit	60 Day Death
Post-EHR Switch	-0.173	-0.185	0.00576***	-0.00415**
	(0.913)	(1.290)	(0.00212)	(0.00200)
Observations	13842146	15186471	12621995	15186471
Mean of Outcome	22.82	80.27	0.05	0.09

Allocative Effects: $\Delta \text{Network}_{Yh}$ Deciles are Balanced

Back

	Characteristics for Transfer Patients					
	(1)	(2)	(3)	(4)	(5)	(6)
	Age	# Chronic Conditions	Any Cancers	Any Heart Conditions	Charlson Score	Aftercare Transfer
Top Decile	-0.395	-0.0110	0.00135	-0.00499	-0.0265	0.0422
	(0.441)	(0.109)	(0.00267)	(0.0168)	(0.0846)	(0.0922)
Observations	394488	386236	386236	386236	394488	394488
Mean of Outcome	72.3	4.780	0.095	0.505	4.868	0.230

Evidence of Spillovers

- EHR vendor switch decision of one hospital may affect patient flow decisions of many other hospitals due to network nature of industry
  - If h switches to the same vendor as h', could affect number of patients h' transfers to h as well as subsequently number of patients h' transfers to h''
  - Former (h' to h) is a treated pair due to positive change in same-vendor status
  - Latter (h' to h'') is a control pair; any change due to treatment is SUTVA violation

- Unfortunately, no "pure" controls in our setting (i.e., no markets with no treated pairs)

- To show potential for spillovers, estimate diff-in-diff at hospital sender-receiver-year level with two independent variables: leave-out local market share of vendor used by sender h in year t, leave-out local market share of vendor used by receiver h' in year t
  - Limit sample to "never treated" (i.e., pairs that never have the same vendor)

Evidence of Spillovers

While each hospital pair never shares same vendor, the decisions of other hospitals in their markets (which determine vendor market shares) affect their patient flows.

	(1)	(2)	(3)	(4)	(5)
Panel A: # of Referrals					
Sender's Vendor Market Share	2.592	3.147	4.614*	4.614	0.0949
	(2.652)	(2.572)	(2.678)	(3.981)	(4.905)
Receiver's Vendor Market Share	15.68***	15.20***	8.611***	8.611**	13.83***
	(2.216)	(2.097)	(1.966)	(3.436)	(4.103)
Observations	1131337	1131337	1109715	1109715	343094
Mean of Outcome	42.00	42.00	42.00	42.00	42.00
Panel B: Fraction of Referrals					
Sender's Vendor Market Share	-0.00223***	-0.00214***	-0.00135**	-0.00135*	-0.00182
	(0.000543)	(0.000542)	(0.000565)	(0.000716)	(0.00119)
Receiver's Vendor Market Share	0.00323***	0.00299***	0.00316***	0.00316***	0.00598***
	(0.000547)	(0.000544)	(0.000589)	(0.000999)	(0.00131)
Observations	1115280	1115280	1093982	1093982	337726
Mean of Outcome	0.016	0.016	0.016	0.016	0.016
Sample	Event	Event	Event	Event	Event
Hospital Covariates		X	X	X	X
Market x Year FEs			X	X	X
Drop System Switchers					X
Level of Cluster	Pair	Pair	Pair	HRR	Pair

Back

Model of Patient Flows

back

Hospital h in market m has a patient p whom it must transfer

h chooses which $h' \in m$ to send p in order to maximize expected utility:

Model of Patient Flows

back

Hospital h in market m has a patient p whom it must transfer

h chooses which $h' \in m$ to send p in order to maximize expected utility:

$$\begin{aligned} u_{hh'pt} = {} & \theta_1 \iota_{e_{ht}, e_{h't}, t} + \theta_2 \mathbf{1}_{hh' \text{ same sys}} + \theta_3 d_{hh'} + \xi_{h'} \\ & + \xi_h + \xi_{mt} + \nu_{hh't} + \bar{\epsilon}_{hn_h(h')pt} + (1-\rho)\bar{\epsilon}_{hh'pt} \end{aligned}$$

- $\iota_{e_{ht}, e_{h't}, t}$ interoperability between EHR vendors e_{ht} and $e_{h't}$ at time t
- $\mathbf{1}_{hh' \text{ same sys}}$ indicator for whether h and h' always in same hospital system
- $d_{hh'}$ distance between h and h'
- two nests n: inside m, outside m

Model of Patient Flows

back

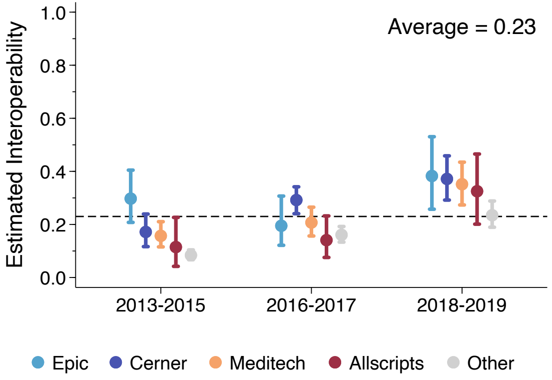
Hospital h in market m has a patient p whom it must transfer

h chooses which $h' \in m$ to send p in order to maximize expected utility:

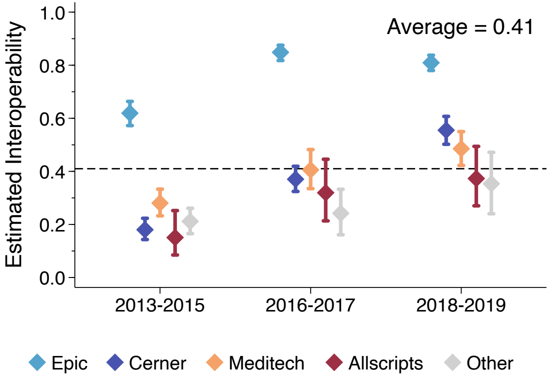
$$u_{hh'pt} = \theta_1 \iota_{e_{ht}, e_{h't}, t} + \theta_2 \mathbf{1}_{hh' \text{ same sys}} + \theta_3 d_{hh'} + \xi_{h'}$$
$$+ \xi_h + \xi_{mt} + \nu_{hh't} + \bar{\epsilon}_{hn_h(h')pt} + (1-\rho)\bar{\epsilon}_{hh'pt}$$

- $\iota_{e_{ht}, e_{h't}, t}$ interoperability between EHR vendors e_{ht} and $e_{h't}$ at time t
- $\mathbf{1}_{hh' \text{ same sys}}$ indicator for whether h and h' always in same hospital system
- $d_{hh'}$ distance between h and h'
- two nests n: inside m, outside m
- **Estimation**: (1) $\iota_{e_{ht}, e_{h't}, t}$ via decomp.; (2) nested logit via GMM system pressure IV

Estimates of Interoperability Levels



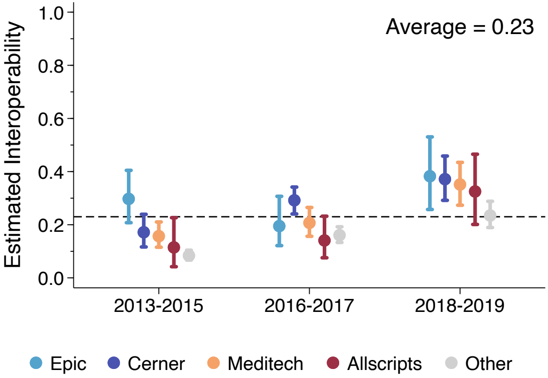
A. Across-Vendor



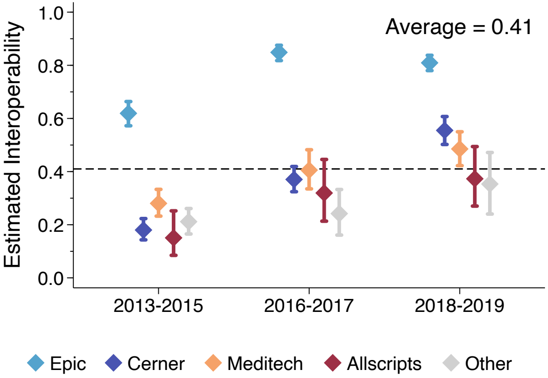
B. Within-Vendor

Estimates of Interoperability Levels

back annual static trend DiD estimates survey evidence



A. Across-Vendor

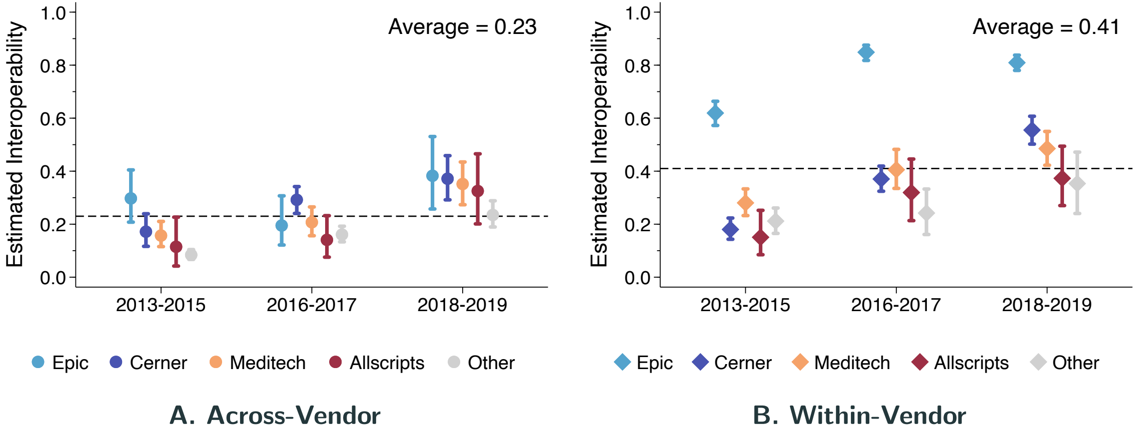


B. Within-Vendor

(1) within > across

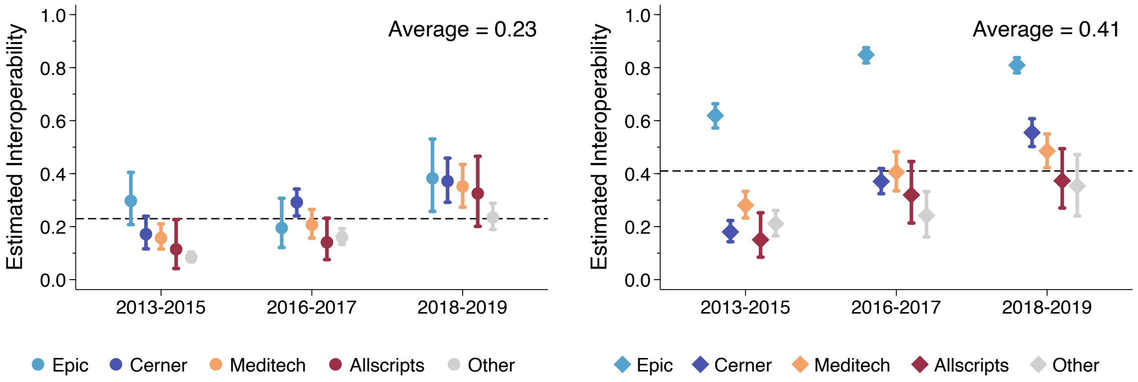
Estimates of Interoperability Levels

back annual static trend DiD estimates survey evidence



(1) within > across, (2) Epic highest within

Estimates of Interoperability Levels



A. Across-Vendor **B. Within-Vendor**

(1) within > across, (2) Epic highest within, (3) within increasing faster

Model Estimates

back | receiver FE predictors

	(1) **Baseline**	(2) **Pair FEs**
θ_1 (Interoperability)	0.283	0.788
	(0.071)	(0.112)
θ_2 (Always Same System)	0.384	
	(0.023)	
θ_3 (Distance)	-0.0043	
	(0.0002)	
ρ (Nest)	0.6	0.27
	(0.02)	(0.03)
Mean Interoperability Elasticity	0.141	0.23
Mean Distance Elasticity	-0.41	
Sender FE	Yes	
Receiver FE	Yes	
HRR $\times$ Year FE	Yes	Yes
Sender $\times$ Receiver FE		Yes

Interoperability elasticity positive, 34-56% of distance elasticity

Estimation of Interoperability Levels

- Each vendor has two interoperability levels: **within-vendor, across-vendor**
- Hospital interoperability ι_{ht} reported in AHA IT:

$$\iota_{ht} = \underbrace{\iota_{e_{ht}, e_{ht}, t}}_{\text{within}} r(ht, e_{ht}) + \underbrace{\iota_{e_{ht}, -e_{ht}, t}}_{\text{across}} (1 - r(ht, e_{ht})) + \epsilon_{ht}$$

  - $r(ht, e_{ht})$ fraction of patient flows h receives in t from other hospitals with same vendor
  - **idea:** if $r(ht, e_{ht}) = 1$, ι_{ht} represents how well e_{ht} integrates data received from e_{ht} users

Estimation of Interoperability Levels

$r(ht, e_{ht})$ heatmap details

- Each vendor has two interoperability levels: **within-vendor, across-vendor**

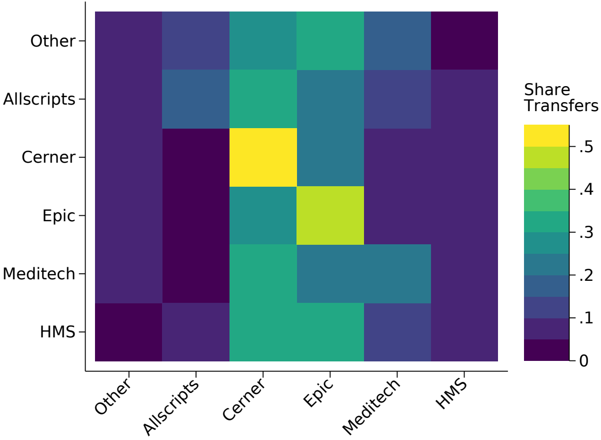
- Hospital interoperability ι_{ht} reported in AHA IT:

$$\iota_{ht} = \underbrace{\iota_{e_{ht},e_{ht},t}}_{\text{within}} r(ht, e_{ht}) + \underbrace{\iota_{e_{ht},-e_{ht},t}}_{\text{across}} (1 - r(ht, e_{ht})) + \epsilon_{ht}$$

  - $r(ht, e_{ht})$ fraction of patient flows h receives in t from other hospitals with same vendor
  - **idea:** if $r(ht, e_{ht}) = 1$, ι_{ht} represents how well e_{ht} integrates data received from e_{ht} users

- Estimation:
  - instrument for $r(ht, e_{ht})$ using share of hospital beds in market m_h in year t who also use e_{ht}
    - $r(ht, e_{ht})$ if h equally shared patients with all other hospitals in its market
  - use ordered probit with control function, bootstrap SEs *(Woolridge 2015)*

Patient Flows: Inpatient Transfers Vendor Heatmap (2017)



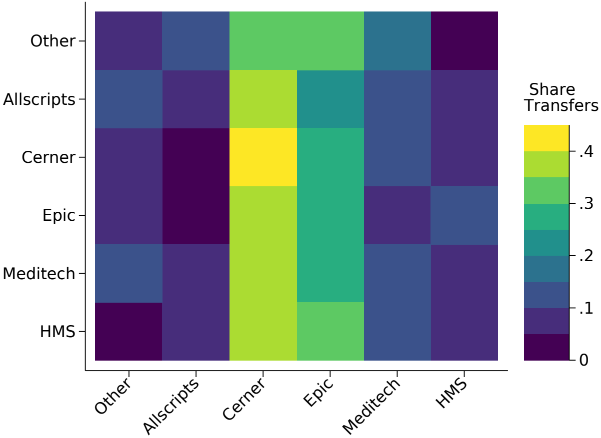
Back

Outside of Hospital Network

Deviation from Random

Hospitals more likely to send patients to other hospitals with same EHR vendor; suggestive of interoperability's role in direction of patient flows

Patient Flows: Inpatient Transfers Vendor Heatmap (2017) - Out of Network



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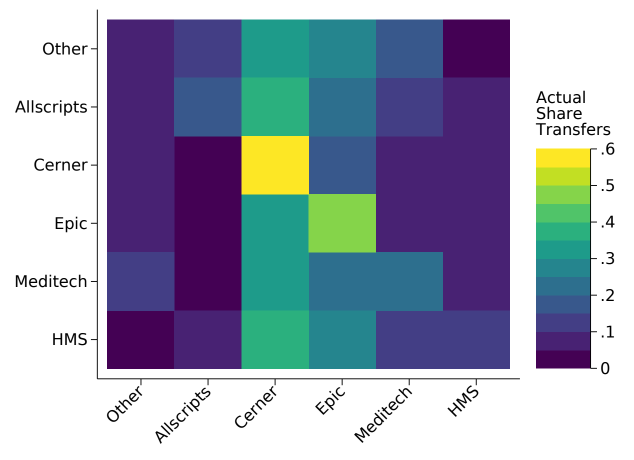
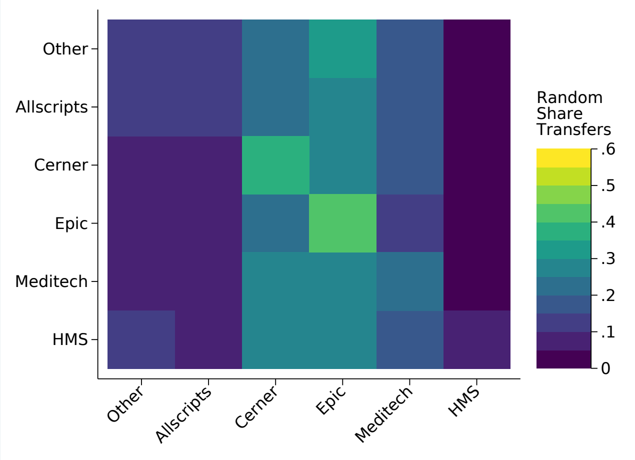
Patient Flows: Inpatient Transfers Vendor Heatmap (2017) - Deviations



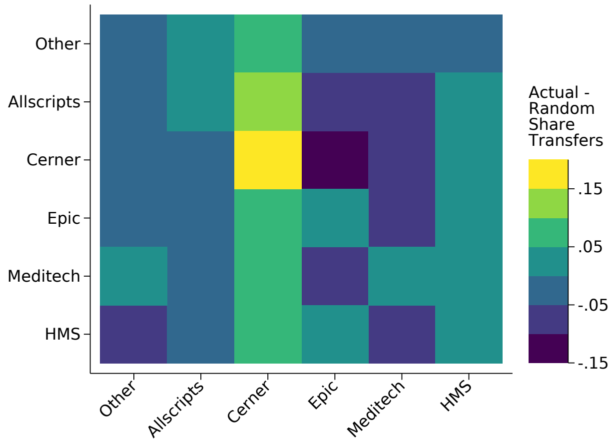
Actual (limited to within HRR)

Patient Flows: Inpatient Transfers Vendor Heatmap (2017) - Deviations



Random

Patient Flows: Inpatient Transfers Vendor Heatmap (2017) - Deviations



Deviations from Random

Back

Estimation Part 1: $\iota_{e_{ht}, e_{h't}}$ - Details

- ι_{ht} is answer to question: *"Does your EHR integrate the information contained in the summary of care records received electronically without the need for manual entry?"*
  - 3 response options: "yes, routinely", "yes, but not routinely", "no"

- Due to categorical responses, estimate decomposition using ordered probit model:

$$\iota_{ht} = \alpha\, r(ht, e_{ht}) + \beta\, \mathrm{RHIO}_{ht,mt} + \epsilon_{ht},$$

  - $\mathrm{RHIO}_{ht,mt}$: share of local beds participating in regional HIO in t if h participates
  - allow for heterogeneity by adding indicators for four major vendors $\times$ 3 time periods and interactions of these indicators with $r(ht, e_{ht})$ and z_{ht}
  - instrument with z_{ht} = share of hospital beds in market m_h in year t who also use e_{ht}
    - $r(ht, e_{ht})$ if h equally shared its patients with all other hospitals in its market
    - standard 2 step estimation *(Woolridge 2015)*

Estimation Part 1: $\iota_{e_{ht},e_{h't}}$ - Details

Back

- Two step estimation *(Woolridge 2015)*:
  - Step 1: estimate control function

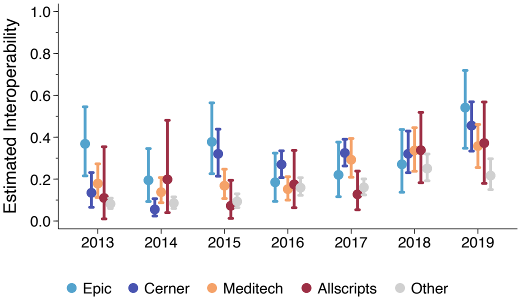
$$r(ht, e_{ht}) = \theta_1 z_{ht} + \theta_2 \text{RHIO}_{ht,mt} + \eta_{ht}$$

  - Retain residuals $\hat{\eta}_{ht}$
  - Step 2: estimate decomposition model using ordered probit with $\gamma(z_{ht}) = \hat{\eta}_{ht}$

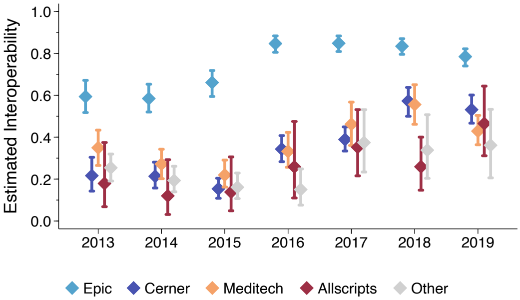
$$\iota_{ht} = \alpha\, r(ht, e_{ht}) + \beta\, \text{RHIO}_{ht,mt} + \gamma(z_{ht}) + \epsilon_{ht}$$

  - Ultimately yields estimates of $\iota_{e_{ht},e_{ht}}$ and $\iota_{e_{ht},-e_{ht}} \in [0, 1]$

Estimates of Interoperability Levels by Year



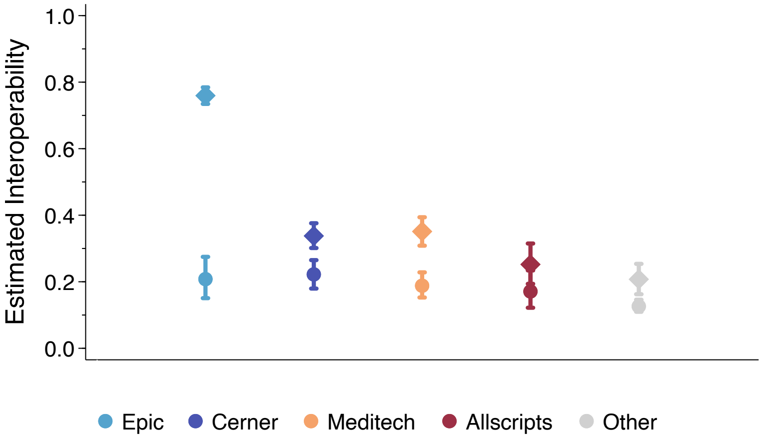
A. Across-Vendor



B. Within-Vendor

Static Interoperability Levels

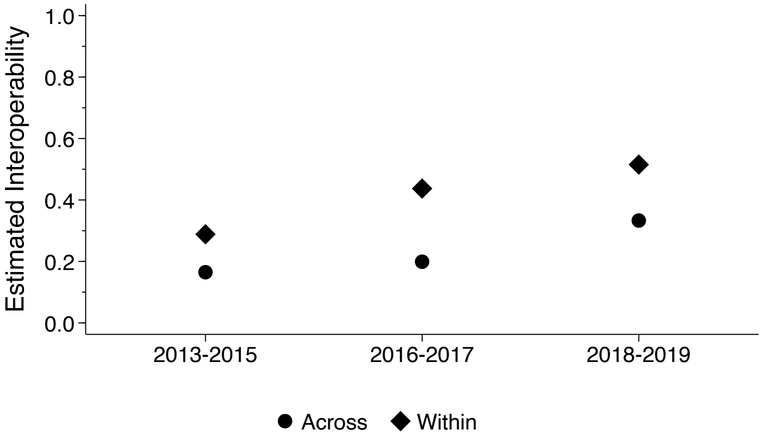
Back



(1) within > across for all vendors

Estimates of Interoperability Levels: Average by Year

Back



(3) within increasing more over time

Diff-in-Diff using Interoperability Levels vs. Same-Vendor Indicator

	(1)	(2)	(3)	(4)	(5)	(6)
			Panel A: # of Transfers			
Same EHR Vendor	0.182**			0.0531		
	(0.0826)			(0.0736)		
Time-Invariant Interoperability		0.475***			0.502***	
		(0.170)			(0.141)	
Time-Varying Interoperability			0.360***			0.561***
			(0.123)			(0.108)
Observations	550991	550991	550991	737113	737113	737113
Mean of Outcome	3.76	3.76	3.76	4.30	4.30	4.30
			Panel B: Fraction of Transfers			
Same EHR Vendor	0.00142*			0.000895		
	(0.000802)			(0.000684)		
Time-Invariant Interoperability		0.00354**			0.00330***	
		(0.00167)			(0.00125)	
Time-Varying Interoperability			0.00249**			0.00348***
			(0.00121)			(0.000976)
Observations	517068	517068	517068	693838	693838	693838
Mean of Outcome	0.0477	0.0477	0.0477	0.0512	0.0512	0.0512
Sample	Event	Event	Event	Full	Full	Full

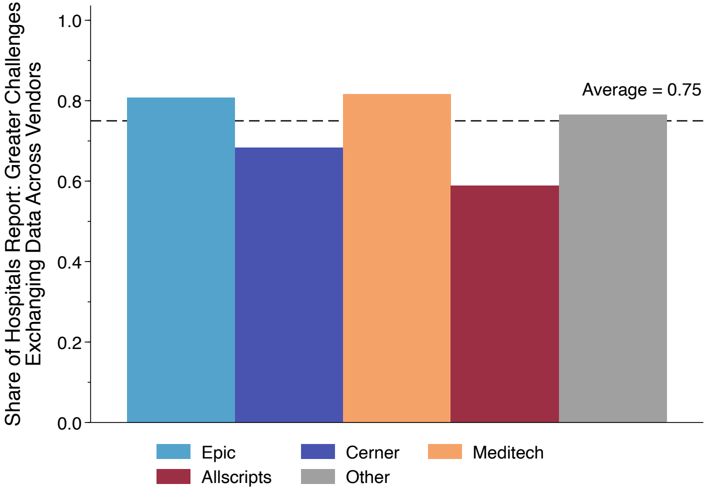
Diff-in-Diff using Interoperability Levels vs. Same-Vendor Indicator

Back

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: # of Referrals						
Same EHR Vendor	1.613**			1.481*		
	(0.812)			(0.811)		
Time-Invariant Interoperability		3.209**			4.095***	
		(1.603)			(1.476)	
Time-Varying Interoperability			2.104*			3.217***
			(1.269)			(1.228)
Observations	856812	856812	856812	1133829	1133829	1133829
Mean of Outcome	43.32	43.32	43.32	52.27	52.27	52.27
Panel B: Fraction of Referrals						
Same EHR Vendor	0.000432**			0.000220		
	(0.000193)			(0.000181)		
Time-Invariant Interoperability		0.000838**			0.000988***	
		(0.000373)			(0.000314)	
Time-Varying Interoperability			0.00100***			0.00132***
			(0.000303)			(0.000264)
Observations	841573	841573	841573	1113803	1113803	1113803
Mean of Outcome	0.0171	0.0171	0.0171	0.0192	0.0192	0.0192
Sample	Event	Event	Event	Full	Full	Full

Survey Evidence Supporting Interoperability Levels

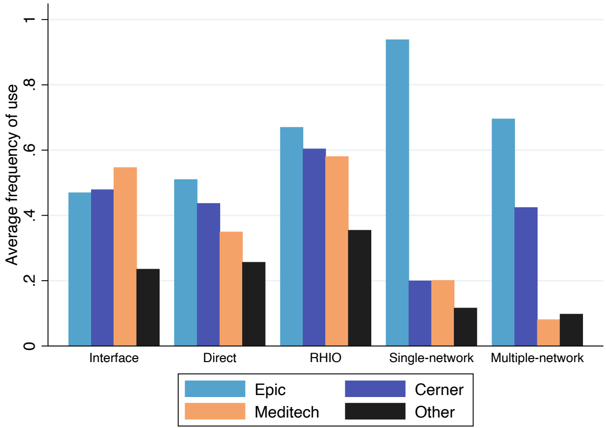
Back



Hospitals using all vendors report greater challenges exchanging across vendors

Survey Evidence Supporting Interoperability Levels

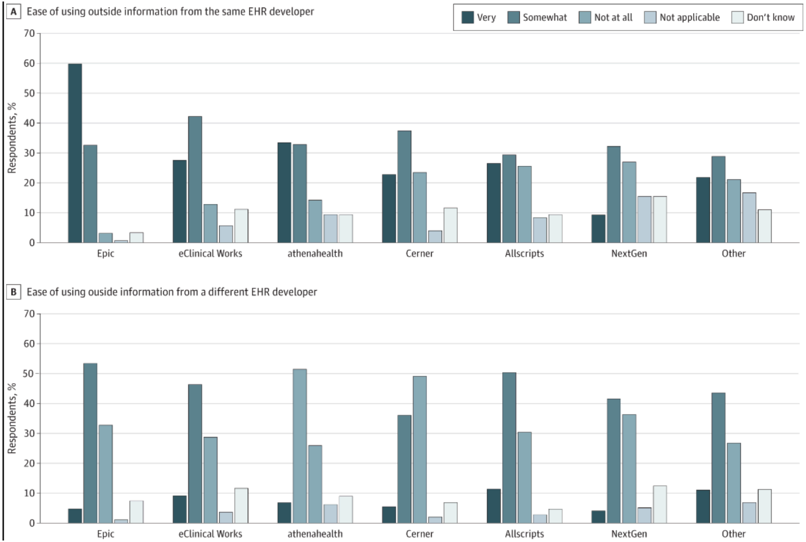
Back



Epic hospitals most likely to use single-vendor network (Care Everywhere)

Survey Evidence Supporting Interoperability Levels

Back



(Everson et al. 2024)

What Goes into Model Receiver FEs

Back

	(1) Receiver FEs
Beds (SD)	0.0980***
	(0.00115)
30 Day Death (SD)	-0.0479***
	(0.000822)
30 Day Readmit (SD)	-0.0773***
	(0.000898)
Charges (SD)	0.0442***
	(0.00103)
In Any System	0.0463***
	(0.00223)
AMC	-0.0131***
	(0.00206)
Trauma Center	0.0377***
	(0.00217)
Cardiac Intensive Care Unit	0.120***
	(0.00235)
Adult Diagnostic Cath Unit	0.0500***
	(0.00295)
Oncology Unit	0.0620***
	(0.00319)
Observations	126294

Full Interoperability Counterfactual - Intensive Patients

Back

Counterfactual	%Δ Total Welfare	Δ Total Welfare (-km)	=	Δ Direct Welfare (-km)	+	Δ Allocative Welfare (-km)	Share Switch
First-Best Full Interop. (All = 1)	20.3%	71.6		71.2		0.4	0.02
Epic Monopoly (All Epic)	12.5%	44.2		43.8		0.4	0.02

Full Interoperability Counterfactual - Extensive Patients

Back

Counterfactual	%Δ Total Welfare	Δ Total Welfare (-km)	$=$	Δ Direct Welfare (-km)	$+$	Δ Allocative Welfare (-km)	Share Switch
First-Best Full Interop. (All $=$ 1)	∞ %	9.9		0.0		9.9	0.245
Epic Monopoly (All Epic)	∞ %	4.3		0.0		4.3	0.157

Full Interoperability Counterfactual: Effects on Patients

Back

	Average Δ Receiver Hospital Characteristics			
	(1)	(2)	(3)	(4)
	Distance (km)	Charges	30 Day Readmit	30 Day Death
First-Best Full Interop. (All $=$ 1)	0.536	-961.4	-0.028	-0.016
Mean of Outcome	27.7	63,388	0.308	0.093

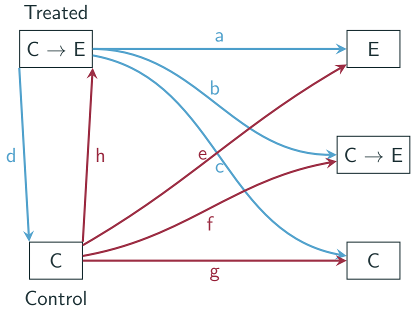
Patient switchers are sent farther away but to cheaper, better-quality hospitals

Hospital-Level Flows Analysis: Mechanical Bias

Back

$$Y_{ht} = \beta_1 \mathbf{1}_{\text{Post-Switch}_{ht}} + \alpha_h + \gamma_t + \delta X_{ht,mt} + \epsilon_{ht}$$

- Y_{ht}: fraction of patients h sends to others with h's post-switch EHR vendor in year t
- $\mathbf{1}_{\text{Post-Switch}_{ht}}$: whether h has yet switched vendors in year t

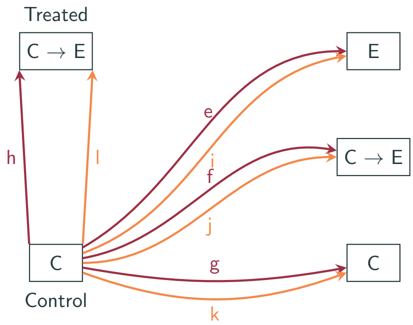


- Let $a + b + c + d = x$
- Let $e + f + g + h = y$
- Assume 2 time periods t
- Assume no Δ transfer patterns from $t = 1$ to $t = 2$
- $\Delta Y_{treated} = \frac{a+b}{x} - \frac{a}{x} = \frac{b}{x}$
- $\Delta Y_{control} = \frac{g}{y} - \frac{f+g+h}{y} = -\frac{f+h}{y}$
- $\text{DiD} = \frac{b}{x} + \frac{f+h}{y} > 0$

Hospital-Level Flows Analysis: Spillovers

Back

- Remove mechanical bias by defining all hospitals by their first observed vendor, from the perspective of all other hospitals
  - e.g., treated hospital has C for all years from POV of other hospitals



- Let $y = e + f + g + h = i + j + k + l$
- Assume 2 time periods
- Assume no Δ transfers sent from treated (no arrows)
- Assume Δ transfers sent from control; $t = 1$, $t = 2$
- $\Delta Y_{treated} = 0$
- $\Delta Y_{control} = \frac{j+k+l}{y} - \frac{f+g+h}{y}$
- $\text{DiD} = \frac{f+g+h}{y} - \frac{j+k+l}{y}$
  - > 0 if control sends fewer to "same vendor"
  - < 0 if control sends more to "same vendor"