Supplementary appendix

Calculating informal integration

Our measure of informal integration is based on the assortativity coefficient of each health system-year network. In network analysis, the assortativity coefficient measures the extent to which nodes with similar features are connected to one another compared to what would be expected if connections were randomly assigned. In our case, the feature that we use is physician specialty (primary care physician, surgeon, medical specialist). Typically, the assortativity coefficient takes positive values if similar nodes are *more* likely to associate and negative values if similar nodes are *less* likely to associate. Because we are more interested in the extent to which dissimilar connections occur, we use the *disassortativity* coefficient (i.e., the reverse of assortativity) such that positive values indicate more cross-specialty ties than we would expect at random.

Mathematically, the disassortativity coefficient that we use to measure integration can be represented as:

$$r = \frac{\sum_i a_i b_i - \sum_i e_{ii}}{1 - \sum_i a_i b_i}$$

where e_{ij} is a quantity that represents the fraction of edges that connect a node of type i to one of type j, $a_i = \sum_j e_{ij}$, $b_j = \sum_i e_{ij}$, and $\sum_{ij} e_{ij} = 1$.[1] A value of r = 1 indicates that *all* edges connect nodes of different types whereas r = 0 indicates that all edges connect similar nodes.

Sensitivity analyses

Our primary regression analysis (Appendix Exhibit 1, Model 1) was a linear probability model with mortality as the outcome, regressed on ACO participation, informal integration, the interaction of the two, and a series of controls. The sample used for this analysis comprises

53,239 beneficiaries for which we have complete data for all variables. We test the sensitivity of the associations we observed in Model 1 through a series of supplementary regression analyses (Appendix Exhibit 1, Models 2-8).

First, in Appendix Exhibit 1, Model 2 we relax the two-procedure threshold for inclusion of health systems that we utilize in our main analysis and include all observations for which we have complete data (53,702 beneficiaries across 1,211 health systems). The results are consistent with those of Model 1, suggesting that the relationship among variables is similar for health systems that only perform one CABG procedure in a year.

Second, to further evaluate potential bias in our models due to low volume systems, in Model 4 we drop observations if the hospital did not perform at least 10 CABG procedures in a given year. This criterion reduces the number of total observations to 40,598, but the regression results are consistent with Model 1 (threshold of 2 procedures) and Model 2 (no threshold).

Third, to ensure our findings are not driven by particularities of the subsample of cases for which we have complete data on all of the control variables, we drop all controls and regress our primary outcome on only informal integration, ACO participation, and the interaction, using all 80,782 observations (Model 3). Although the explanatory power of the model decreases (R^2= 0.002 vs. 0.03) without the controls, we note that the relationships of interest are consistent with our main results, suggesting that the associations among informal integration, ACO participation, and mortality are similar within the subsample of observations that are lost due to incomplete control variable data.

Fourth, in Model 5 we adjust our main model for CABG procedures that were performed on an emergent basis, which helps to further account for heterogeneity in case complexity. Unsurprisingly, the dummy variable for whether or not the procedure was performed on an emergent basis had a positive and statistically significant ($p<0.01$) relationship with mortality. However, the results were otherwise consistent with Model 1.

Fifth, to account for instances where outcomes may be more attributable to surgeon skill, we exclude 741 observations where the beneficiary died within 3 days of surgery (Model 6). Again, the analysis supports our reported results.

Sixth, in Model 7 we conduct an analysis that includes both the dummy variable for emergent cases and the exclusion of 3-day mortality. The coefficient on the emergent case variable is consistent with Model 5 and the results for informal integration, ACO participation, and the interaction term are consistent with our main results.

Finally, in Model 8 we run the fully adjusted specification from Model 7 using health system fixed effects instead of the random effects.[2] Although the magnitude of the coefficient on informal integration is reduced relative to other specifications, it is still statistically significant and the results are largely consistent with those of Model 1.

Appendix Table 1. Models for 90-d operative mortality for CABG beneficiaries (2008-2014)

Variable	1. Main model	2. All health systems	3. ≥10 procedures	4. No controls	5. Emergent surgery
Beneficiary characteristics					
Charlson score	0.01***	0.01***	0.02***		0.02***
	(0.00)	(0.00)	(0.00)		(0.00)
Emergent surgery (0 = No, 1 = Yes)					0.04***
					(0.00)
Sex (0 = Male, 1 = Female)	0.02***	0.02***	0.02***		0.02***
	(0.00)	(0.00)	(0.00)		(0.00)
White (0 = No, 1 = Yes)	0.00	0.00	0.00		0.00
	(0.01)	(0.01)	(0.01)		(0.01)
Black (0 = No, 1 = Yes)	0.00	-0.00	-0.00		-0.00
	(0.01)	(0.01)	(0.01)		(0.01)
Age	0.00***	0.00***	0.00***		0.00***
	(0.00)	(0.00)	(0.00)		(0.00)
Lives in a rural area	0.00	0.00	0.00		0.00
	(0.01)	(0.01)	(0.02)		(0.01)
% living below federal poverty line (mean)	0.00†	0.00	0.00†		0.00†
	(0.00)	(0.00)	(0.00)		(0.00)
% with a bachelor's degree (mean)	-0.00***	-0.00***	-0.00*		-0.00***
	(0.00)	(0.00)	(0.00)		(0.00)
Health system characteristics					
Total CABG beneficiaries	-0.00***	-0.00***	-0.00***		-0.00***
	(0.00)	(0.00)	(0.00)		(0.00)
Total physicians caring for CABG (mean)	0.00***	0.00***	0.00***		0.00***
	(0.00)	(0.00)	(0.00)		(0.00)
Proportion of cross-specialty ties	-0.07***	-0.08***	-0.09***		-0.08***
	(0.02)	(0.02)	(0.03)		(0.02)
Proportion of beneficiaries from outside the CBSA	0.00	0.01	0.01		-0.00
	(0.01)	(0.01)	(0.01)		(0.01)
Academic hospital (0 = No, 1 = Yes)	0.00	0.00	0.00		0.00
	(0.00)	(0.00)	(0.00)		(0.00)
Government hospital (0 = No, 1 = Yes)	0.00	0.01	0.00		0.00
	(0.00)	(0.00)	(0.00)		(0.00)
For-profit hospital (0 = No, 1 = Yes)	0.01*	0.01*	0.00		0.01*
	(0.00)	(0.00)	(0.01)		(0.00)
Electronic health records (0 = No, 1 = Yes)	-0.01	-0.01	-0.02*		-0.01
	(0.01)	(0.01)	(0.01)		(0.01)
Pioneer ACO (0 = No, 1 = Yes)	0.00	0.00	0.00		0.00
	(0.01)	(0.01)	(0.01)		(0.01)
Community characteristics					
Total resident population (log)	0.01	0.01	0.00		0.01†
	(0.00)	(0.00)	(0.00)		(0.00)
Total black population (log)	-0.00*	-0.00*	-0.00		-0.00*
	(0.00)	(0.00)	(0.00)		(0.00)
Total Hispanic population (log)	-0.00	-0.00	-0.00		-0.00
	(0.00)	(0.00)	(0.00)		(0.00)
Acute care hospital beds per 1,000 residents	0.01*	0.01*	0.00		0.01*
	(0.00)	(0.00)	(0.00)		(0.00)
PCPs per 100,000 residents	-0.00	-0.00	0.00		-0.00
	(0.00)	(0.00)	(0.00)		(0.00)
Medical specialists per 100,000 residents	-0.00	-0.00	-0.00		-0.00
	(0.00)	(0.00)	(0.00)		(0.00)
Surgeons per 100,000 residents	-0.00	-0.00	-0.00		-0.00
	(0.00)	(0.00)	(0.00)		(0.00)
ACO membership and informal clinical integration					
Joined ACO (0 = No, 1 = Yes)	0.01	0.01	0.01	0.01	0.01
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Health system integration	-0.20***	-0.18***	-0.21***	-0.30***	-0.19***
	(0.04)	(0.04)	(0.05)	(0.03)	(0.04)
Joined ACO * integration	-0.25*	-0.21*	-0.20†	-0.23**	-0.24*
	(0.10)	(0.10)	(0.11)	(0.09)	(0.10)
Constant	-0.24***	-0.23***	-0.18***	0.09***	-0.24***
	(0.03)	(0.03)	(0.04)	(0.00)	(0.03)
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	53,239	53,702	40,598	80,782	53,239
R^2	0.03	0.03	0.03	0.00	0.03

Standard errors (clustered by health system) in parentheses. ACO: accountable care organization; CBSA: core-based statistical area; PCP: primary care physician

† < 0.1

*p < .05

**p < .01

***p < .001

Appendix Table 1. Models for 90-d operative mortality for CABG beneficiaries (2008-2014), continued

Variable	6. 3-day survival	7. 3-day survival + emergent	8. Health system fixed effects
Beneficiary characteristics			
Charlson score	0.01***	0.01***	0.01***
	(0.00)	(0.00)	(0.00)
Emergent surgery (0 = No, 1 = Yes)		0.03***	0.03***
		(0.00)	(0.00)
Sex (0 = Male, 1 = Female)	0.02***	0.01***	0.01***
	(0.00)	(0.00)	(0.00)
White (0 = No, 1 = Yes)	-0.00	0.00	0.00
	(0.01)	(0.01)	(0.01)
Black (0 = No, 1 = Yes)	-0.00	-0.01	-0.01
	(0.01)	(0.01)	(0.01)
Age	0.00***	0.00***	0.00***
	(0.00)	(0.00)	(0.00)
Lives in a rural area	0.00	0.00	0.00
	(0.01)	(0.01)	(0.01)
% living below federal poverty line (mean)	0.00*	0.00*	-0.00
	(0.00)	(0.00)	(0.00)
% with a bachelor's degree (mean)	-0.00***	-0.00***	-0.00†
	(0.00)	(0.00)	(0.00)
Health system characteristics			
Total CABG beneficiaries	-0.00***	-0.00***	-0.00***
	(0.00)	(0.00)	(0.00)
Total physicians caring for CABG (mean)	0.00***	0.00***	0.00***
	(0.00)	(0.00)	(0.00)
Proportion of cross-specialty ties	-0.07***	-0.07***	-0.18***
	(0.02)	(0.02)	(0.03)
Proportion of beneficiaries from outside the CBSA	0.00	-0.00	-0.00
	(0.01)	(0.01)	(0.01)
Academic hospital (0 = No, 1 = Yes)	0.00	0.00	-0.00
	(0.00)	(0.00)	(0.01)
Government hospital (0 = No, 1 = Yes)	0.00	0.00	0.02
	(0.00)	(0.00)	(0.01)
For-profit hospital (0 = No, 1 = Yes)	0.01†	0.01*	0.01
	(0.00)	(0.00)	(0.02)
Electronic health records (0 = No, 1 = Yes)	-0.01	-0.01	-0.02*
	(0.01)	(0.01)	(0.01)
Pioneer ACO (0 = No, 1 = Yes)	-0.00	-0.00	0.00
	(0.01)	(0.01)	(.)
Community characteristics			
Total resident population (log)	0.00	0.00	0.12*
	(0.00)	(0.00)	(0.06)
Total black population (log)	-0.00	-0.00	-0.00
	(0.00)	(0.00)	(0.02)
Total Hispanic population (log)	-0.00	-0.00	-0.01
	(0.00)	(0.00)	(0.03)
Acute care hospital beds per 1,000 residents	0.01*	0.01*	-0.06
	(0.00)	(0.00)	(0.15)
PCPs per 100,000 residents	-0.00	-0.00	-0.00
	(0.00)	(0.00)	(0.00)
Medical specialists per 100,000 residents	-0.00	-0.00	-0.00
	(0.00)	(0.00)	(0.00)
Surgeons per 100,000 residents	0.00	-0.00	0.01*
	(0.00)	(0.00)	(0.00)
ACO membership and informal clinical integration			
Joined ACO (0 = No, 1 = Yes)	0.01	0.01	0.01
	(0.01)	(0.01)	(0.01)
Health system integration	-0.21***	-0.21***	-0.11*
	(0.03)	(0.03)	(0.05)
Joined ACO * integration	-0.20*	-0.20*	-0.22*
	(0.09)	(0.09)	(0.11)
Constant	-0.22***	-0.22***	-0.85*
	(0.03)	(0.03)	(0.39)
Year fixed effects	Yes	Yes	Yes
Observations	52,498	52,498	52,498
R^2	0.03	0.03	0.03

Standard errors (clustered by health system) in parentheses. ACO: accountable care organization; CBSA: core-based statistical area; PCP: primary care physician

† < 0.1

*p < .05

**p < .01

***p < .001

Appendix Table 2. Patient, health system, and community characteristics by ACO participation, level of informal clinical integration

	Did not join ACO						Joined ACO, Pre-Joining						Joined ACO, Post-Joining						
	Level of informal integration						Level of informal integration						Level of informal integration						
	Lower		Moderate		Higher		Lower		Moderate		Higher		Lower		Moderate		Higher		Overall
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	p-value
Beneficiary characteristics																			
Patient mortality (90d)	0.08	0.27	0.07	0.25	0.06	0.23	0.07	0.26	0.07	0.25	0.05	0.22	0.08	0.28	0.07	0.25	0.03	0.16	0.03
Charlson score	2	1.96	1.95	1.91	1.7	1.75	2.09	1.97	1.96	1.94	1.74	1.75	2.31	2.1	2.1	2.02	1.79	1.83	<0.01
Emergent surgery	0.2	0.4	0.22	0.42	0.23	0.42	0.18	0.38	0.2	0.4	0.24	0.42	0.19	0.39	0.18	0.38	0.21	0.41	<0.01
Died 3 days post-CABG (0 = No, 1 = Yes)	0.01	0.12	0.01	0.11	0.02	0.12	0.01	0.12	0.01	0.11	0.01	0.12	0.01	0.11	0.02	0.13	0.01	0.09	1.00
Sex (0 = Male, 1 = Female)	0.3	0.46	0.3	0.46	0.29	0.45	0.3	0.46	0.3	0.46	0.29	0.45	0.28	0.45	0.29	0.45	0.26	0.44	0.58
White (0 = No, 1 = Yes)	0.93	0.25	0.94	0.24	0.95	0.22	0.93	0.25	0.94	0.24	0.96	0.2	0.93	0.25	0.94	0.24	0.95	0.22	0.45
Black (0 = No, 1 = Yes)	0.04	0.2	0.04	0.19	0.03	0.17	0.04	0.2	0.04	0.2	0.02	0.15	0.04	0.2	0.04	0.19	0.02	0.15	0.74
Age	74.89	5.89	74.82	5.82	74.54	5.67	75.18	5.93	74.84	5.84	74.94	5.77	75.14	6.05	75.1	5.96	74.46	5.66	<0.01
Lives in a rural area	0.01	0.08	0.01	0.09	0.01	0.09	0.01	0.08	0.01	0.08	0.00	0.04	0.00	0.05	0.00	0.05	0.00	0.04	1.00
% living below federal poverty line (mean)	14.73	3.86	15.18	3.74	15.92	4.13	13.4	3.75	14.14	3.76	14.85	4.48	13.09	4.28	14.12	3.54	15.89	4.2	<0.01
% with a bachelor's degree (mean)	26.1	6.92	25.25	6.8	23.52	6.52	29.02	7.24	27.17	7.03	26.39	7.06	33.13	7.1	30.56	6.79	28.72	7.68	<0.01
Health system characteristics																			
Total CABG beneficiaries	22.73	16.4	19.21	14.52	13.58	9.3	29.62	22	20.04	12.11	15.28	8.9	26.67	19.24	18.16	9.98	12.75	7.47	<0.01
Total physicians caring for CABG (mean)	150.28	114.14	108.14	76.45	61.42	36.84	217	186.61	120.34	64.24	73.51	40.21	200.77	124.73	117.48	64.5	65.04	33.47	<0.01
Proportion of cross-specialty ties	0.53	0.06	0.57	0.06	0.62	0.06	0.52	0.05	0.55	0.06	0.6	0.05	0.52	0.05	0.54	0.06	0.61	0.05	<0.01
Proportion of beneficiaries from outside the CBSA	0.57	0.24	0.61	0.23	0.57	0.27	0.6	0.24	0.6	0.26	0.61	0.26	0.63	0.26	0.61	0.24	0.57	0.23	<0.01
Academic hospital (0 = No, 1 = Yes)	0.68	0.47	0.59	0.49	0.5	0.5	0.8	0.4	0.75	0.44	0.78	0.41	0.81	0.39	0.76	0.43	0.63	0.48	<0.01
Government hospital (0 = No, 1 = Yes)	0.12	0.32	0.09	0.29	0.1	0.3	0.03	0.18	0.05	0.21	0.02	0.13	0	0.07	0.03	0.16	0.01	0.07	<0.01
For-profit hospital (0 = No, 1 = Yes)	0.13	0.34	0.15	0.35	0.17	0.38	0.03	0.17	0.04	0.21	0.01	0.11	0.02	0.15	0.02	0.15	0.05	0.21	<0.01
Electronic health records (0 = No, 1 = Yes)	0.96	0.19	0.97	0.18	0.96	0.19	0.99	0.11	0.97	0.18	0.99	0.1	1.00	0.00	1.00	0.00	0.99	0.11	0.00
Health system integration	0.01	0.02	0.04	0.01	0.09	0.03	0.01	0.02	0.04	0.01	0.08	0.02	0.01	0.02	0.04	0.01	0.09	0.02	<0.01
Community characteristics																			
Total resident population (log)	6.15	1.07	5.91	0.96	5.49	0.85	6.13	0.9	5.89	0.88	5.64	0.76	5.99	1.02	5.91	1.06	5.98	0.78	<0.01
Total black population (log)	3.94	1.82	3.51	1.82	2.68	1.79	3.92	1.69	3.44	1.63	2.73	1.55	3.55	1.73	3.31	1.81	3.08	1.41	<0.01
Total Hispanic population (log)	3.66	1.69	3.3	1.56	2.84	1.46	3.83	1.36	3.29	1.42	2.82	1.38	3.74	1.57	3.27	1.81	3.38	1.48	<0.01
Acute care hospital beds per 1,000 residents	2.01	0.51	2.01	0.5	2.05	0.54	1.98	0.45	1.88	0.42	1.84	0.46	1.85	0.36	1.92	0.4	1.8	0.35	<0.01
PCPs per 100,000 residents	70.42	18.25	67.75	15.1	64.51	13.61	75.52	17.13	71.78	15.45	69.89	14.45	77.65	18.87	74.05	15.97	70.92	15.63	<0.01
Medical specialists per 100,000 residents	53.67	17.12	49.52	14.09	43.62	11.07	58.92	18.51	51.84	13.64	48.75	11.54	62.41	20.55	54.71	17.28	47.61	9.9	<0.01
Surgeons per 100,000 residents	36.77	8.25	36.21	7.79	34.84	7.64	37.25	7.48	36.25	8.11	34.94	7.37	37.86	7.55	35.66	6.1	35.07	8.34	<0.01

ACO: accountable care organization; CBSA: core-based statistical area; PCP: primary care physician

p-values from Kruskal-Wallis test except for categorical variables (χ^2 test)

Appendix Table 3. Control variables

Variable	Measure/Data Source
Beneficiary characteristics	**Non-claims based beneficiary characteristics are measured using data from the same year as the patient's surgery (e.g., if beneficiary was treated in 2008, Census Bureau data from 2008 is used to calculate measure)**
Charlson score	Comorbidity index, higher score indicates lower 10-year survival; calculated from Medicare claims
Emergent surgery	CABG surgery was emergent; based on Medicare claims
Died 3 days post-CABG (0 = No, 1 = Yes)	Patient died within three days of procedure; based on Medicare claims
Sex (0 = Male, 1 = Female)	Medicare claims
White (0 = No, 1 = Yes)	Medicare claims
Black (0 = No, 1 = Yes)	Medicare claims
Age	Medicare claims
Lives in a rural area	Patient's home zip code is classified as rural by US Census Bureau
% living below federal poverty line (mean)	Percentage of residents living below poverty line based on patient's home zip; American Community Survey
% with a bachelor's degree (mean)	Percentage of residents with a bachelor's degree based on patient's home zip; American Community Survey
Health system characteristics	**Health system characteristics are measured for each year in the sample and associated with beneficiaries based on the date of surgery**
Total CABG beneficiaries (mean)	Number of CABG beneficiaries for each health system-year, within sample
Total physicians caring for CABG (mean)	Number of unique physicians (PCPs, surgeons, medical specialists) caring for CABG beneficiaries for each health system-year, within sample
Proportion of cross-specialty ties	Ratio of cross-specialty ties to within-specialty ties for each health system-year
Proportion of beneficiaries from outside the CBSA	Proportion of CABG beneficiaries whose home zip is outside the core-based statistical area of the treating medical center
Academic hospital (0 = No, 1 = Yes)	Treating medical center is affiliated with a medical school; American Hospital Association (AHA) Annual Survey
Government hospital (0 = No, 1 = Yes)	Treating medical center is a government hospital, based on Control Code; AHA Annual Survey
For-profit hospital (0 = No, 1 = Yes)	Treating medical center is a for-profit hospital, based on Control Code; AHA Annual Survey
Electronic health records (0 = No, 1 = Yes)	Treating medical center uses electronic health records, based on Control Code; AHA Annual Survey
Pioneer ACO (0 = No, 1 = Yes)	Health system belongs to a Pioneer ACO; CMS Pioneer ACO Participants
Community characteristics	**Community characteristics are measured at the health service area (HSA) level based on the zip code of the treating medical center**
Total resident population (log)	American Community Survey
Total black population (log)	American Community Survey
Total Hispanic population (log)	American Community Survey
Acute care hospital beds per 1,000 residents	Dartmouth Atlas
PCPs per 100,000 residents	Dartmouth Atlas
Medical specialists per 100,000 residents	Dartmouth Atlas
Surgeons per 100,000 residents	Dartmouth Atlas

References

1. Newman, Mark EJ. Mixing patterns in networks. Physical Review E 67, no. 2 (2003): 026126.
2. Specifying Model 1 with fixed effects instead of random effects also yields similar results to Model 8. Results can be provided upon request.