Supplementary Appendix

This appendix has been provided by the authors to give readers additional information about their work.

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Supplementary Appendix for "Year One of the Bundled Payments for Care Improvement – Advanced Model"

Contents

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Detailed Methodology

We used a modified segmented regression approach, with two control groups, to examine changes in slopes for each outcome during the baseline versus intervention period, and then compared those changes in slopes between BPCI-A participants and the never-joiners, and between BPCI-A participants and late joiners. Unlike a standard segmented regression, no pre-post-intervention terms were added to the model because no acute effects of the intervention were expected. We assumed that learning and program implementation would take time before progressive benefits would be seen. Cost and clinical outcome analyses were run at the episode level, with each outcome in a separate model. BPCI-A participants included both hospitals that participated throughout the study period and those that dropped out early. Time zero was set as program initiation (quarter 4 of 2018). The Time1 variable was an indicator for quarter, from -6 to +4, and was treated as a continuous predictor. The Time2 variable was set to zero until October 2018, and then continuous from quarter 1 to 4 thereafter. Both time variables were treated as continuous to allow simple interpretation of slopes (quarterly trends) and slope changes. Interaction terms between Time1 and never-joiners, and between Time1 and late joiners, allowed for different slopes in the 3 groups in the pre-intervention period. The primary predictors were interaction terms between Time2 and never-joiners, and between Time2 and late joiners. The main Time2 variable allowed for a change in slope, due to intervention, in the BPCI-A participants. The two interaction terms with Time2 captured the difference in the slope change in never-joiners versus the slope change in participants; and the difference in the slope change in late joiners versus the slope change in participants.

The segmented regression model described above was implemented using a marginal, generalized equation approach (the GENMOD procedure in the SAS statistical package). The extent of correlation

between patient outcomes, over time, within hospitals, was estimated from the model residuals using an unstructured correlation matrix. In estimating the model coefficients, we used an independent working correlation structure to allow each episode to have equal influence and to avoid problems with unbalanced sample sizes between hospitals. An identity link was specified in order to allow interpretation of the time trends as linear slopes. No distribution for the outcome variable is required to be assumed; only membership in the exponential family. In addition to the time and time-by-group interaction terms mentioned above, we included indicator variables for month of year (to account for seasonal fluctuations), for never joiners and late joiners, DRGs, individual patient-level CCW comorbidities, and hospital characteristics including ownership, teaching status, rural location, and region. Model results are reported as effect estimates with 95% confidence intervals, unadjusted for multiple testing, and significance levels from standard Wald tests.

The primary model equation for all cost data, as well as healthy days at home, is as follows:

> Expected Total payments = Intercept + Time1 + Time2 + NeverJoiner + LateJoiner + Time1*NeverJoiner + Time1*LateJoiner + Time2*NeverJoiner + Time2*LateJoiner + Month (1-12) + DRG (1-101) + CCW (1-27) + For-Profit-Hospital + Public-Hospital + Minor-Teaching-Hospital + Non-Teaching-Hospital + Urban-Hospital + Midwest-Hospital + Southern-Hospital + Western-Hospital

The impact of the intervention was captured by interaction terms between the continuous variable Time2 and never-joiners, and between Time2 and late joiners, where significance determined whether there had been a greater change in slope in any outcome in patients at BPCI-A hospitals compared to either of the control groups.

The primary model equation for binary clinical outcomes (mortality; readmissions; and the composite of the two), was identical to the above, but with a logit-link (and a binomial distribution) between the probability of the outcome occurring and the predictors on the right-hand side. Secondary models for the cost outcomes used the identical model but with a log-link and a gamma distribution.

Model Assumptions and Limitations: The GEE approach is robust in that a particular distribution for the outcome variable is not required to be specified, only that the distribution be within the exponential family, which included many common distributions including normal, gamma, and logistic. And the approach does not require specification of the correlation structure since the correlation is estimated empirically from the model residuals. We did however specify an independent working correlation structure so that each episode would count equally in the effect estimates and so that imbalances in samples sizes between hospitals would not create a bias. Regardless of the specified working correlation, the effect estimates will be consistent as long as there are a sufficient number of hospitals and our models include over 3000 hospitals. We also assumed an identity link for the mean function, so that covariates would have additive rather than multiplicative effects on the outcome, and so that continuous covariates would have linear rather than curvilinear effects over their range. The incorporation of linear time effects is consistent with other similar studies, is simple to interpret for readers, and is consistent with the visual impression of time trends in our data. To ensure that our results were robust to the selection of a linear link, we show the results of alternative models in Appendix Table S3, where we specified a gamma distribution for the data and a log-link. For the binary clinical outcomes, we specified a binary distribution for the data and a logit-link.

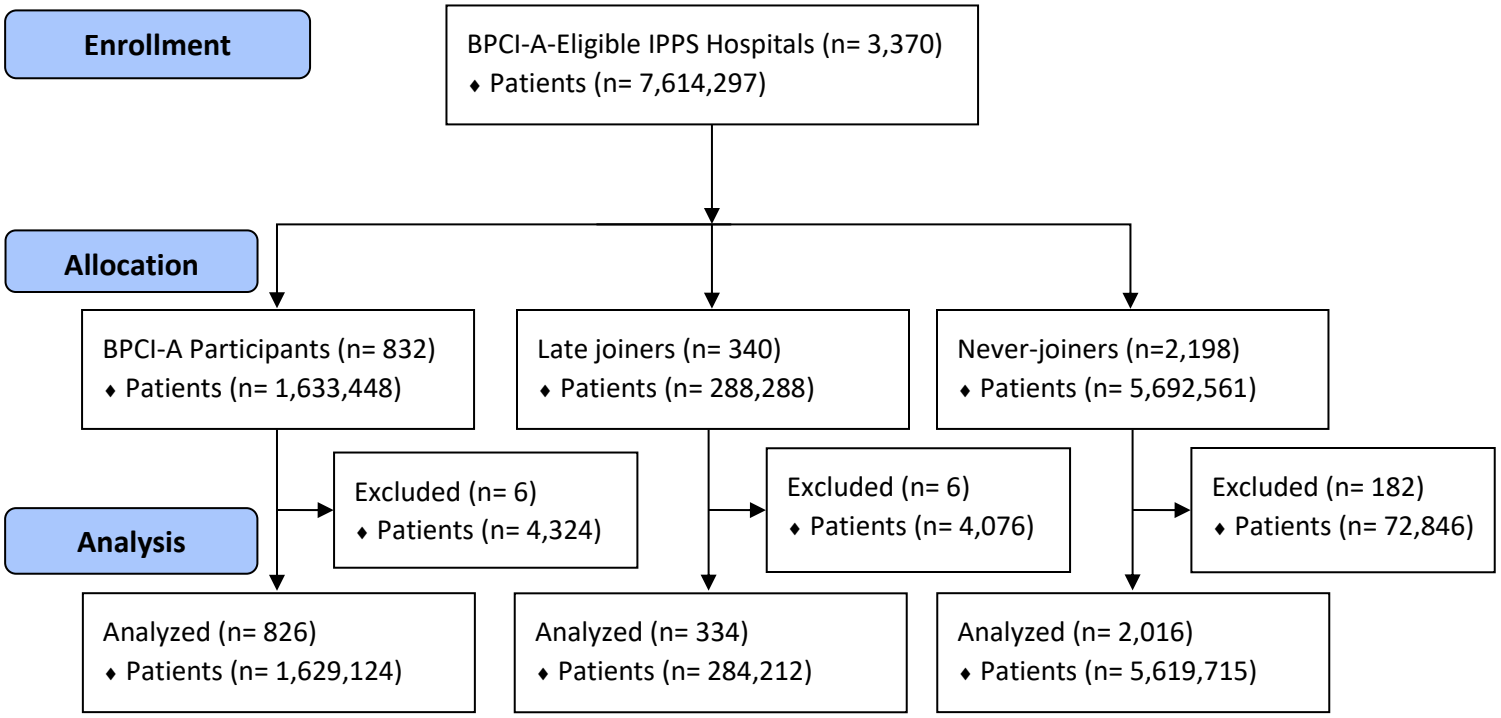
Finally, we hope that the patient and hospital level covariates that have been included in our models (as listed above) have reduced any confounding differences between the three groups of hospitals, although we acknowledge that residual confounding must certainly remain. We have also run and, in the appendix, show the results from an alternative mixed model using hospital random effects. With the mixed model, time trends are estimated primarily from within-hospital changes, so that between hospital differences become less relevant.

In addition to the model assumptions, we included time in the model as a linear predictor (log-linear for the binary outcomes and for the secondary log-link cost models) for a number of reasons. First, for ease of interpretation: slopes and changes in slopes are simple to compare and interpret between groups. Second, because of the relatively short time intervals for both the baseline and intervention periods and because of the appearance of the data in the figures, we believed that linear trends captured the essence of the behavior of the data. Third, we included monthly indicators in all of our analysis models to smooth out any seasonal variations that appeared in the figures of the raw data. And, finally, because adding quadratic terms to the model did not improve the fit of the model, as expressed in the QIC.

An additional limitation unrelated to the model specifications is that we were unable to link all hospitals to the American Hospital Association file to determine key hospital characteristics. This applied to 0.7%, 1.8%, and 8.3% of hospitals in the BPCI-A participants, late joiners, and never-joiners, respectively. Typically, hospitals that are less likely to link are either smaller ones that don't fill out the survey annually, or new/merged hospitals that don't have survey data available yet (i.e. a hospital opens or changes names in 2019, and the 2019 survey data aren't available until 2021). We suspect this is why the numbers are highest in the never-joiners, though we don't know for sure.

Outcome Variables: The primary outcome variables were specified in the study protocol as total costs and 90-day readmission rates. Each of these two outcomes was compared between BPCI-A hospitals and Never-Joiners, and also between BPCI-A hospitals and Late-Joiners. Because this generates 4 p-values, a Bonferroni-adjusted level of $p<0.0125$ was required for significance. No p-values are presented for the secondary outcomes: Index hospitalization costs; SNF costs; Readmission costs; Long-term care costs; Rehabilitation costs; Home health aide costs; Durable medical equipment costs; 30-day readmission rates; 30-mortality rates; 90-day mortality rates; 30-day readmission or mortality rates; 90-day readmission or mortality rates; and Healthy Days At Home.

Figure S1: Hospital Selection Diagram



BPCI-A=Bundled Payments for Care Improvement-Advanced. IPPS=Inpatient Prospective Payment System.

Hospitals that were excluded in the "analysis" level are those that did not link to the American Hospital Association data for hospital characteristics. No patients were excluded other than those at hospitals which were excluded. Patients refer to unique patient episodes rather than unique patients. Patients could appear in the sample more than once if their episodes were at least 90 days apart.

Table S1: Conditions and Hospitals

Condition	BPCI-A Initial Participants	BPCI-A Late Joiners	BPCI-A Never-Joiners
Total	832	340	2198
CONGESTIVE HEART FAILURE	508	34	2198
SEPSIS	480	171	2198
CARDIAC ARRHYTHMIA	409	73	2198
SIMPLE PNEUMONIA AND RESPIRATORY INFECTIONS	402	67	2198
ACUTE MYOCARDIAL INFARCTION	386	68	2198
URINARY TRACT INFECTION	363	62	2198
CHRONIC OBSTRUCTIVE PULMONARY DISEASE	359	95	2198
STROKE	355	54	2198
RENAL FAILURE	314	59	2198
MAJOR JOINT REPLACEMENT OF THE LOWER EXTREMITY	273	26	2198
HIP & FEMUR PROCEDURES EXCEPT MAJOR JOINT	255	24	2198
GASTROINTESTINAL HEMORRHAGE	221	44	2198
PERCUTANEOUS CORONARY INTERVENTION	215	38	2198
CELLULITIS	209	29	2198
GASTROINTESTINAL OBSTRUCTION	177	40	2198
PACEMAKER	134	13	2198
SPINAL FUSION (NON-CERVICAL)	126	0	2198
CORONARY ARTERY BYPASS GRAFT	123	18	2198
BACK & NECK EXCEPT SPINAL FUSION	118	13	2198
MAJOR BOWEL PROCEDURE	110	12	2198
LOWER EXTREMITY AND HUMERUS PROCEDURE EXCEPT HIP	106	8	2198
CERVICAL SPINAL FUSION	96	0	2198
MAJOR JOINT REPLACEMENT OF THE UPPER EXTREMITY	85	19	2198
FRACTURES OF THE FEMUR AND HIP OR PELVIS	82	12	2198
DISORDERS OF LIVER EXCEPT MALIGNANCY	67	12	2198
CARDIAC DEFIBRILLATOR	58	11	2198
CARDIAC VALVE	43	16	2198
DOUBLE JOINT REPLACEMENT OF THE LOWER EXTREMITY	15	1	2198
COMBINED ANTERIOR POSTERIOR SPINAL FUSION	12	0	2198

BPCI-A=Bundled Payments for Care Improvement-Advanced.

Initial participants are those that joined in 10/1/2018 at the initiation of the program. Late joiners are those that joined in 2020, after the follow-up for this study. Never-joiners are the remaining hospitals. Because if a hospital joined for any condition it was excluded from being a control for other conditions, the number of hospitals in this column represents all hospitals that never joined any BPCI-A condition, and thus is the same in every row.

Table S2: Regional and Market Characteristics

	BPCI-A Participants (n=826)	Late Joiners (n=334)		Never-Joiners (n=2016)	
	n/Mean	n/Mean	SMD	n/Mean	SMD
Region – Northeast	19.7%	6.8%	0.36	15.1%	0.12
Region – Midwest	24.3%	24.8%	0.01	22.6%	0.04
Region – South	36.1%	46.9%	0.22	44.4%	0.17
Region – West	19.7%	20.4%	0.02	18.0%	0.04
In system	38.2%	37.0%	0.02	22.4%	0.36
County Level:					
Population 65+ est. 2017	1156593	1113000	0.02	714100	0.27
Median Income 2017	61895	59818	0.13	57112	0.29
% Medicare Advantage 2017	33.8	35.2	0.11	30.2	0.26
SNF beds Per 10,000 in county	5178.0	4920.8	0.03	3143.8	0.30
# Rehabilitation Hosps 2017	0.97	0.94	0.02	0.55	0.33
Market share at county level	0.36	0.39	0.09	0.54	0.44
HHI at county level	0.15	0.14	0.06	0.19	0.22

BPCI-A=Bundled Payments for Care Improvement-Advanced. HHI=Herschman-Herfindahl Index. SMD=standardized mean difference. SNF=skilled nursing facility.

Standardized mean difference is the difference in means between the two groups divided by the pooled standard deviation of the two groups. Each control group is compared to the BPCI-A participant group.

Market share is calculated as the number of hospitalizations in a particular hospital per year divided by the total number of hospitalizations in the county So, for example, if a county had three hospitals, one of which had 500 hospitalizations, one of which had 900 hospitalizations, and one of which had 100 hospitalizations, those hospitals would have market shares of 33%, 60%, and 6.7%, respectively. HHI is calculated as the sum of squares of market shares in a market, in this case a county. So, for the example above, HHI would be calculated as 0.33 squared plus 0.6 squared plus 0.067 squared, or 0.47. The higher the number, the more concentrated the market (if only one hospital exists in a market, their market share is 100% and the HHI is 1*1, or 1); the lower the number, the more competitive the market.

County-level variables represent the means for the entire county in which a hospital is located. So, for example, among counties with a BPCI-A hospital, median income was, on average, $61,895, whereas among counties where never-joiners were located, median income was, on average, $57,112.

Table S3: Changes in Relative Trends in Medicare Payment per Episode, Using Log Link and Gamma Distribution

Outcome	BPCI Groups	Baseline Payments	Relative quarterly decline, baseline	Relative quarterly decline, intervention	Ratio of relative quarterly declines	Ratio of ratios of decline	Lower CI	Upper CI
Total payments*	BPCI-A	$27,315	0.997	0.995	0.997	Ref		
	Never-Joiners	$25,994	0.997	0.995	0.999	1.002	1.001	1.002
	Late Joiners	$26,807	0.995	0.994	1.000	1.003	1.001	1.004
Index hospitalization	BPCI-A	$9,599	0.996	0.995	0.999	Ref		
	Never-Joiners	$10,163	0.996	0.996	1.000	1.001	1.000	1.001
	Late Joiners	$9,409	0.998	0.998	1.000	1.001	1.000	1.002
Skilled Nursing Facilities	BPCI-A	$5,640	0.989	0.984	0.996	Ref		
	Never-Joiners	$5,164	0.991	0.990	0.999	1.004	1.001	1.006
	Late Joiners	$5,571	0.982	0.987	1.004	1.009	1.003	1.014
Readmission	BPCI-A	$4,473	1.003	1.001	0.997	Ref		
	Never-Joiners	$3,924	1.000	0.999	0.999	1.002	1.000	1.004
	Late Joiners	$4,467	0.996	0.996	1.000	1.002	0.998	1.007
Long Term Care Hospitals	BPCI-A	$429	0.942	0.959	1.018	Ref		
	Never-Joiners	$283	0.917	0.937	1.021	1.003	0.984	1.023
	Late Joiners	$387	0.929	0.941	1.013	0.995	0.951	1.041
Inpatient Rehab Facilities	BPCI-A	$717	1.014	1.001	0.988	Ref		
	Never-Joiners	$643	1.004	1.001	0.997	1.010	1.002	1.017
	Late Joiners	$630	1.013	1.004	0.992	1.004	0.988	1.021
Home Health	BPCI-A	$1,252	0.999	0.994	0.996	Ref		
	Never-Joiners	$1,131	0.996	0.991	0.995	1.000	0.998	1.001
	Late Joiners	$1,125	1.002	0.997	0.994	0.999	0.995	1.002
Durable Medical Equipment	BPCI-A	$44	1.014	1.011	0.997	Ref		
	Never-Joiners	$45	1.009	1.008	0.999	1.002	0.999	1.006
	Late Joiners	$38	1.011	1.011	1.000	1.003	0.995	1.011

* To help interpretation, for total payments, for BPCI-A hospitals, costs were declining by 0.3% per quarter (0.997), or approximately $82 per quarter (with diminishing savings each subsequent quarter) during the baseline period. Costs declined more rapidly, 0.5%, in the intervention

period (with the dollar amount depending on the adjusted payment during the 4th quarter of 2018), leading to the relative reduction between the two time periods of 0.997 (0.995/0.997). In the same two time periods, hospitals that never joined BPCI-A also showed a greater savings decline in the intervention period than during the baseline period, but the relative decline was only 0.999 (the numbers in the table do not show enough significant digits to reproduce this calculation). The ratio of the relative declines: 1.002 = (0.999 / 0.997), captures the greater change in BPCI-A hospitals and thereby the relative benefit of the BPCI-A program.

BPCI-A=Bundled Payments for Care Improvement-Advanced. CI=confidence interval. Ratios>1 indicate that BPCI-A was associated with reductions in payments compared to the indicated group. Baseline data represent the raw estimate from the first quarter of the study period.

Table S4: Changes in Trends in Medicare Payments per Episode, Alternative Model Specifications

Outcome	BPCI Groups	Baseline Payments	Baseline quarterly trend	Intervention quarterly trend	Change in trends	Diff in Change	Lower CI	Upper CI
Random hospital effects included in models	BPCI-A	$27,315	-$70	-$147	-$77	Ref		
	Never-Joiners	$25,994	-$89	-$116	-$27	$50	$35	$65
	Late Joiners	$26,807	-$153	-$147	$5	$82	$48	$116
Model including only late joiners as controls	BPCI-A	$27,315	-$74	-$150	-$76	Ref		
	Late Joiners	$26,807	-$151	-$144	$7	$83	$43	$123
Model including only never-joiners as controls	BPCI-A	$27,315	-$32	-$123	-$91	Ref		
	Never-Joiners	$25,994	-$58	-$98	-$40	$51	$33	$69

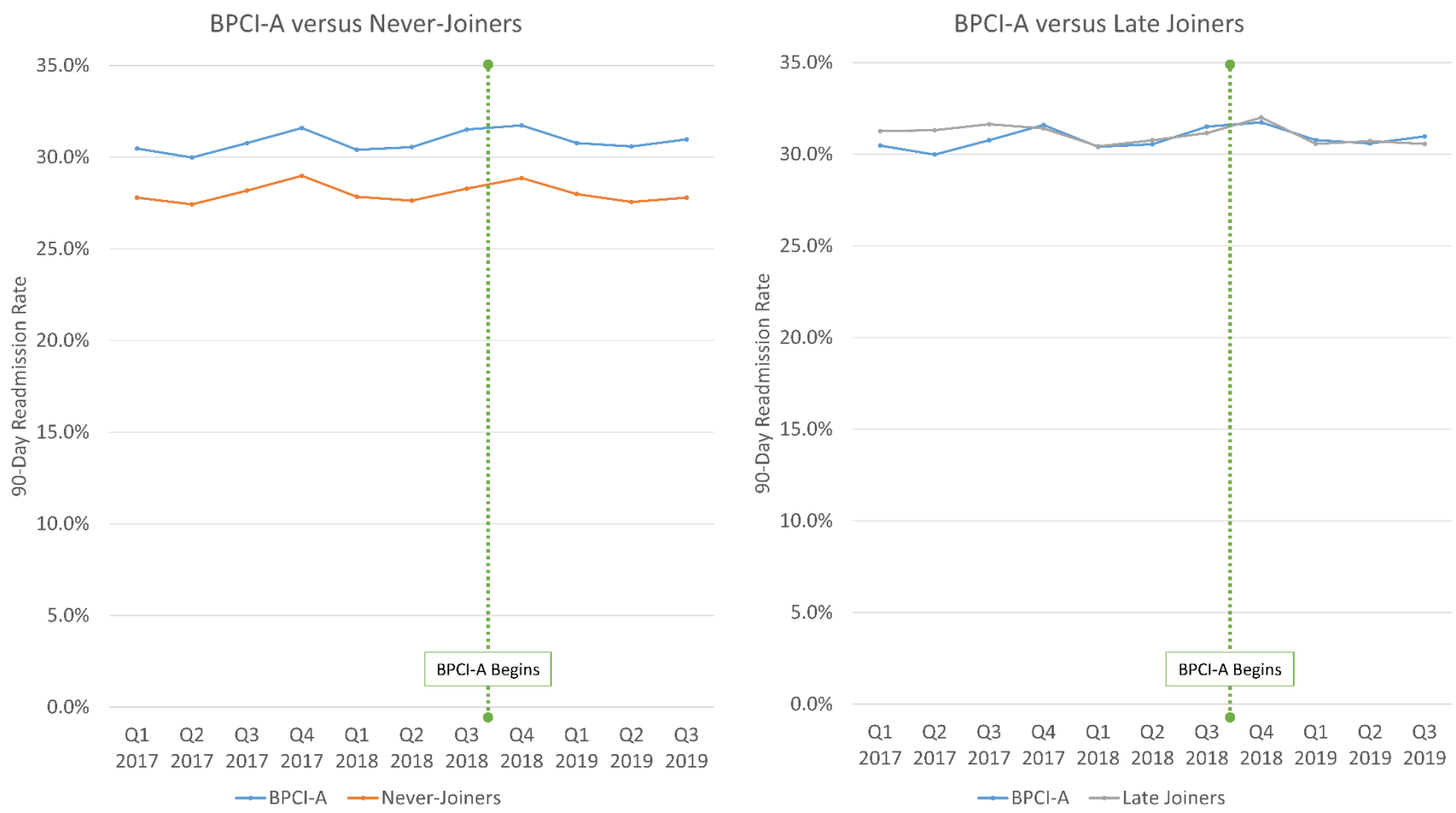
BPCI-A=Bundled Payments for Care Improvement-Advanced. CI=confidence interval.

Table S5: Changes in Trends in Medicare Payments per Episode, by Condition

Condition	BPCI Groups	Baseline Payments	Baseline quarterly trend	Intervention quarterly trend	Change in trends	Diff in Change	Lower CI	Upper CI
Sepsis	BPCI-A	$31,550	-$33	-$106	-$73	Ref		
	Never-Joiners	$29,172	-$15	-$53	-$37	$36	$1	$71
	Late Joiners	$30,561	-$71	-$91	-$20	$53	-$14	$120
Heart Failure	BPCI-A	$28,631	-$121	-$217	-$96	Ref		
	Never-Joiners	$27,147	-$97	-$195	-$98	-$1	-$42	$39
	Late Joiners	$28,182	-$271	-$323	-$53	$44	-$141	$229
Pneumonia	BPCI-A	$23,022	-$90	-$146	-$56	Ref		
	Never-Joiners	$21,930	-$154	-$163	-$9	$47	$8	$85
	Late Joiners	$22,657	-$254	-$174	$80	$135	$3	$268
Cardiac Arrhythmia	BPCI-A	$19,798	-$16	-$69	-$53	Ref		
	Never-Joiners	$19,461	-$84	-$87	-$3	$50	$4	$96
	Late Joiners	$19,600	-$30	-$122	-$92	-$39	-$215	$138
COPD	BPCI-A	$22,087	-$31	-$91	-$61	Ref		
	Never-Joiners	$20,300	-$37	-$65	-$28	$32	-$12	$76
	Late Joiners	$21,193	-$48	-$98	-$50	$11	-$116	$137
Myocardial Infarction	BPCI-A	$27,716	-$153	-$172	-$19	Ref		
	Never-Joiners	$26,704	-$88	-$136	-$47	-$29	-$102	$45
	Late Joiners	$27,750	-$167	-$143	$24	$43	-$186	$271
Urinary tract infection	BPCI-A	$25,133	-$59	-$101	-$42	Ref		
	Never-Joiners	$23,430	-$43	-$48	-$5	$37	-$10	$83
	Late Joiners	$23,518	-$207	-$69	$137	$179	$38	$320
Stroke	BPCI-A	$29,904	-$157	-$216	-$59	Ref		
	Never-Joiners	$29,794	-$155	-$182	-$27	$32	-$27	$91
	Late Joiners	$29,825	-$435	-$296	$140	$199	$38	$359
Renal Failure	BPCI-A	$26,520	-$76	-$107	-$31	Ref		
	Never-Joiners	$25,270	-$67	-$87	-$20	$11	-$38	$61
	Late Joiners	$26,820	-$336	-$170	$166	$197	$64	$330
GI Bleed	BPCI-A	$23,440	-$88	-$61	$27	Ref		
	Never-Joiners	$21,545	-$43	-$38	$5	-$22	-$71	$27
	Late Joiners	$23,931	-$364	-$257	$108	$81	-$83	$244

BPCI-A=Bundled Payments for Care Improvement-Advanced. CI=confidence interval. COPD=chronic obstructive pulmonary disease. GI=gastrointestinal.

Figure S2: 90-Day Readmissions by Quarter, Among Participants, Never-Joiners, and Late Joiners



BPCI-A=Bundled Payments for Care Improvement-Advanced.

Table S6: Changes in Trends in Volume and Case Mix

Outcome	BPCI Groups	Baseline Values	Baseline quarterly trend	Intervention quarterly trend	Change in trends	Diff in Change	Lower CI	Upper CI
Quarterly volume	BPCI-A	30.3	-0.52	-0.37	0.15	Ref		
	Never-Joiners	16.0	-0.21	-0.13	0.08	-0.08	-0.11	-0.04
	Late Joiners	29.6	-0.54	-0.33	0.21	0.06	-0.02	0.13
Age≥80	BPCI-A	44.3%	-0.30%	-0.17%	0.13%	Ref		
	Never-Joiners	40.1%	-0.22%	-0.12%	0.10%	-0.03%	-0.07%	0.02%
	Late Joiners	43.1%	-0.39%	-0.23%	0.15%	0.03%	-0.06%	0.11%
Percent female	BPCI-A	56.5%	0.01%	-0.03%	-0.03%	Ref		
	Never-Joiners	56.4%	-0.01%	-0.04%	-0.02%	0.01%	-0.03%	0.05%
	Late Joiners	56.2%	-0.12%	-0.10%	0.01%	0.05%	-0.05%	0.14%
Percent Black	BPCI-A	10.0%	0.01%	-0.03%	-0.03%	Ref		
	Never-Joiners	9.0%	-0.03%	-0.05%	-0.02%	0.01%	-0.01%	0.04%
	Late Joiners	10.0%	-0.01%	-0.05%	-0.03%	0.00%	-0.06%	0.06%
Average n of CCWs	BPCI-A	4.30	-0.002	0.005	0.007	Ref		
	Never-Joiners	4.03	-0.000	0.005	0.005	-0.002	-0.004	0.000
	Late Joiners	4.20	-0.006	0.001	0.007	0.000	-0.004	0.004
Percent in highest-complexity DRG	BPCI-A	47.8%	0.21%	0.26%	0.05%	Ref		
	Never-Joiners	41.2%	0.12%	0.19%	0.06%	0.01%	-0.03%	0.06%
	Late Joiners	54.4%	0.02%	0.11%	0.10%	0.05%	-0.05%	0.14%
Percent with outlier payments	BPCI-A	1.8%	-0.10%	-0.04%	0.05%	Ref		
	Never-Joiners	6.3%	-0.09%	-0.03%	0.06%	0.01%	-0.01%	0.03%
	Late Joiners	2.0%	-0.11%	-0.05%	0.06%	0.01%	-0.02%	0.03%

BPCI-A=Bundled Payments for Care Improvement-Advanced. CCW=Chronic Conditions Warehouse, indicative of the number of major comorbidities. CI=confidence interval. DRG=Diagnosis-Related Group, which indicates both clinical condition and degree of complexity (e.g. heart failure with major complications or comorbidities, heart failure with complications or comorbidities, heart failure without complications or comorbidities).