Online Supplement:

Impact of Health Information Exchange Adoption on Referral Patterns

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A. Additional Statistics on Matched Sample

In the following table, we demonstrate that HIE members and Non-members in the matched sample are balanced regarding the variable "odds of receiving referrals from HIE members". For this purpose, we apply the statistical t-test for comparing the means of two populations. First, for each year *t*, we compared the average of the odds variable for the group of practices who adopted in year *t+1* with that of the group of practices who have not yet adopted by *t+1*. This group of non-adopting practices includes those practices who have either adopted after *t+1* or not. Second, for each year *t*, we compared the average of the odds variable for the group of practices who have adopted in year *t+1*, with that of the group which has not adopted anytime in the panel of the study. The p-values of these tests are presented in Table S.1. As evident from the p-values, the difference between HIE members and non-members in the average of the odds variable is not significant in any of these comparisons. Furthermore, we note from Table S.1 that although the mean for group A is higher than that of group B in year 2011, the variance of group A is also significantly higher than that of group B and the p-value is quite high. In sum, as the p-values are the deciding criteria in the test of equality of means of the two populations in each comparison, we conclude that the groups are balanced regarding the odds variable.

Table S.1 Additional Statistics on the Odds of Receiving from HIE Members in the Matched Sample

Year (t)	2009	2010	2011
The average of the odds variable in year t for the group of practices who adopted in year t+1 (Standard Deviation) (denoted as group A)	0.15 (0.34)	7.93 (30.34)	36.81 (123.5)
The average of the odds variable in year t for group of practices who have not yet adopted by t+1 (Standard Deviation) (denoted as group B)	0.24 (0.44)	0.95 (5.16)	5.63 (38.95)
The average of the odds variable in year t for the group not adopted anytime in the panel of the study (Standard Deviation) (denoted as group C)	0.22 (0.38)	1.05 (5.55)	5.63 (38.95)[2]
P-value[1] obtained from t-test when comparing groups A and B	**0.37**	**0.80**	**0.40**
P-value obtained from t-test when comparing groups A and C	**0.44**	**0.21**	**0.40**

[1]: *The level of significance for testing the hypothesis in which the difference between means of the two groups is zero.*

[2]: *Note that group C and B in year 2011, are the same and the group includes those who never adopted in the period of the study.*

B. Placebo Tests

In the following we first present the results of the placebo tests discussed in Section 6.3 of the main manuscript to check the validity of our findings regarding H_1 and H_3. Next, we show the corresponding results for H_2 and H_4.

B.I. Placebo Tests for H_1 and H_3

Table S.2. Parameter Estimations (Standard Errors) Obtained from one-year placebo test using (Hydari et al., 2019) (Poisson)

Parameter	Referrals sent to HIE members	Referrals received from HIE members
HIE	-0.22 (0.27)	-0.14 (0.29)
Time and Physician dummies	Yes	Yes
Full Log Likelihood	-15281.09	-15750.60

Columns 2-3 show the results on testing H_1 and H_3 respectively. The Generalized Linear Model (GLM) is used to estimate the parameters of Eq.1 where post adoption data is removed, and it is assumed that HIE adoption happens one year before the actual date of adoption. Standard errors in parentheses are clustered by practice. The insignificant effect obtained for the variable HIE shows there is not any pre-treatment effect one year before adoption.

Table S.3. Parameter Estimations (Standard Errors) Obtained from one-year placebo test (Hydari et al., 2019) (OLS)

Parameter	Referrals sent to HIE members	Referrals received from HIE members
HIE	-0.41 (0.3)	-0.24 (0.32)
Time and Physician dummies	Yes	Yes
R^2	0.92	0.94

Columns 2-3 show the results on testing H_1 and H_3 respectively. The Ordinary Least Squares (OLS) is used to estimate the parameters of Eq.2 where post adoption data is removed, and it is assumed that HIE adoption happens one year before the actual

date of adoption. Standard errors in parentheses are clustered by practice. The insignificant effect obtained for the variable HIE shows there is not any pre-treatment effect one year before adoption.

Table S.4. Parameter Estimations (Standard Errors) Obtained from two-year placebo test (Hydari et al., 2019) (Poisson)

Parameter	Referrals sent to HIE members	Referrals received from HIE members
HIE	0.5 (0.8)	0.91 (0.7)
Time and Physician dummies	Yes	Yes
Full Log Likelihood	-15287.89	-15499.90

Columns 2-3 show the results on testing H_1 and H_3 respectively. The Generalized Linear Model (GLM) is used to estimate the parameters of Eq.1 where post adoption data is removed, and it is assumed that HIE adoption happens one year before the actual date of adoption. Standard errors in parentheses are clustered by practice. The insignificant effect obtained for the variable HIE shows there is not any pre-treatment effect two years before adoption.

Table S.5. Parameter Estimations (Standard Errors) Obtained from two-year placebo test (Hydari et al., 2019) (OLS)

Parameter	Referrals sent to HIE members	Referrals received from HIE members
HIE	0.28 (0.37)	0.54 (0.28)
Time and Physician dummies	Yes	Yes
R^2	0.92	0.94

Columns 2-3 show the results on testing H_1 and H_3 respectively. The Ordinary Least Squares (OLS) is used to estimate the parameters of Eq.2 where post adoption data is removed, and it is assumed that HIE adoption happens one year before the actual date of adoption. Standard errors in parentheses are clustered by practice. The insignificant effect obtained for the variable HIE shows there is not any pre-treatment effect two years before adoption.

Table S.6. Parameter Estimations (Standard Errors) Obtained from placebo test (Chang et al., 2019) (Poisson)

Parameter	Referrals sent to HIE members	Referrals received from HIE members
$H \times Time$	-0.09 (0.2)	0.02 (0.2)
Time and Physician dummies	Yes	Yes
Full Log Likelihood	-15359.34	-15790.96

Columns 2-3 show the results on testing H_1 and H_3 respectively. The Generalized Linear Model (GLM) is used to estimate the parameters of Eq.5 where post adoption data is removed. Standard errors in parentheses are clustered by practice. The insignificant effect obtained for the variable $H \times Time$ shows members and non-members have similar trends in the pre-adoption period.

Table S.7. Parameter Estimations (Standard Errors) Obtained from placebo test (Chang et al., 2019) (OLS)

Parameter	Referrals sent to HIE members	Referrals received from HIE members
$H \times Time$	-0.16 (0.21)	0.01 (0.22)
Time and Physician dummies	Yes	Yes
R^2	0.92	0.94

Columns 2-3 show the results on testing H_1 and H_3 respectively. The ordinary Least Squares (OLS) is used to estimate the parameters of Eq.5 where post adoption data is removed. Standard errors in parentheses are clustered by practice. The insignificant effect obtained for the variable $H \times Time$ shows members and non-members have similar trends in the pre-adoption period.

B. II. Placebo Tests for H_2 and H_4

In the following we present the results of the placebo tests discussed in Section 6.3 of the main manuscript to check the validity of our findings regarding H_2 and H_4.

Table S.8. Parameter Estimations (Standard Errors) Obtained from one-year placebo test using (Hydari et al., 2019) (Poisson)

Parameter	Referrals sent to Non-HIE members	Referrals received from Non-HIE members
HIE	0.04 (0.04)	0.05 (0.04)
Time and Physician dummies	Yes	Yes
Full Log Likelihood	-12498.69	-12388.92

Columns 2-3 show the results on testing H_2 and H_4 respectively. The Generalized Linear Model (GLM) is used to estimate the parameters of Eq.1 where post adoption data is removed, and it is assumed that HIE adoption happens one year before the actual date of adoption. Standard errors in parentheses are clustered by practice. The insignificant effect obtained for the variable HIE shows there is not any pre-treatment effect one year before adoption.

Table S.9. Parameter Estimations (Standard Errors) Obtained from one-year placebo test (Hydari et al., 2019) (OLS)

Parameter	Referrals sent to Non-HIE members	Referrals received from Non-HIE members
HIE	-0.09 (0.1)	-0.16 (0.13)
Time and Physician dummies	Yes	Yes
R^2	0.93	0.93

The Ordinary Least Squares (OLS) is used to estimate the parameters of Eq.2 where post adoption data is removed, and it is assumed that HIE adoption happens one year before the actual date of adoption. Standard errors in parentheses are clustered by practice. The insignificant effect obtained for the variable HIE shows there is not any pre-treatment effect one year before adoption.

Table S.10. Parameter Estimations (Standard Errors) Obtained from two-year placebo test (Hydari et al., 2019) (Poisson)

Parameter	Referrals sent to Non-HIE members	Referrals received from Non-HIE members
HIE	-0.06 (0.06)	-0.05 (0.06)
Time and Physician dummies	Yes	Yes
Full Log Likelihood	-12497.03	-12416.29

Columns 2-3 show the results on testing H_2 and H_4 respectively. The Generalized Linear Model (GLM) is used to estimate the parameters of Eq.1 where post adoption data is removed, and it is assumed that HIE adoption happens one year before the actual date of adoption. Standard errors in parentheses are clustered by practice. The insignificant effect obtained for the variable HIE shows there is not any pre-treatment effect two years before adoption.

Table S.11. Parameter Estimations (Standard Errors) Obtained from two-year placebo test (Hydari et al., 2019) (OLS)

Parameter	Referrals sent to Non-HIE members	Referrals received from Non-HIE members
HIE	-0.18 (0.14)	-0.15 (0.18)
Time and Physician dummies	Yes	Yes
R^2	0.93	0.95

Columns 2-3 show the results on testing H_2 and H_4 respectively. The Ordinary Least Squares (OLS) is used to estimate the parameters of Eq.2 where post adoption data is removed, and it is assumed that HIE adoption happens one year before the actual date of adoption. Standard errors in parentheses are clustered by practice. The insignificant effect obtained for the variable HIE shows there is not any pre-treatment effect two years before adoption.

Table S.12. Parameter Estimations (Standard Errors) Obtained from placebo test (Chang et al., 2019) (Poisson)

Parameter	Referrals sent to Non-HIE members	Referrals received from Non-HIE members
$H \times Time$	0.01 (0.04)	0.02 (0.03)
Time and Physician dummies	Yes	Yes
Full Log Likelihood	-12523.05	-12425.13

Columns 2-3 show the results on testing H_2 and H_4 respectively. The Generalized Linear Model (GLM) is used to estimate the parameters of Eq.5 where post adoption data is removed. Standard errors in parentheses are clustered by practice. The insignificant effect obtained for the variable $H \times Time$ shows members and non-members have similar trends in the pre-adoption period.

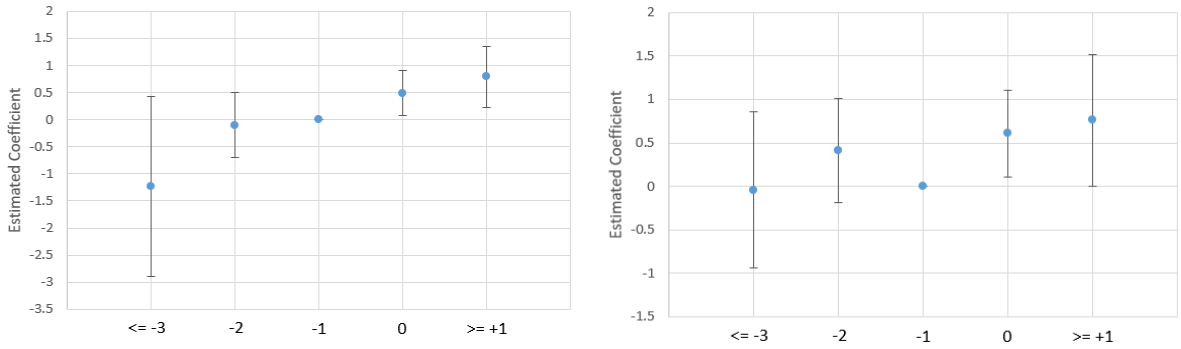
Table S.13. Parameter Estimations (Standard Errors) Obtained from placebo test (Chang et al., 2019) (OLS)

Parameter	Referrals sent to Non-HIE members	Referrals received from Non-HIE members
$H \times Time$	-0.11 (0.09)	-0.12 (0.13)
Time and Physician dummies	Yes	Yes
R^2	0.94	0.96

Columns 2-3 show the results on testing H_2 and H_4 respectively. The ordinary Least Squares (OLS) is used to estimate the parameters of Eq.5 where post adoption data is removed. Standard errors in parentheses are clustered by practice. The insignificant effect obtained for the variable $H \times Time$ shows members and non-members have similar trends in the pre-adoption period.

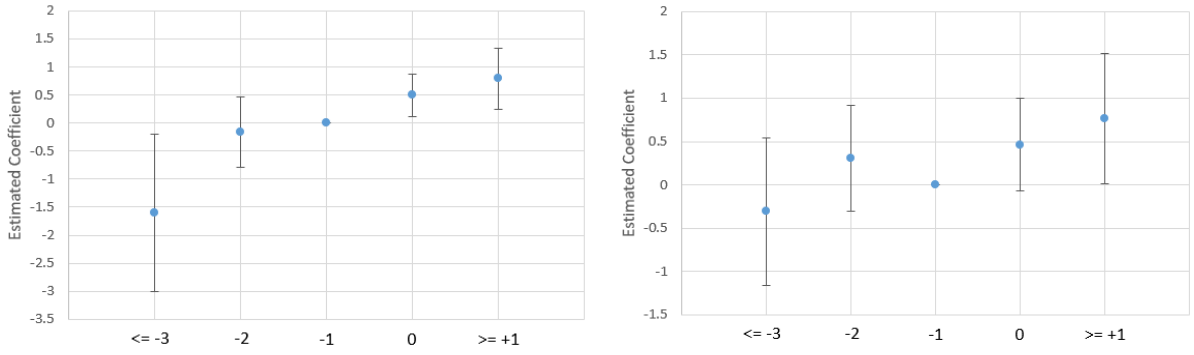
C. Leads and Lags Analysis on Only Treated Sample

In the following we first present the results of the leads and lags analysis on only the treated sample regarding our supported hypotheses (H_1 and H_3.) Next, we present the corresponding results for hypotheses (H_2 and H_4).



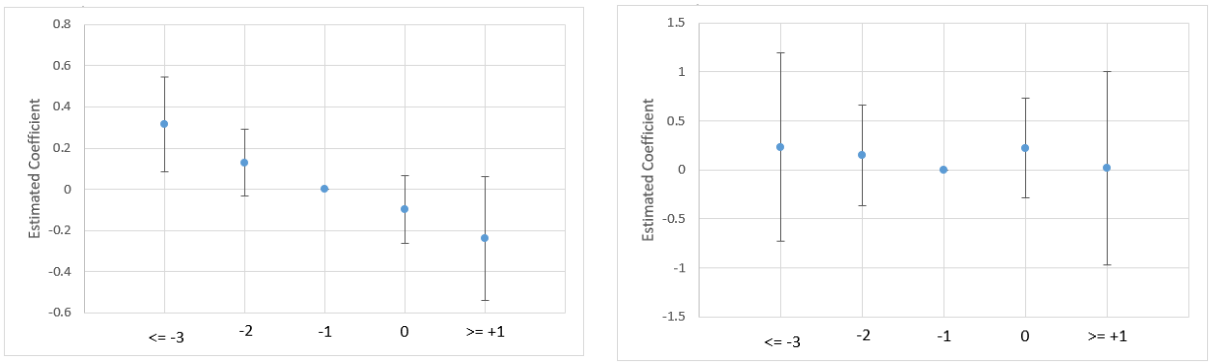
(a) Poisson Model (Eq.1) (b) OLS Model (Eq.2)

Figure S.1. Leads and Lags Analysis on Referrals Sent to HIE members (H_1), using only the Treated Sample (Bars show 95% confidence intervals).



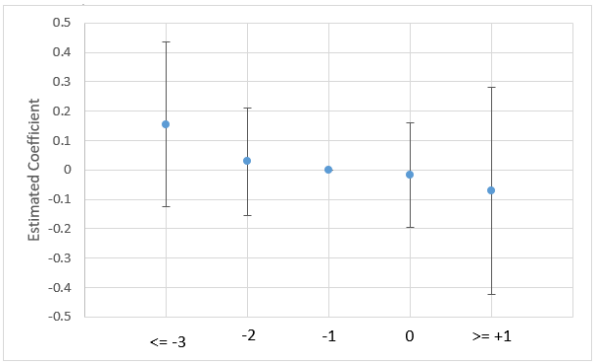
(a) Poisson Model (Eq.1) (b) OLS Model (Eq.2)

Figure S.2. Leads and Lags Analysis on Referrals Received from HIE members (H_3), using only the Treated Sample (Bars show 95% confidence intervals).

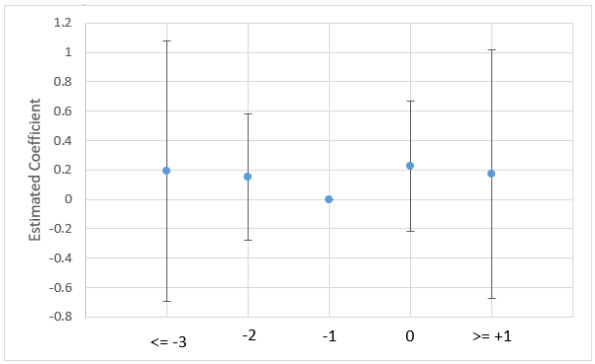


(a) Poisson Model (Eq.1) (b) OLS Model (Eq.2)

Figure S.3. Leads and Lags Analysis on Referrals Sent to Non-HIE Members (H_2), using only the Treated Sample (Bars show 95% confidence intervals).



(a) Poisson Model (Eq.1)

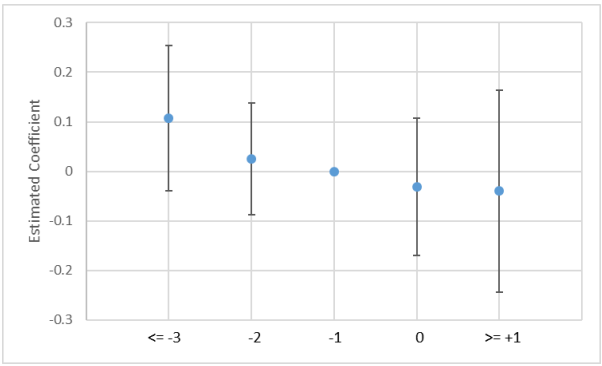


(b) OLS Model (Eq.2)

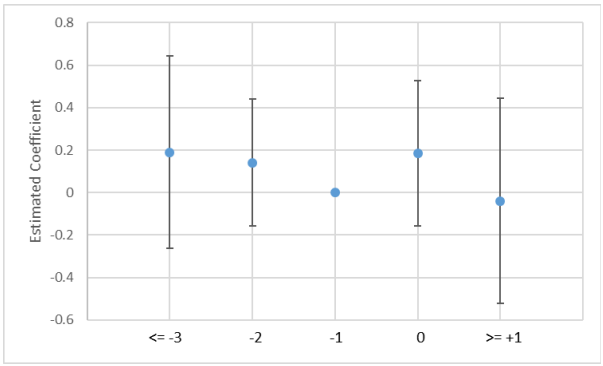
Figure S.4. Leads and Lags Analysis on Referrals Received from Non-HIE Members (H_4), using only the Treated Sample (Bars show 95% confidence intervals).

D. Leads and Lags Analysis on the Whole Sample for H_2 and H_4

In the following we present the results of the leads and lags analysis on the whole sample for hypotheses H_2 and H_4.

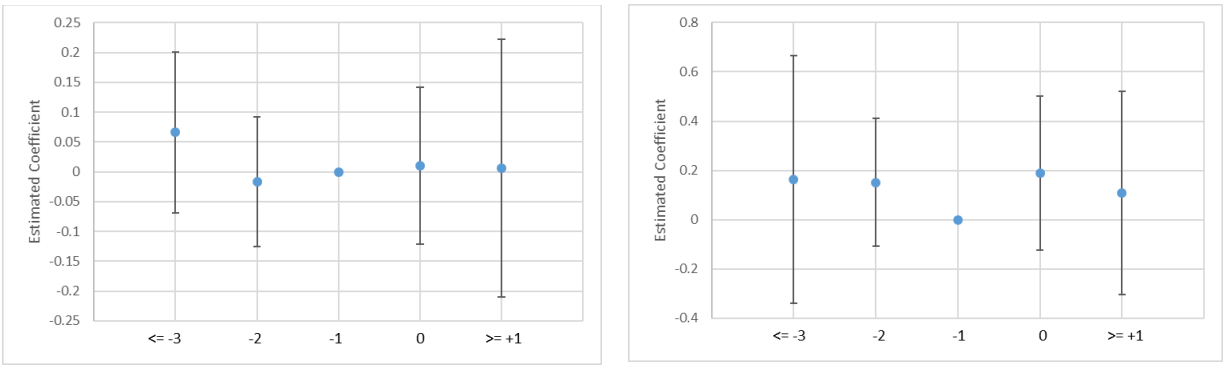


(a) Poisson Model (Eq.1)



(b) OLS Model (Eq.2)

Figure S.5. Leads and Lags Analysis on Referrals Sent to Non-HIE Members (H_2) (Bars show 95% confidence intervals).



(a) Poisson Model (Eq.1) (b) OLS Model (Eq.2)

Figure S.6. Leads and Lags Analysis on Referrals Received from Non-HIE Members (H_4) (Bars show 95% confidence intervals).

E. Goodman-Bacon Analysis for H_2 and H_4

Table S.14. Goodman-Bacon Weighted Average Analysis for H_2 and H_4

Type of comparison (Treatment Vs. Control)	**Weight**	**Average of DID estimate (Referrals Sent to Non-HIE Members)**	**Average of DID estimate (Referrals Received from Non-HIE Members)**
Earlier Vs. Later Treated	0.04	-0.92	-0.78
Later Vs. Always Treated	0.28	0.26	0.36
Later Vs. Earlier Treated	0.07	-0.42	-0.43
Treated Vs. Untreated	0.61	-0.20	-0.11

F. Calloway and Sant'Anna DID Framework for H_2 and H_4

Table S.15. DID effects for the HIE impact on referrals sent to Non-HIE members (H_2)

	Control group: Never-treated sample		Control group: Not-yet-treated sample	
Simple-aggregated Effect	-0.32 (0.19)		-0.32 (0.18)	
Dynamic Effects (Event Study)	Event time	ATT (SE)	Event time	ATT (SE)
	-2	0.05 (0.32)	-2	-0.18 (0.28)
	-1	0.33 (0.24)	-1	0.31 (0.22)
	0	-0.09 (0.16)	0	-0.12 (0.16)
	1	-0.56* (0.28)	1	-0.55* (0.26)
	2	-0.46 (0.35)	2	-0.46 (0.35)
Dynamic-aggregated Effect	-0.37 (0.21)		-0.38* (0.19)	
Group-aggregated Effect	-0.24 (0.18)		-0.25 (0.16)	

**p<0.05, *p<0.1

Table S.16. DID effects for the HIE impact on referrals received from Non-HIE members (H_4)

	Control group: Never-treated sample		Control group: Not-yet-treated sample	
Simple-aggregated Effect	-0.22 (0.19)		-0.2 (0.19)	
Dynamic Effects (Event Study)	Event time	ATT (SE)	Event time	ATT (SE)
	-2	-0.21 (0.32)	-2	-0.44 (0.28)
	-1	0.27 (0.26)	-1	0.31 (0.27)
	0	-0.09 (0.16)	0	-0.1 (0.16)
	1	-0.42 (0.27)	1	-0.37 (0.26)
	2	-0.13 (0.44)	2	-0.13 (0.48)
Dynamic-aggregated Effect	-0.21 (0.25)		-0.19 (0.24)	
Group-aggregated Effect	-0.17 (0.19)		-0.15 (0.19)	

$^{**}p<0.05$, $^{*}p<0.1$

G. DID Analysis on only the Treated Sample for H_1 and H_3

The results of the DID analysis on only the treated sample using the Poisson model (Eq.1 of the main manuscript) are presented in the main manuscript. In the following, we present the results using the OLS model (Eq.2 of the main manuscript).

Table S.17. Parameter Estimations (Standard Errors) Obtained from DID Model in Eq.2 with only the Treated Sample

Parameter	**Referrals sent to HIE members**	**Referrals received from HIE members**
HIE	0.49 (0.25) **	0.32 (0.26)
Time and Physician dummies	Yes	Yes
R^2	0.88	0.89

$^{**}p<0.05$, $^{*}p<0.1$, Columns 2-3 show the results on testing H_1 and H_3 using only the treated sample respectively. The Ordinary Least Squares (OLS) is used to estimate the parameters of Eq.1. Standard errors in parentheses are clustered by practice. No of observations =908 (No of Panels:4, No of Physicians: 227)

H. DID Analysis on only the Treated Sample for H_2 and H_4

Table S.18. Parameter Estimations (Standard Errors) Obtained from DID Model in Eq.1 with only the Treated Sample

Parameter	**Referrals sent to Non-HIE members**	**Referrals received from Non-HIE members**
HIE	-0.07 (0.07)	0.002 (0.07)
Time and Physician dummies	Yes	Yes
Full Log Likelihood	-21212.60	-19672.81

$^{**}p<0.05$, $^{*}p<0.1$, Columns 2-3 show the results on testing H_2 and H_4 using only the treated sample respectively. The Generalized Linear Model (GLM) is used to estimate the parameters of Eq.1. Standard errors in parentheses are clustered by practice. No of observations =908 (No of Panels:4, No of Physicians: 227)

Table S.19. Parameter Estimations (Standard Errors) Obtained from DID Model in Eq.2 with only the Treated Sample

Parameter	Referrals sent to Non-HIE members	Referrals received from Non-HIE members
HIE	0.25 (0.23)	0.22 (0.21)
Time and Physician dummies	Yes	Yes
R^2	0.91	0.92

$^{**}p<0.05$, $^{*}p<0.1$, Columns 2-3 show the results on testing H_2 and H_4 using only the treated sample respectively. The Ordinary Least Squares (OLS) is used to estimate the parameters of Eq.1. Standard errors in parentheses are clustered by practice. No of observations =908 (No of Panels:4, No of Physicians: 227)

I. Analysis on Integrated Delivery Systems (IDS)

The results on the IDS analysis using Poisson model (Eq.1 of the main manuscript) are presented in the main manuscript. In the following, we present the IDS analysis using the OLS model (Eq.2 of the main manuscript).

Table S.20. Parameter Estimations (Standard Errors) Obtained from DID Model in Eq.2 Using IDS Members

Parameter	Referrals sent to HIE members	Referrals sent to Non-HIE members	Referrals received from HIE members	Referrals Received from Non-HIE members
HIE	0.53** (0.27)	0.23 (0.22)	0.39 (0.26)	0.24 (0.19)
Time and Physician dummies	Yes	Yes	Yes	Yes
R^2	0.89	0.93	0.91	0.93

$^{**}p<0.05$, $^{*}p<0.1$, Columns 2-5 show the results on testing H_1-H_4 respectively on the sample of IDS members. The Ordinary Least Squares (OLS) is used to estimate the parameters of Eq.2. Standard errors in parentheses are clustered by practice. No of observations =1052 (No of Panels: 4, No of Physicians: 263). Among 263 physicians, 178 adopt HIE during the panel, and the rest remain non-member.

Table S.21. Parameter Estimations (Standard Errors) Obtained from DID Model in Eq.2 Using Non-IDS Members

Parameter	Referrals sent to HIE members	Referrals sent to Non-HIE members	Referrals received from HIE members	Referrals Received from Non-HIE members
HIE	0.78 (0.57)	-0.24 (0.31)	0.78 (0.59)	-0.17 (0.32)
Time and Physician dummies	Yes	Yes	Yes	Yes
R^2	0.93	0.92	0.94	0.94

$^{**}p<0.05$, $^{*}p<0.1$, Columns 2-5 show the results on testing H_1-H_4 respectively on the sample of non-IDS members. The Ordinary Least Squares (OLS) is used to estimate the parameters of Eq.2. Standard errors in parentheses are clustered by practice. No of observations =364 (No of Panels: 4, No of Physicians: 91). Among 91 physicians, 49 adopt HIE during the panel, and the rest remain non-member.

J. Survival analysis

In the following we present the results of the survival analysis (Eq.3 and Eq.4 of the main manuscript).

Table S.22. Analysis of Maximum Likelihood Estimates from PH Model in Eq. 3

Parameter	Coefficient (SE)	Hazard
R_{t-1}	0.009*** (0.002)	1.009
S_{t-1}	-0.005 (0.006)	0.995
Size	-0.012 (0.007)	0.988
EHR	0.458** (0.203)	1.580
PQRS	0.780*** (0.229)	2.181
ERX	1.018*** (0.217)	2.768
Urban	0.494 (0.282)	1.639
Degree centrality	0.099*** (0.028)	1.104
Isomophormic qoutient	-0.073 (0.538)	0.930

****: P_value <0.01, **: P_value <0.05, -2 log likelihood: 1520.98*

Table S.23. Parameter Estimations (Standard Errors) Obtained from AFT Model in Eq.4

Parameter	Year 2010	Year 2011	Year 2012
R	-0.180 (0.296)	-0.026*** (0.008)	-0.009*** (0.003)
S	0.228 (0.305)	-0.002 (0.011)	0.021 (0.048)
Size	0.013** (0.006)	0.026** (0.012)	0.060 (0.032)
EHR	-0.383** (0.173)	-0.074** (0.287)	-0.803 (0.555)
PQRS	-0.678*** (0.196)	-0.936*** (0.325)	-0.724 (0.569)
ERX	-0.882*** (0.195)	-1.413*** (0.321)	-0.878 (0.543)
Urban	-0.425 (0.244)	-0.281 (0.364)	-1.543 (1.089)
Degree centrality	-0.097*** (0.023)	-0.147*** (0.057)	-0.286** (0.136)
Isomorphic quotient	0.037 (0.472)	-0.441 (0.700)	-1.149 (0.798)
Scale	0.858 (0.063)	1.081(0.108)	0.939 (0.194)
Weibull Shape	1.166 (0.086)	0.925 (0.093)	1.065 (0.220)
Model Features			
Akaike information criterion (AIC)	711.024	522.186	184.140
Bayesian information criterion (BIC)	754.481	563.740	223.350
No of Non-censored Observations	145	84	22
No of Censored Observations	239	239	239

****: P_value <0.01, **: P_value <0.05*

K. Physicians' Referral Handling Capacity

We used the maximum number of referrals handled by a physician over the four-year study period as a measure of the referral handling capacity of the physician. The average of the physicians' referral handling

capacity is equal to 1534.84. The average number of referrals received by the physician during the period of our study are presented in the following Table. As evident by the table, the average of the physicians' referral handling capacity exceeds the average number of referrals received by the physician in each year during the period of our study.

Table S.24. Total Received Referrals by Physicians in the Matched Sample

Year	2009	2010	2011	2012
Average (Standard Deviation)	934.35 (1916.63)	1035.6 (2062.73)	1095.11 (2259.49)	925.51 (1859.53)

L. Interview Protocol of the Exploratory Filed Study

Impact of HIE Use on Referral Patterns

Purpose:

In this study, we intend to examine how Health Information Exchange (HIE) is being used in clinical practices and see if it has any impact on how medical practices send and receive referrals from others.

Interview Questions:

During the interview we ask the following questions:

1- When did your practice adopt HIE and how much have you been using it lately?

2- Which of the services provided by HIE is more useful for you?

3- Did you make any changes in your workflow to be able to use HIE more easily and effectively?

4- Do you think HIE services have made your job easier?

5- Specifically, when it comes to receiving referred patients who have medical history created by other providers, do you think HIE can be helpful? If so, how exactly?

6- How about when it comes to referring one of your patients to anther provider? Is there anything during the referral process that HIE can help facilitate? If so, how exactly?

7- Hypothetically, between two physicians that are exactly equal, except for their HIE membership, do you have any preference to send your patients to the one who is an HIE member? If so, why?

8- Hypothetically, between two physicians that are exactly equal, except for their HIE membership, do you have any preference to receive your patients to the one who is an HIE member? If so, why?

Procedure:

Participation in this interview is voluntary. We will keep all the interviews confidential and will not report any information that may identify an individual or medical practice. We will record the interviews for coding purposes. However, we will not share those recording with anyone outside of the research team.

Benefits:

We will share the findings of this study with the participants as soon as possible. This will hopefully inform clinical practices about the best ways to improve how they use HIE and increase the return on their investment on HIE technologies. This research will also inform them about the potential impact of HIE on the number of referrals they send and receive from other practices.

Risks:

We do not anticipate any risks or harms to the participants of this study. Yet, there is always a very small chance for a security breach or hacking attack. This may lead to exposure of the interview files. While this is extremely unlikely, we will follow every security guidelines and privacy policy to ensure that this does not happen. For example, we will keep the interview files on a hard disk, disconnected from the internet network at most times and will destroy the files once the research is published.