

Alternative Payment Models and Hospital Engagement in Health Information Exchange

Sunny C. Lin, MS; John M. Hollingsworth, MD, MS; and Julia Adler-Milstein, PhD

Failures in information sharing between hospitals and postacute care providers following hospital discharge can result in higher-cost, lower-quality care.¹⁻³ Electronic health information exchange (HIE) can improve the accessibility of information during hospital discharges, leading to cost savings and better outcomes.^{4,5} However, volume-based reimbursement does not create incentives for provider organizations to engage in HIE.⁴⁻⁸ Medicare's alternative payment models (APMs) are expected to change this dynamic: By rewarding hospitals for improving the quality and cost-efficiency of care received across the care continuum, APMs create financial incentives for hospitals to engage in greater HIE.⁹ However, even under APMs, significant barriers, such as lack of technical standards across electronic health record (EHR) products, poor usability of HIE solutions, concerns about data security, and potential loss of profitable fee-for-service patients to competitors, may impede hospital pursuit of HIE.^{4,10}

If hospitals participating in APMs are not engaging in greater HIE, it is an ominous sign about the potential for HIE growth, as it suggests that even aligned financial incentives are not strong enough to overcome these barriers. It is therefore important to not only assess whether APM participation is associated with greater hospital HIE, but to do so in a way that reflects the multiple ways that HIE can generate value under APMs. Given that avoiding hospital readmissions is a core performance metric under APMs, improving HIE between hospitals and postacute care providers is likely to be a prioritized use case for HIE.

The extent of hospital HIE engagement with postacute care can be measured along 4 dimensions: volume, diversity, breadth, and depth.¹¹ Volume refers to the proportion of discharged patients for whom data are transmitted electronically. Diversity refers to the types of data that are transmitted electronically. Breadth refers to the types of trading partners to whom data are electronically transmitted. Finally, depth refers to the nature of the technical approach through which data are transmitted (ie, push and/or pull).

Prior research on the association between APMs and HIE suggests that HIE is perceived as valuable to the achievement of financial rewards under APMs.¹²⁻¹⁴ However, these studies have

ABSTRACT

OBJECTIVES: To assess whether hospital participation in alternative payment models (APMs) is associated with greater engagement in health information exchange (HIE) along 4 dimensions: volume of patients for whom information is exchanged, diversity of information types, breadth of partner types, and depth of technical approach.

STUDY DESIGN: Pooled, cross-sectional analysis of data on US hospitals from 2014 to 2015.

METHODS: APM participation came from Leavitt Partners data, Medicare public use files, and the American Hospital Association (AHA) Annual Survey. We used Medicare data to measure HIE volume for 798 hospitals attesting to stage 2 Meaningful Use and the AHA Information Technology Supplement to measure HIE diversity, breadth, and depth for 1730 hospitals. We used mixed-effects regression to estimate the association between participation in APMs and each dimension of HIE.

RESULTS: Compared with nonparticipating hospitals, full-year APM participation was associated with lower HIE volume (data were sent for 11 percentage points fewer discharges; $P = .003$), greater HIE diversity (of 4 data types, 0.3 more were transmitted; $P < .001$), greater HIE breadth (of 3 partner types, data were sent to 0.3 more; $P < .001$), and greater HIE depth (the odds of using a push and pull approach were 1.68 times greater; $P = .004$).

CONCLUSIONS: Our finding that APM participation was associated with greater HIE diversity, breadth, and depth suggests that value-based payment may be spurring improvements in HIE infrastructure. However, our finding that APM participation is associated with lower HIE volume suggests that there may be an incentive to focus HIE investments on a limited number of partners.

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TAKEAWAY POINTS

Under alternative payment models (APMs), hospitals are incentivized to improve health information exchange (HIE) engagement in order to facilitate better healthcare quality and reduce cost. However, even under value-based reimbursement, substantial challenges to improving HIE may still remain.

- ▶ Hospital participation in APMs was associated with greater engagement in 3 of 4 HIE dimensions: diversity of data types, breadth of partner types, and depth of exchange approach.
- ▶ APM participation was associated with lower HIE volume.
- ▶ Our work suggests that under value-based reimbursement, indirect incentives may improve HIE infrastructure, but hospitals may be limiting HIE efforts to a few partner-specific connections, resulting in lower overall HIE volume.

not systematically examined whether hospitals in APMs engage in greater HIE or whether HIE efforts focus specifically on supporting care coordination following discharges.

To assess whether participation in APMs is associated with greater HIE engagement with postacute care providers along 4 dimensions (volume, diversity, breadth, and depth), we used mixed-effects regression analysis on data on US hospitals from 2014 to 2015. We defined APM participation as the proportion of the calendar year that a hospital participated in at least 1 of the following programs: Medicare or commercial accountable care organizations (ACOs), the Medicare Bundled Payments for Care Improvement (BPCI) initiative, and any type of medical home. Results from this study are critical to informing policy efforts aimed at improving interorganizational care coordination—a national policy priority. In particular, this work sheds light on challenges that may exist in reaching that goal through greater HIE under value-based incentives, such as those initiated under the Medicare Access and CHIP Reauthorization Act of 2015 (MACRA).

METHODS

Setting and Data Sources

The study population includes all nonfederal acute care hospitals in the continental United States with HIE data for at least 1 year of the study period. Data for this study came from the Leavitt Partners ACO database (current as of 2016), 2014–2015 Medicare BPCI public use file, 2014–2015 American Hospital Association (AHA) Annual Survey, 2014–2015 Meaningful Use public use file, and 2017 Area Health Resource File.

Hospital Participation in APMs

Under MACRA, hospitals can participate in APMs that provide value-based incentives for hospitals to engage in HIE. With APM participation, hospitals are held accountable for the cost and quality of care provided by their outpatient partners. APMs include ACOs, the BPCI program, and medical homes. ACOs offer shared savings to participating hospitals if per-patient spending is lower than a targeted amount. The BPCI program bundles inpatient and outpatient services into single episodes of care. Lastly, hospitals

can participate in medical homes as part of their hospital-based ambulatory care practices. Medical homes provide performance-based rewards, along with per-member-per-month fees for care management.¹⁵

Measures

Independent variable: APM participation.

We measured hospital participation in APMs by calculating the portion of the calendar year in which a hospital participated in any APM (a Medicare or commercial ACO, phase 2 of any BPCI model, and/or a medical home).

ACO start dates for all ACOs formed as of 2016 were obtained from Leavitt Partners on Medicare or commercial ACO participation. Quarterly participation in BPCI was obtained from the Medicare public use file. Medical home participation was obtained from the AHA survey; because start and end dates were unavailable, we assumed full calendar year participation.

Dependent variables: 4 dimensions of HIE. Drawing on a framework developed by Massetti and Zmud, we measured HIE engagement along 4 dimensions: volume, diversity, breadth, and depth.¹¹

We measured volume as the proportion of discharged patients for whom summary of care records (SCRs) were sent electronically during a hospital's stage 2 Meaningful Use attestation period. (For more on this measure and methodology, refer to Lin et al.⁴) Data on this measure came from the Medicare Meaningful Use public use file.

Following prior work,^{16,17} we measured diversity as the number of data types (ie, structured SCRs, radiology results, laboratory results, and medical history) that are routinely sent electronically by a hospital to ambulatory providers outside its system.

Breadth indicates how successful a hospital is at creating and maintaining connections with a variety of partners. Following prior work,¹⁶ we measured breadth as the number of partner types (ie, out-of-system ambulatory care providers, long-term care providers, and behavioral health providers) to which a hospital routinely sends structured SCRs.

We measured depth by assessing whether or not a hospital routinely transmits SCRs using either push or pull, or both approaches. In the push approach, patient data are directly sent to another electronic system, whereas the pull approach aggregates data from multiple sources into a database that a provider can query. Hospitals that used neither push nor pull (eg, eFax, mail, or fax) were dropped from the analysis. Both push and pull approaches are useful for care coordination; however, the availability of both approaches is associated with greater provider satisfaction and higher use.^{18–20} A hospital was considered as using a push approach if it used secure messaging to routinely transmit SCRs and a pull approach if it used patient portals or Epic's Care Everywhere HIE platform (ie, the hospital reported using Epic as their primary inpatient EHR vendor and using a third party to routinely transmit SCRs) to routinely transmit SCRs. Data on HIE diversity, breadth,

and depth came from the AHA Information Technology Supplement.

Control variables. To control for potential confounding, we included controls that could be associated with both HIE engagement and APM participation: hospital size, urbanicity, teaching status, system membership, network membership, ownership, disproportionate share hospital (DSH) percentage, case mix index, critical access hospital status, and market share from the AHA Annual Survey and the Medicare Impact File.^{4,5,21,22} To control for confounding that may arise from the number of trading partners, we included the number of skilled nursing facilities (SNFs), hospitals, and primary care providers (PCPs) in the county from the Area Health Resource File. Missing controls for a given year were imputed using forward, then backward, imputation. If no data were available on 1 or more control variables, the hospital was dropped.

Analytic Approach: Design and Statistical Analysis

Using hospital-year data from 2014 to 2015, we used mixed-effects models regressing each dimension of HIE engagement on APM participation and controls; we included hospital mixed effects to control for unobserved heterogeneity over time and across hospitals, year fixed effects to control for temporal effects, and hospital-clustered standard errors to account for serial correlation. For our models of HIE volume, diversity, and breadth, we used linear regression; for our model of HIE depth, we used logistic regression.

Four sensitivity analyses were conducted: (1) To test whether our results were driven by concurrent participation in multiple APM types, we reran our analyses including the number of APM types in which a hospital participated; (2) To test whether participation in different APM types had different associations with HIE, we reran our analyses using a 3-way interaction term interacting participation in each of the 3 APM types in any given year; (3) To test whether using linear regression resulted in overestimated effect sizes, we reran the diversity and breadth models using negative binomial models; and (4) To test the sensitivity of our volume analysis to sample selection bias, we ran a Heckman model.

RESULTS

Of 6101 hospitals in the AHA Annual Survey Database from 2014 to 2015, we dropped 1537 noncontinental federal hospitals. Of the remaining 4564 hospitals, 2233 had data on all control variables.

TABLE. Descriptive Statistics for Hospitals in Samples

	Hospitals With Data on Volume (n = 798)	Hospitals With Data on Diversity and Breadth (n = 1730)	Hospitals With Data on Depth (n = 1427)
	n (%)	n (%)	n (%)
APM participation*			
Ever in ACO	728 (91%)	696 (40%)	605 (42%)
Ever in BPCI	152 (19%)	222 (13%)	196 (14%)
Ever in medical home	390 (49%)	604 (35%)	540 (38%)
Any APM participation*			
Ever participated in any APM	766 (96%)	980 (57%)	856 (60%)
Never participated	32 (4%)	750 (43%)	571 (40%)
Size			
<100 beds	183 (23%)	576 (33%)	434 (30%)
100-399 beds	457 (57%)	903 (52%)	762 (53%)
≥400 beds	158 (20%)	251 (15%)	231 (16%)
Urbanicity			
Large urban	433 (54%)	732 (42%)	613 (43%)
Other urban	249 (31%)	575 (33%)	486 (34%)
Rural	116 (15%)	423 (24%)	328 (23%)
Teaching			
Nonteaching	300 (38%)	814 (47%)	636 (45%)
Major	111 (14%)	171 (10%)	158 (11%)
Minor	387 (49%)	745 (43%)	633 (44%)
System membership			
Not in system	136 (17%)	520 (30%)	425 (30%)
In system	662 (83%)	1210 (70%)	1002 (70%)
Ownership			
Government	80 (10%)	243 (14%)	191 (13%)
Nonprofit	659 (83%)	1218 (70%)	1040 (73%)
For profit	59 (7%)	269 (16%)	196 (14%)

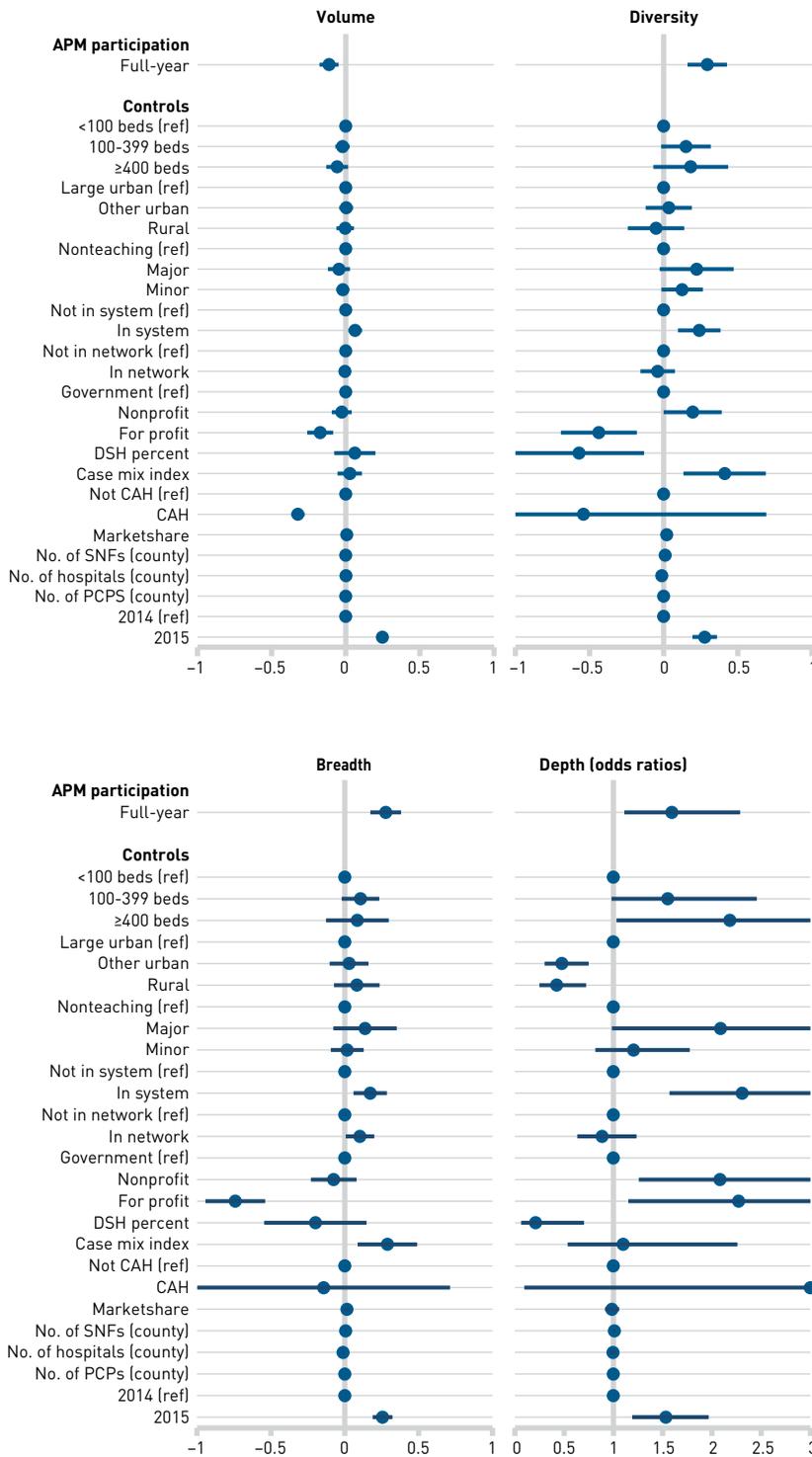
ACO indicates accountable care organization; APM, alternative payment model; BPCI, Bundled Payments for Care Improvement.

*Ever/never participation as of 2015.

Of those, 798 had at least 1 year of data on HIE volume (397 had 1 year and 401 had 2 years) and were included in our sample for HIE volume analysis. There were 1730 hospitals that had at least 1 year of data on HIE diversity and breadth (550 had 1 year and 1180 had 2 years) and were included in our sample for those analyses. There were 1427 hospitals that had at least 1 year of data on HIE depth and used push and/or pull to transmit SCRs electronically (662 had 1 year and 765 had 2 years); these hospitals were included in our sample for HIE depth analysis (Table).

Hospitals in our samples differed in important ways from hospitals that were missing HIE data (eAppendix Table 1 [eAppendix available at ajmc.com]). Hospitals in all 3 samples were more likely to participate in APMs. They were also more likely to be nonprofit; to be in hospital networks; to be larger, urban, teaching hospitals; to have a higher case mix index and higher market share; and to be in counties with more SNFs and PCPs.

FIGURE 1. Regression Results: Adjusted Association Between APM Participation and Dimensions of HIE Engagement*



APM indicates alternative payment model; CAH, critical access hospital; DSH, disproportionate share hospital; HIE, health information exchange; PCP, primary care provider; ref, reference; SNF, skilled nursing facility.

*All models include hospital mixed effects and year fixed effects. Circles indicate effect size estimates and lines indicate 95% CIs; depth analysis presented as odds ratios.

Unadjusted bivariate analyses revealed that, compared with nonparticipating hospitals, hospitals participating in APMs for any portion of the calendar year engaged in greater HIE on all dimensions except volume (eAppendix Figure 1). The average value of HIE volume was 53% among nonparticipating and 48% among participating hospitals. The average value of HIE diversity was 2.4 data types among nonparticipating and 3.1 data types among participating hospitals. The average value of HIE breadth was 1.2 partner types among nonparticipating and 1.8 partner types among participating hospitals. Of the subsample of hospitals that used push and/or pull approaches, the percentage of hospitals that used both push and pull approaches was 54% among nonparticipating and 69% among participating hospitals.

After adjusting for controls and hospital-specific trends, full-year APM participation was associated with a -11 percentage point difference in HIE volume (21% fewer discharges than nonparticipating hospitals; $P = .001$), a difference of 0.31 data types in HIE diversity (13% more data types than nonparticipating hospitals; $P < .001$), a difference of 0.29 partner types in HIE breadth (24% more partner types than nonparticipating hospitals; $P < .001$), and greater HIE depth (the odds of using both push and pull approaches were 1.68 times greater in participating than nonparticipating hospitals; $P = .004$) (Figure 1 and eAppendix Table 2).

To make these results more interpretable, the adjusted predicted 2015 values for each HIE dimension for a common hospital type (medium-sized, urban, nonteaching, nonsystem, nonnetwork, nonprofit, non-critical access hospital, with DSH percentage, case mix index, and market share held at their population means) are presented in Figure 2. The average predicted HIE volume for nonparticipating hospitals was 62% compared with 51% for hospitals participating for the full calendar year. The average predicted value for HIE diversity for nonparticipating hospitals was 2.8 data types compared with 3.1 data types for hospitals participating for the full calendar year. The adjusted predicted value for HIE breadth for nonparticipating hospitals was 1.4 partner types compared with 1.7 partner types for hospitals participating for the full calendar year. The probability of a nonparticipating hospital

using both push and pull approaches versus only 1 approach was 72% compared with 80% among hospitals participating for the full calendar year.

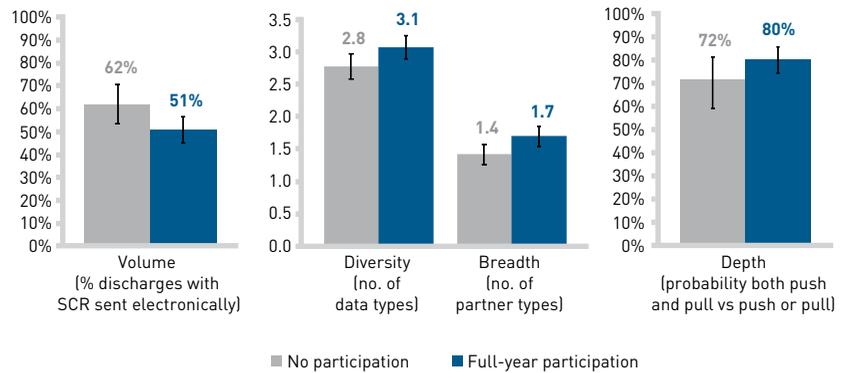
Sensitivity Analysis

Results from our first sensitivity analyses suggest that our main results were not driven by concurrent participation in multiple APM types (eAppendix Table 3). Results from our second sensitivity analysis suggest that the associations between APM participation types and dimensions of HIE access are similar to our main analysis (eAppendix Figure 2). For ease of comparison, we used the model with 3-way interactions to estimate 95% CIs for each dimension of HIE for each pattern of APM participation. We then compared these CIs with that of our main analysis in Figure 2. Each of the CIs overlapped, suggesting that the associations between APM participation and dimensions of HIE did not significantly vary by APM participation type. Results from our third sensitivity analysis suggest that effect sizes from the analyses of HIE diversity and breadth may be slightly overestimated as a result of using linear models. However, because we were unable to run the negative binomial models using hospital mixed effects, we present the results of the negative binomial models in eAppendix Table 4. Results from our final sensitivity analysis revealed evidence of moderate sample selection bias ($\text{athrho} = -0.42$; $P \leq .001$). However, because results were similar to our main results and we were unable to control for hospital mixed effects in the Heckman model, we present these results in eAppendix Table 5.

DISCUSSION

Using national data on US hospitals from 2014 to 2015, we found that hospital APM participation was associated with greater HIE accessibility along 3 dimensions: diversity (number of transmitted data types), breadth (number of exchange partner types), and depth (number of technical approaches). However, APM participation had a negative association with HIE volume (percent of discharges in which an SCR was transmitted electronically). This finding suggests that challenges exist to increasing utilization of HIE for all patients under value-based reimbursement. There are several possible explanations. First, unlike other dimensions of HIE accessibility, greater HIE volume requires process and workflow changes that depend on clinician involvement. It may be that hospitals that participate in APMs increase the burden on clinicians to engage in multiple quality improvement initiatives at once, resulting in change fatigue and poorer performance on HIE volume. Change fatigue may be exacerbated by modifications to health information technology structures, which may be occurring under APMs.^{12,13}

FIGURE 2. 2015 Predicted Performance on 4 Dimensions of Hospital HIE Engagement by APM Participation^a



APM indicates alternative payment model; HIE, health information exchange; SCR, summary of care record.

^aBased on 2015 predicted values for medium-sized, urban, nonteaching, nonsystem, nonnetwork, nonprofit, non-critical access hospitals, with disproportionate share hospital percentage, case mix index, and market share held at their population means. Predicted values shown in bars and 95% CIs shown in lines. 2015 predictions based on mixed-effects regression models controlling for hospital mixed effects, year fixed effects, and hospital characteristics.

Another explanation is that, under APMs, hospitals focus HIE efforts on a few partner-specific connections, resulting in overall decreases in HIE, especially if HIE partners are not also those with whom hospitals share the highest volume of patients. On the other hand, APM-participating hospitals may be focusing HIE efforts on high-cost or complex patients to prevent readmissions. Future research should examine how the number of HIE partners changes under APMs, as well as patient-level factors that predict HIE use and the relationship to quality measures such as readmission rates.

Our finding that APM participation is associated with greater HIE diversity, breadth, and depth suggests that value-based payment reform may be spurring investments in HIE infrastructure as hospitals strive to achieve performance-based incentives through information-driven care coordination improvements for discharged patients.²³ However, given the limitations of our cross-sectional design, we were unable to say with strong certainty whether these associations reflect a causal relationship. It is possible that instead of APM participation driving changes in HIE, hospitals that choose to join APMs are also those that exchange data for fewer patients and have more mature HIE systems. It will be important to continue monitoring HIE activities in APM-participating organizations in the future.

Our findings have important implications for policy makers. Prior efforts have primarily used direct incentives to promote HIE engagement through the Meaningful Use program. With the passage of the 21st Century Cures Act, efforts have shifted to developing interoperable infrastructures and reducing information blocking. This study suggests that indirect incentives, through the form of value-based payments, may be an effective driver of HIE infrastructure that can overcome competitive forces that drive information blocking, at least among the hospital population included in this study.^{22,24}

Our findings suggest that even under value-based reimbursement, challenges may exist to improving HIE use. We find that APM participation is associated with worse HIE volume, which may be because hospitals restrict HIE efforts to a limited number of affiliated partners. This suggests that policies should focus on promoting HIE connections among all partners, not just those with whom hospitals have a strategic reason to share information. For example, medical home accreditation programs currently require engagement in HIE, but not a specific threshold of engagement. Specifying a threshold based on patient volume may incentivize hospitals to improve overall interoperability rather than focus on partner-specific connections. Future studies should also examine whether APMs are promoting HIE connections with the most appropriate partners. Prior evidence suggests that although hospital HIE infrastructure is improving, these connections may not be serving the highest-volume partnerships.²⁵ On the other hand, APM-participating hospitals may be targeting HIE efforts toward high-cost or complex patients to prevent readmissions. Future research should also examine patient-level factors that predict HIE use.

Limitations

This study has important limitations. First, because measures of HIE were only available for 2014 to 2015, we were unable to use robust approaches to causal inference. Second, our measures of HIE dimensions do not take into account variation in other dimensions. For example, our measure of HIE breadth captures the number of partner types and not the number of partners within a single type with which a hospital shares information. It may be that hospitals only share information with a few partners of a specific type and we would not be able to detect this. Finally, because our analyses were restricted to hospitals with HIE data, hospitals in our sample differed from hospitals out of sample, limiting generalizability. Specifically, our sample for all models had a smaller proportion of smaller, rural, nonteaching, nonsystem, nonnetwork, or for-profit hospitals than hospitals out of sample (eAppendix Table 1). Therefore, our findings that APM participation is associated with lower HIE volume and higher HIE diversity, breadth, and depth may not apply to these hospitals. It will be important to assess whether our findings still hold for hospitals underrepresented in this study population.

CONCLUSIONS

Our study assesses the association between APM participation and HIE engagement along 4 important dimensions: volume of data exchange, diversity of data types, breadth of partner types, and depth of exchange approach. We find that APM participation is associated with lower HIE volume, but greater HIE diversity, breadth, and depth. This finding suggests that under value-based reimbursement, indirect incentives may improve HIE infrastructure, but significant challenges to achieving high HIE volume remain and may require more targeted policy actions. ■

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eAppendix Table 1. Descriptive Statistics for Hospitals In and Out of Sample

	Hospitals without Data on Volume	Hospitals with Data on Volume		Hospitals without Data on Diversity and Breadth	Hospitals with Data on Diversity and Breadth		Hospitals without Data on Depth	Hospitals with Data on Depth	
	No. (%)	No. (%)	<i>P</i>	No. (%)	No. (%)	<i>P</i>	No. (%)	No. (%)	<i>P</i>
APM Participation			<0.001			<0.001			<0.001
Never Participated	1004 (69.97%)	32 (4.01%)		286 (56.86%)	750 (43.35%)		465 (57.69%)	571 (40.01%)	
Ever in 1 APM Type	339 (23.62%)	359 (44.99%)		135 (26.84%)	563 (32.54%)		213 (26.43%)	485 (33.99%)	
Ever in 2 APM Types	90 (6.27%)	311 (38.97%)		59 (11.73%)	342 (19.77%)		99 (12.28%)	302 (21.16%)	
Ever in 3 APM Types	2 (0.14%)	96 (12.03%)		23 (4.57%)	75 (4.34%)		29 (3.6%)	69 (4.84%)	
Ever Participated	431 (30.03%)	766 (95.99%)		217 (43.14%)	980 (56.65%)		341 (42.31%)	856 (59.99%)	
Total (Never + Ever)	1435 (100%)	798 (100%)		503 (100%)	1730 (100%)		806 (100%)	1427 (100%)	
Size			<0.001			<0.001			<0.001
< 100 Beds	653 (45.51%)	183 (22.93%)		260 (51.69%)	576 (33.29%)		402 (49.88%)	434 (30.41%)	
100-399 beds	656 (45.71%)	457 (57.27%)		210 (41.75%)	903 (52.2%)		351 (43.55%)	762 (53.4%)	
400+ beds	126 (8.78%)	158 (19.8%)		33 (6.56%)	251 (14.51%)		53 (6.58%)	231 (16.19%)	
Total	1435 (100%)	798 (100%)		503 (100%)	1730 (100%)		806 (100%)	1427 (100%)	
Urbanicity			<0.001			0.001			0.001
Large Urban	482 (33.59%)	433 (54.26%)		183 (36.38%)	732 (42.31%)		302 (37.47%)	613 (42.96%)	
Other Urban	485 (33.8%)	249 (31.2%)		159 (31.61%)	575 (33.24%)		248 (30.77%)	486 (34.06%)	
Rural	468 (32.61%)	116 (14.54%)		161 (32.01%)	423 (24.45%)		256 (31.76%)	328 (22.99%)	
Total	1435 (100%)	798 (100%)		503 (100%)	1730 (100%)		806 (100%)	1427 (100%)	
Teaching			<0.001			<0.001			<0.001
Non-Teaching	820 (57.14%)	300 (37.59%)		306 (60.83%)	814 (47.05%)		484 (60.05%)	636 (44.57%)	
Major	73 (5.09%)	111 (13.91%)		13 (2.58%)	171 (9.88%)		26 (3.23%)	158 (11.07%)	
Minor	542 (37.77%)	387 (48.5%)		184 (36.58%)	745 (43.06%)		296 (36.72%)	633 (44.36%)	
Total	1435 (100%)	798 (100%)		503 (100%)	1730 (100%)		806 (100%)	1427 (100%)	
System Membership			<0.001			0.26			0.43
Not in System	542 (37.77%)	136 (17.04%)		158 (31.41%)	520 (30.06%)		253 (31.39%)	425 (29.78%)	
In System	893 (62.23%)	662 (82.96%)		345 (68.59%)	1210 (69.94%)		553 (68.61%)	1002 (70.22%)	
Total	1435 (100%)	798 (100%)		503 (100%)	1730 (100%)		806 (100%)	1427 (100%)	
Network Membership			<0.001			<0.001			<0.001
Not in Network	893 (62.23%)	330 (41.35%)		316 (62.82%)	907 (52.43%)		496 (61.54%)	727 (50.95%)	
In Network	542 (37.77%)	468 (58.65%)		187 (37.18%)	823 (47.57%)		310 (38.46%)	700 (49.05%)	
Total	1435 (100%)	798 (100%)		503 (100%)	1730 (100%)		806 (100%)	1427 (100%)	
Ownership			<0.001			<0.001			<0.001
Government	235 (16.38%)	80 (10.03%)		72 (14.31%)	243 (14.05%)		124 (15.38%)	191 (13.38%)	
Non-Profit	828 (57.7%)	659 (82.58%)		269 (53.48%)	1218 (70.4%)		447 (55.46%)	1040 (72.88%)	

For-Profit	372 (25.92%)	59 (7.39%)		162 (32.21%)	269 (15.55%)		235 (29.16%)	196 (13.74%)	
Total	1435 (100%)	798 (100%)		503 (100%)	1730 (100%)		806 (100%)	1427 (100%)	
	Average (SD)	Average (SD)		Average (SD)	Average (SD)				
DSH percent	0.27 (0.16)	0.27 (0.15)	0.007	0.25 (0.15)	0.27 (0.16)	0.018	0.27 (0.17)	0.27 (0.15)	0.89
Case Mix Index	1.47 (0.34)	1.58 (0.29)	<0.001	1.46 (0.36)	1.53 (0.32)	<0.001	1.45 (0.36)	1.55 (0.3)	<0.001
Marketshare	1.59 (2.34)	2.02 (2.56)	<0.001	1.27 (1.9)	1.88 (2.54)	<0.001	1.24 (1.86)	2.03 (2.65)	<0.001
No. of SNF Facilities (County)	17.8 (26.34)	29.98 (39.83)	<0.001	17.79 (26.35)	23.42 (33.8)	<0.001	17.98 (26.7)	24.52 (34.93)	<0.001
No. of Hospitals (County)	8.16 (12.7)	11.39 (14.81)	<0.001	8.57 (13.52)	9.53 (13.59)	0.161	8.34 (12.82)	9.86 (13.96)	0.110
No. of PCPs (County)	382 (660)	722 (1011)	<0.001	406 (678)	532 (854)	0.002	413 (692)	413 (692)	<0.001

eAppendix Table 2. Full Regression Results, Adjusted Association Between APM Participation and Dimensions of HIE Engagement

	(1)	(2)	(3)	(4)
	Volume	Diversity	Breadth	Depth
Full Year APM participation	-0.11***	0.31***	0.29***	1.68**
	(0.03)	(0.07)	(0.05)	(0.307)
Size (Ref: <100 beds)				
100-399 beds	-0.02	0.16	0.11	1.60*
	(0.02)	(0.09)	(0.07)	(0.376)
400+ beds	-0.06	0.20	0.10	2.28*
	(0.04)	(0.13)	(0.11)	(0.889)
Urban (Ref: Large Urban)				
Other Urban	0.00	0.04	0.03	0.48**
	(0.02)	(0.08)	(0.07)	(0.110)
Rural	-0.01	-0.07	0.07	0.41**
	(0.03)	(0.10)	(0.08)	(0.112)
Teaching (Ref: Non-Teaching)				
Major	-0.05	0.21	0.13	1.99
	(0.04)	(0.13)	(0.11)	(0.826)
Minor	-0.02	0.12	0.02	1.19
	(0.02)	(0.07)	(0.06)	(0.238)
System (Ref: Not in System)				
In System	0.05	0.20*	0.15*	2.27***
	(0.03)	(0.08)	(0.06)	(0.488)
Network (Ref: Not in Network)				
In Network	-0.00	-0.02	0.12*	0.93
	(0.02)	(0.06)	(0.05)	(0.159)
Ownership (Ref: Government)				
Non-Profit	-0.02	0.23*	-0.05	2.26**
	(0.03)	(0.10)	(0.08)	(0.561)
For-Profit	-0.16***	-0.38**	-0.70***	2.64**
	(0.04)	(0.13)	(0.10)	(0.910)
DSH percent	0.06	-0.56*	-0.19	0.21*
	(0.07)	(0.22)	(0.18)	(0.133)
Case Mix Index	0.02	0.40**	0.28**	1.05
	(0.04)	(0.14)	(0.10)	(0.398)
CAH Status (Ref: Not CAH)				
CAH	-0.33***	-0.53	-0.13	3.34
	(0.02)	(0.64)	(0.43)	(5.019)
Marketshare	0.01	0.02	0.02	0.99
	(0.00)	(0.01)	(0.01)	(0.037)
No. of SNF Facilities (County)	0	0.01***	0.01**	1.01
	(0.00)	(0.00)	(0.00)	(0.008)

No. of Hospitals (County)	0.00	-0.01*	-0.01**	1.00
	(0.00)	(0.01)	(0.00)	(0.015)
No. of PCPs (County)	-0.00	-0.00*	-0.00	1.00
	(0.00)	(0.00)	(0.00)	(0.000)
Year (Ref: 2014)				
2015	0.26***	0.34***	0.30***	1.97***
	(0.01)	(0.05)	(0.04)	(0.285)
N (Hospital-Year Obs)	1199.00	2906.00	2906.00	2192.00

Note: Hospital-clustered SE in Parentheses, all models contain hospital mixed effects and year fixed effects; depth effects presented as odds ratios

eAppendix Table 3. Sensitivity Analysis Full Regression Results, Participation in Multiple APM Types

	(1)	(2)	(3)	(1)
	Volume	Diversity	Breadth	Depth
Full Year Participation (Ref: No Participation)				
In 1 APM Type	-0.11** (0.034)	0.35*** (0.070)	0.32*** (0.057)	1.65** (0.323)
In 2 APM Types	-0.12*** (0.035)	0.24** (0.088)	0.23** (0.072)	1.71* (0.420)
In 3 APM Types	-0.04 (0.044)	0.12 (0.166)	0.21 (0.135)	2.05 (1.054)
Size (Ref: <100 beds)				
100-399 beds	-0.02 (0.026)	0.16* (0.082)	0.11 (0.066)	1.60* (0.376)
400+ beds	-0.06 (0.039)	0.21 (0.135)	0.10 (0.110)	2.26* (0.882)
Urban (Ref: Large Urban)				
Other Urban	0.00 (0.024)	0.03 (0.082)	0.03 (0.066)	0.48** (0.110)
Rural	-0.01 (0.032)	-0.07 (0.096)	0.07 (0.078)	0.41** (0.112)
Teaching (Ref: Non-Teaching)				
Major	-0.05 (0.037)	0.23 (0.138)	0.14 (0.112)	1.98 (0.822)
Minor	-0.02 (0.022)	0.13 (0.072)	0.02 (0.058)	1.19 (0.237)
System (Ref: Not in System)				
In System	0.04 (0.027)	0.20** (0.075)	0.15* (0.061)	2.26*** (0.485)
Network (Ref: Not in Network)				
In Network	-0.00 (0.018)	-0.01 (0.060)	0.12* (0.049)	0.93 (0.158)
Ownership (Ref: Government)				
Non-Profit	-0.02 (0.032)	0.23* (0.091)	-0.05 (0.074)	2.25** (0.560)
For-Profit	-0.16*** (0.045)	-0.38** (0.118)	-0.70*** (0.096)	2.65** (0.912)
DSH percent	0.07 (0.067)	-0.56** (0.207)	-0.19 (0.168)	0.21* (0.134)
Case Mix Index	0.02 (0.042)	0.41** (0.124)	0.28** (0.101)	1.04 (0.395)
CAH Status (Ref: Not CAH)				
CAH	-0.33 (0.274)	-0.54 (0.509)	-0.14 (0.413)	3.36 (5.046)
Marketshare	0.01 (0.004)	0.02 (0.014)	0.02 (0.012)	0.99 (0.037)
No. of SNF Facilities (County)	-0.00 (0.001)	0.01*** (0.003)	0.01* (0.002)	1.01 (0.008)
No. of Hospitals (County)	0.00 (0.002)	-0.01* (0.005)	-0.01** (0.004)	1.00 (0.015)
No. of PCPs (County)	-0.00 (0.000)	-0.0002* (0.000)	-0.00 (0.000)	1.00 (0.000)
Year (Ref: 2014)				

2015	0.25***	0.35***	0.31***	1.96***
	(0.017)	(0.048)	(0.039)	(0.284)
N (Hospital-Year Obs)	1199.00	2906.00	2906.00	2192.00

eAppendix Table 4. Sensitivity Analysis Full Regression Results, Negative Binomial Model

	(1)	(2)
	Diversity	Breadth
Full Year APM participation	0.12***	0.19***
	(0.026)	(0.035)
Size (Ref: <100 beds)		
100-399 beds	0.05	0.09*
	(0.034)	(0.045)
400+ beds	0.06	0.08
	(0.048)	(0.070)
Urban (Ref: Large Urban)		
Other Urban	0.02	0.01
	(0.029)	(0.042)
Rural	-0.02	0.05
	(0.038)	(0.051)
Teaching (Ref: Non-Teaching)		
Major	0.07	0.06
	(0.045)	(0.067)
Minor	0.05	0.02
	(0.027)	(0.037)
System (Ref: Not in System)		
In System	0.09**	0.12*
	(0.031)	(0.047)
Network (Ref: Not in Network)		
In Network	-0.01	0.06*
	(0.022)	(0.032)
Ownership (Ref: Government)		
Non-Profit	0.08*	-0.04
	(0.040)	(0.047)
For-Profit	-0.17**	-0.65***
	(0.057)	(0.072)
DSH percent	-0.21*	-0.12
	(0.093)	(0.111)
Case Mix Index	0.16**	0.18**
	(0.055)	(0.070)
CAH Status (Ref: Not CAH)		
CAH	-0.24	-0.13
	(0.301)	(0.335)
Marketshare	0.01	0.01
	(0.004)	(0.007)
No. of SNF Facilities (County)	0.00***	0.00**
	(0.001)	(0.001)
No. of Hospitals (County)	-0.01*	-0.01**
	(0.002)	(0.003)
No. of PCPs (County)	-0.00*	-0.00
	(0.000)	(0.000)
Year (Ref: 2014)		
2015	0.13***	0.21***
	(0.018)	(0.033)
N (Hospital-Year Obs)	2906.00	2906.00

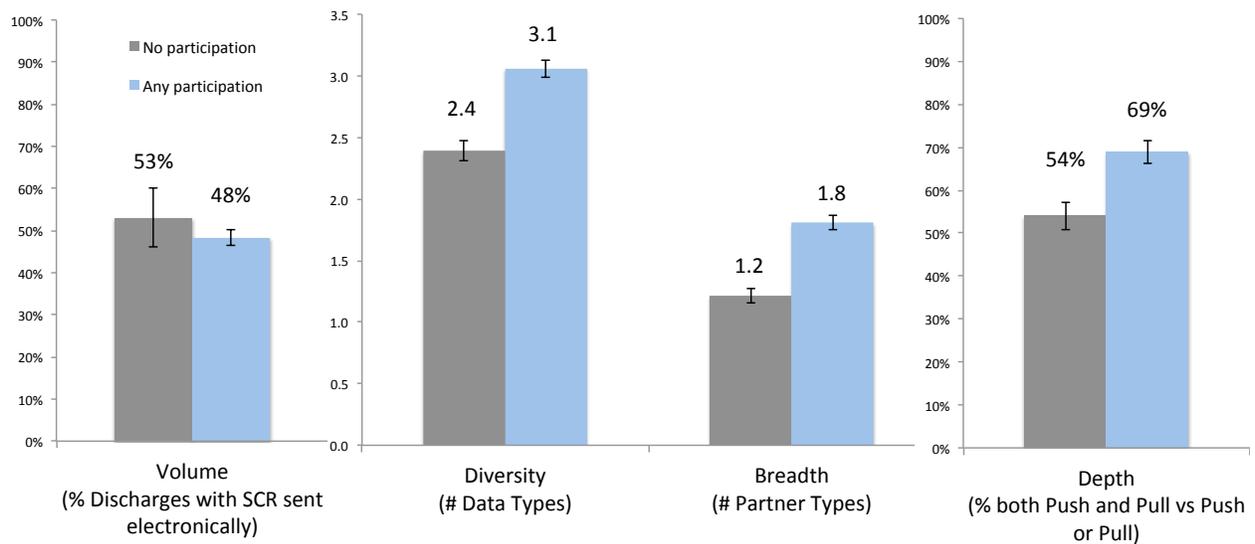
Note: Hospital-clustered SE in Parentheses, all models contain year fixed effects.

eAppendix Table 5. Sensitivity Analysis, Full Regression Results Heckman Selection Model

	(1)		(2)	
	Volume		Attestation (Selection)	
Full Year APM participation	-0.10**	(0.032)	0.30***	(0.090)
Size (Ref: <100 beds)				
100-399 beds	-0.00	(0.022)	0.05	(0.081)
400+ beds	-0.04	(0.034)	0.11	(0.119)
Urban (Ref: Large Urban)				
Other Urban	0.02	(0.021)	0.03	(0.068)
Rural	0.00	(0.027)	0.07	(0.091)
Teaching (Ref: Non-Teaching)				
Major	-0.11***	(0.033)	-0.14	(0.112)
Minor	-0.04	(0.019)	0.02	(0.062)
System (Ref: Not in System)				
In System	0.06*	(0.027)	-0.05	(0.139)
Network (Ref: Not in Network)				
In Network	-0.02	(0.015)	-0.03	(0.054)
Ownership (Ref: Government)				
Non-Profit	-0.06	(0.031)	-0.08	(0.102)
For-Profit	-0.21***	(0.035)	-0.03	(0.129)
DSH percent	0.12	(0.063)	0.14	(0.197)
Case Mix Index	0.05	(0.036)	-0.08	(0.130)
CAH Status (Ref: Not CAH)				
CAH	-0.06	(0.053)	-1.25	(0.725)
Marketshare	0.00	(0.004)	-0.01	(0.013)
No. of SNF Facilities (County)	-0.00*	(0.001)	-0.00	(0.002)
No. of Hospitals (County)	0.00**	(0.001)	-0.01	(0.004)
No. of PCPs (County)	-0.00	(0.000)	0.00*	(0.000)
Year (Ref: 2014)				
2015	0.09***	(0.012)	0.49***	(0.083)
Latest S1 Attestation Year (Ref: Never)				
2012			10.69***	(0.302)
2013			3.65***	(0.177)
2014			2.76***	(0.172)
2015			-4.58***	(0.174)
2016			-4.59***	(0.177)
athrho	-0.42***	(0.061)		
N	4310.00			

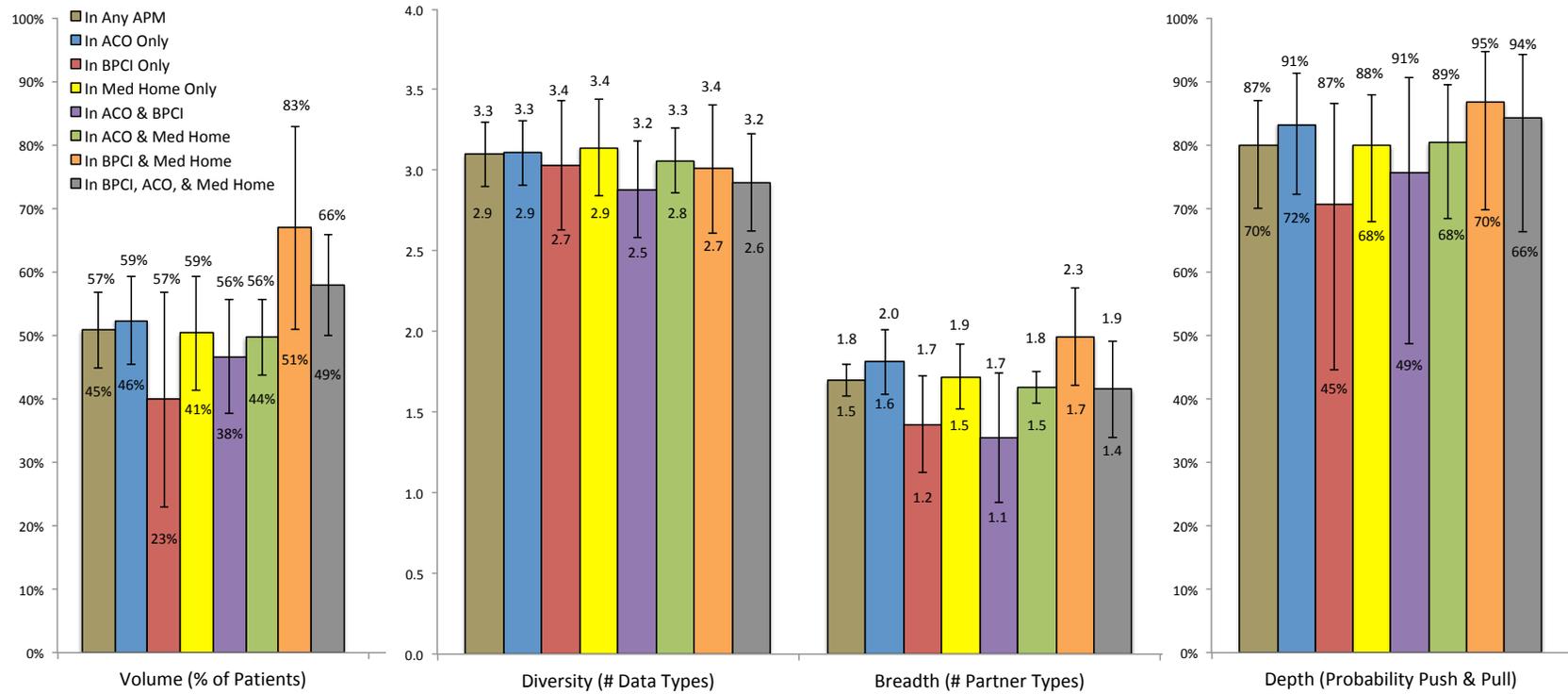
Note: Hospital-clustered SE in Parentheses, all models contain year fixed effects. For more details on this methodology, see Lin, Everson, and Adler-Milstein, 2018.⁴

eAppendix Figure 1. Unadjusted Performance on Four Dimensions of HIE Engagement by APM Participation



Average shown in bars, 95% confidence interval shown in lines. Measures of HIE volume based on 801 hospitals, data on HIE diversity, breadth based on 2,085 hospitals, data on HIE depth based on 1427 hospitals pooled across 2014 and 2015

eAppendix Figure 2. Sensitivity Analysis Comparing Any APM participation to participation by APM Type, Predicted Performance on Four Dimensions of Hospital HIE Engagement



Predicted values for medium sized, urban, non teaching, non system member, non network member, non-profit, non critical access hospitals with all other continuous variables at the sample mean; predictions based on models with a 3-way interaction term interacting any year participation in each of 3 APM types.