http://dx.doi.org/10.2106/JBJS.21.0259

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APPENDIX

Appendix Exhibit 1: Definition and construction of outcomes and covariates

To identify ***outcomes***, we first adjudicated claims categories based on a combination of revenue codes, provider categories, procedure codes, type-of-bill codes, and timing of claims (Table S1).

We defined discharge destinations based on the types of claims that followed discharge from the index hospitalization. We categorized episodes as discharged to institutional post-acute care settings if there were skilled nursing, inpatient rehabilitation, or long-term care claims within one day of discharge from the index hospitalization; we categorized them as discharged to home with home health services if there were home health service claims within seven days of discharge.[1]

We adjusted expenditures for cost of living using MSA-level wage indexes published by Centers for Medicare & Medicaid Services.[2] Because MSA definitions changed in 2015, we created a time-series dataset of wage indexes by MSA or, for those MSAs with metropolitan division codes, by division code. The dataset included a crosswalk for MSAs and zip codes. For those observations that were missing MSA or metropolitan division codes in HCCI data, we matched by provider zip code. For observations missing metropolitan division code and provider zip code, we used the mean wage index for the entire MSA.

Our ***covariates*** included age, which, in HCCI data, is only available as a categorical variable with five levels (45-54, 55-64, 65-74, 75-84, and 85+); gender; insurance plan details (including plan type, and, for commercial insurance, indicators for high-deductible plans and individual market plans); type of joint replacement; Elixhauser readmission score (as a categorical variable with four levels (< -1, 0-3, 4-10, or > 10); major complications or comorbidities during the index hospitalization (identified as MS-DRG 469 versus 470); and the MSA-level percentage of hospitals ineligible for the CJR program due to participation in the Bundled Payments for Care Improvement program. HCCI data do not include each enrollee’s racial, ethnic, or socioeconomic variables, so we adjusted for 5-year estimates from the American Community Survey of the percent of the population within patients’ zip codes below the Federal poverty level, the percent with at least a high school education, and percent non-Hispanic white. For observations with missing zip codes, we used the MSA-level mean for these variables.

http://dx.doi.org/10.2106/JBJS.21.0259

Appendix Exhibit 2: Model specification and assumptions

The model specification is as follows:

$$y_{imt} = \beta_0 + \beta_1 \mathbb{I}(t \geq 2016) \times d + \beta_x \mathbf{x} + \alpha_m + \gamma_t + \varepsilon_{imt}$$

where y_{imt} is the outcome for individual i in MSA m during quarter-year t, and d = 1 if the joint replacement took place in an MSA assigned to CJR, or 0 otherwise. In addition, α_m are MSA fixed effects, γ_t are time fixed effects, and ε_{imt} are residual errors. Finally, $\mathbf{x}$ includes age group, gender, zip code-level demographics and socioeconomic factors (percent living under the federal poverty line, percent with a high school education, and percent non-Hispanic white), type of insurance plan, type of lower extremity joint replacement (knee elective, hip elective, or hip fracture), Elixhauser readmission score, major complications (MS-DRG 469 versus 470), and MSA-level percentage of hospitals participating in the Bundled Payments for Care Improvement program. Models for the commercial insurance stratum were also adjusted for indicators of high deductible plans and individual market plans. We estimated the spillover effect by including the interaction between a binary measure for admission in 2016 or 2017 and a binary measure for joint replacements that took place in one of the 67 MSAs assigned to CJR (versus joint replacements in the 103 comparison MSAs). The coefficient β_1 estimates the size of spillover effects.

To provide flexibility in accounting for differences between CJR and comparison MSAs in secular trends, we also conducted a sensitivity analysis where we adjusted for differential linear time trends by including the interaction between the binary measure of CJR MSA and continuous measure of year-quarter. We found that estimates of spillover effects did not differ meaningfully between two models with and without differential linear time trends included (Table S2 and Table S3). In addition, the differential linear trend terms were not significant in all models that included linear time trends (Table S2 and Table S3).

Because CMS randomized MSAs within 8 strata to oversample from MSAs with historically higher costs, we applied inverse probability weights, normalized by strata, to all models and tabulations.[3] We also clustered standard errors on each MSA.

Parallel Pre-Trends Test To evaluate the assumption that the 103 comparison MSAs provide a reasonable counterfactual for the intervention in the 67 CJR MSAs, we limited the sample to the pre-intervention period and performed a joint test of treatment-by-time interaction terms. Specifically, we fit a model that included quarter-year fixed effects and all of the adjustments in the vector $\mathbf{x}$ described above, and quarter-years interacted with indicators for joint replacements performed in CJR MSAs. We also fit a nested model that omits the quarter-year-by-CJR interactions. We then conducted a Wald test of nested models.

Two outcomes (readmission and outpatient expenditures) in the analysis of commercial insurance patients and three outcomes (discharges to inpatient rehabilitation facilities, discharges to home without services, and index hospitalization length of stay) in the analysis of Medicare Advantage patients violated the parallel pre-trends assumption, but sensitivity analyses of these outcomes that included an adjustment for differential linear trends did not show meaningful differences. See Table S2 and Table S3.

References

1. Kim H, Grunditz JI, Meath THA, Quiñones AR, Ibrahim SA, McConnell KJ. Accuracy of Hospital Discharge Codes in Medicare Claims for Knee and Hip Replacement Patients: *Medical Care*. Published online January 2020:1. doi:10.1097/MLR.0000000000001290
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http://dx.doi.org/10.2106/JBJS.21.0259

Table S1. Adjudication of claim categories.

	Data source		
Category[1]	Inpatient	Physician	Outpatient
Skilled nursing facility	Revenue code 0022, POS 31[2]-32[3(page 6)], or TOB 21-23[2]	Revenue code 0022, POS 31[2]-32[3], or TOB 21-23[2]	~
Home with services	Provider category 0036-0037, Revenue code 0023, or TOB 32-34[2]	Provider category 0036-0037, Revenue code 0023, or TOB 32-34[2]	Procedure codes 99500-99602 or TOB 300-399[3]
Long term care hospital	Provider category 0110[2]	Provider category 0110[2]	
Inpatient rehabilitation facility	POS 61 or Revenue code 0024[2]	POS 61 or Revenue code 0024[2]	~
Emergency department	First & last dates outside initial index admit & discharge dates and revenue code 0450-0459[3(page 23),4] or 0981[4]	First & last dates outside initial index admit & discharge dates and procedure code 99281-99292 or 99466-99476[3]	Revenue code 0450-0459[3,4] or 0981[4] or procedure code 99281-99292 or 99466-99476[3]
Index stay	First & last dates within initial index admit & discharge dates and not otherwise classified as SNF, LTCH, IRF, HH, or ED	First & last dates within initial index admit & discharge dates and not otherwise classified as SNF, LTCH, IRF, HH, or ED	Meets criteria for ED but takes place during the index stay (index admission through ED)
Readmission	First date outside of initial index admit & discharge dates and not otherwise classified as SNF, LTCH, IRF, HH, or ED	First date outside of initial index admit & discharge dates and POS 21, 34, or 55	~
Other outpatient	~	Not otherwise classified	Not otherwise classified as HH, ED, or DME.

[1] Claim categories listed in hierarchical order.
[2] Biniek, Jean Fuglesten, Bloschichak, Aaron, Rodriguez, Sally. Comparing Post-Acute Care Use and First Site of Care Among Medicare Advantage Enrollees and Medicare Fee-for-Service Beneficiaries. Health Care Cost Institute; 2019. https://healthcostinstitute.org/hcci-research/comparing-post-acute-care-use-and-first-site-of-care-among-medicare-advantage-enrollees-and-medicare-fee-for-service-beneficiaries. Accessed April 13, 2020. Page 5.
[3] 2017 *Health Care Cost and Utilization Report: Analytic Methodology*. Health Care Cost Institute; 2019. https://healthcostinstitute.org/images/pdfs/HCCI_2017_Methodology_public_v1.0.pdf. Accessed April 13, 2020.

[4] ResDAC. How to Identify Hospital Claims for Emergency Room Visits in the Medicare Claims Data. https://www.resdac.org/resconnect/articles/144. Published 2015.

http://dx.doi.org/10.2106/JBJS.21.0259

Table S2. Evaluation of parallel trends, primary outcomes.

	ATT[a] adjusted for trend[b]	ATT not adjusted for trend[c]	Differential linear trend (CI)[d]	p[e]	Range of coefficients, non-linear trend[f]	p[g]
Discharge to institutional PAC						
CI	0.0% (-2.4%, 2.3%)	-0.9% (-5.1%, 3.2%)	-0.3% (-1.2%, 0.7%)	0.579	(-1.3%, 0.4%)	0.427
MA	-3.1% (-7.2%, 0.9%)	-2.0% (-5.8%, 1.7%)	0.3% (-0.5%, 1.1%)	0.399	(0.7%, 3.9%)	0.380
Total expenditures, $						
CI	-60 (-1,846, 1,725)	-138 (-2,119, 1,843)	-23 (-508, 461)	0.925	(-1,157, 313)	0.381
MA	1,012 (123, 1,902)	650 (-114, 1,414)	-112 (-320, 96)	0.289	(-581, 385)	0.772
Readmission						
CI	1.3% (-0.7%, 3.3%)	0.7% (-1.8%, 3.3%)	-0.2% (-0.8%, 0.4%)	0.543	(-1.6%, 1.7%)	0.015
MA	1.0% (-0.8%, 2.8%)	0.6% (-0.7%, 2.0%)	-0.1% (-0.5%, 0.3%)	0.601	(-1.1%, 0.7%)	0.679

[a]*ATT = Average effect of treatment on the treated*
[b]*Main analytic model*
[c]*Sensitivity analysis*
[d]*Estimate and 95% confidence interval for* β_3 *(see model specification in supplemental section S5)*
[e]*t-test for the coefficient* β_3
[f]*Range of coefficients for time fixed effects in a model fit to the pre-intervention period only, including all adjustments described in supplemental section S5.*
[g]*Wald test of nested models, comparing models with and without time-by-treatment interactions after restricting the dataset to the pre-intervention period.*

Table S3. Evaluation of parallel trends, secondary outcomes.

	ATT[a] adjusted for trend[b]	ATT not adjusted for trend[c]	Differential linear trend (CI)[d]	p[e]	Range of coefficients, non-linear trend[f]	p[g]
Discharge to SNF						
CI	-0.6% (-2.2%, 1.1%)	-1.4% (-5.3%, 2.4%)	-0.3% (-1.2%, 0.7%)	0.587	(-1.3%, 0.3%)	0.799
MA	-3.5% (-7.3%, 0.2%)	-2.8% (-6.3%, 0.8%)	0.2% (-0.6%, 1.1%)	0.575	(0.4%, 2.9%)	0.668
Discharge to IRF						
CI	0.6% (-0.7%, 2.0%)	0.5% (-0.5%, 1.5%)	0.0% (-0.2%, 0.1%)	0.703	(-0.6%, 0.4%)	0.552
MA	0.4% (-0.5%, 1.3%)	0.7% (-0.4%, 1.9%)	0.1% (-0.1%, 0.3%)	0.313	(0.1%, 1.0%)	0.025
Discharge to LTCH						
CI	-0.1% (-0.2%, 0.0%)	0.0% (-0.1%, 0.1%)	0.0% (0.0%, 0.1%)	0.357	(0.0%, 0.1%)	0.401
MA	0.0% (-0.1%, 0.0%)	0.0% (-0.1%, 0.0%)	0.0% (0.0%, 0.0%)	0.293	(0.0%, 0.1%)	0.618
Discharge to home health						
CI	4.8% (-1.0%, 10.6%)	3.1% (-6.1%, 12.3%)	-0.5% (-2.8%, 1.8%)	0.674	(-5.3%, 1.5%)	0.172
MA	1.7% (-2.9%, 6.3%)	3.0% (-2.8%, 8.8%)	0.4% (-0.8%, 1.6%)	0.509	(-2.7%, 0.3%)	0.084
Discharge to home						
CI	-4.8% (-10.0%, 0.5%)	-2.2% (-8.6%, 4.2%)	0.8% (-1.0%, 2.6%)	0.399	(-0.2%, 6.6%)	0.169
MA	1.5% (-3.4%, 6.3%)	-0.9% (-5.1%, 3.2%)	-0.7% (-1.9%, 0.4%)	0.190	(-4.2%, 0.4%)	0.022
Length of index stay, days						
CI	-0.31 (-0.64, 0.03)	-0.08 (-0.46, 0.30)	0.07 (-0.04, 0.17)	0.212	(-0.07, 0.18)	0.168
MA	-0.31 (-0.80, 0.19)	-0.16 (-0.40, 0.08)	0.05 (-0.07, 0.16)	0.418	(-0.24, 0.33)	0.029
Days of institutional PAC						
CI	-0.07 (-0.44, 0.31)	-0.14 (-0.77, 0.49)	-0.02 (-0.15, 0.11)	0.725	(-0.20, 0.13)	0.431
MA	-0.26 (-1.05, 0.54)	-0.25 (-1.07, 0.58)	0.00 (-0.20, 0.21)	0.978	(0.06, 0.78)	0.154
ED visits						
CI	0.1% (-1.2%, 1.5%)	0.3% (-0.6%, 1.2%)	0.0% (-0.3%, 0.4%)	0.814	(-2.4%, -0.1%)	0.296
MA	1.1% (-0.3%, 2.5%)	0.8% (0.0%, 1.6%)	-0.1% (-0.5%, 0.3%)	0.596	(-0.9%, 1.3%)	0.470

http://dx.doi.org/10.2106/JBJS.21.0259

	ATT[a] adjusted for trend[b]	**ATT not adjusted for trend[c]**	**Differential linear trend (CI)[d]**	**p[e]**	**Range of coefficients, non-linear trend[f]**	**p[g]**
Index stay expenditures, $						
CI	217 (-1,408, 1,841)	60 (-1,761, 1,882)	-47 (-452, 357)	0.819	(-874, -244)	0.660
MA	393 (-41, 828)	230 (-202, 661)	-51 (-201, 99)	0.506	(-516, 178)	0.179
Institutional PAC expenditures, $						
CI	60 (-237, 358)	21 (-334, 376)	-12 (-55, 31)	0.586	(-116, 19)	0.424
MA	189 (-198, 575)	75 (-296, 447)	-35 (-123, 53)	0.431	(-250, 246)	0.166
Home health expenditures, $						
CI	46 (-54, 146)	20 (-171, 212)	-8 (-50, 34)	0.715	(-149, 15)	0.057
MA	76 (-77, 229)	87 (-94, 268)	3 (-41, 48)	0.882	(-27, 79)	0.891
Outpatient expenditures, $						
CI	-89 (-337, 160)	-99 (-406, 208)	-3 (-104, 98)	0.952	(-244, 169)	0.033
MA	216 (84, 349)	105 (18, 192)	-34 (-68, -1)	0.044	(-108, 133)	0.135

[a]*ATT = Average effect of treatment on the treated*
[b]*Main analytic model*
[c]*Sensitivity analysis*
[d]*Estimate and 95% confidence interval for* β_3 *(see model specification in supplemental section S5)*
[e]*t-test for the coefficient* β_3
[f]*Range of coefficients for time fixed effects in a model fit to the pre-intervention period only, including all adjustments described in supplemental section S5.*
[g]*Wald test of nested models, comparing models with and without time-by-treatment interactions after restricting the dataset to the pre-intervention period.*