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This supplementary material has been provided by the authors to give readers additional information about their work.
SUPPLEMENTARY APPENDIX

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I. Derivation of analytic cohort

Our analytic cohort consisted of a random 20% sample of Medicare beneficiaries age 65 and older with continuous fee-for-service Medicare (i.e., Part A and Part B) coverage in 2013 or 2014 and in the immediately preceding year (required to assess baseline health). (The Centers for Medicare and Medicaid Services [CMS] assesses hospital readmissions for Medicare beneficiaries age 65 and older.) For decedents in a given year, we required continuous enrollment during the year until the date of death. We also excluded beneficiaries in ZIP codes (e.g., U.S. territories) that could not be linked to geographic measures of socioeconomic status.

Among remaining beneficiaries, we limited our sample to those with at least 1 unplanned hospital admission in 2013 or 2014. We excluded admissions and readmissions that were planned based on CMS definitions. CMS excludes readmissions for planned conditions in the HRRP, and index admissions in the Hospital Readmission Reduction Program (HRRP) are largely unplanned (i.e., myocardial infarction, congestive heart failure, and pneumonia are unanticipated health events or may be exacerbations of existing chronic conditions). We also excluded admissions and readmissions for cancer or psychiatric conditions (consistent with CMS definitions for hospital-wide readmissions).

Among unplanned admissions, we included only those that (1) occurred in an acute care hospital not subject to the HRRP; (2) did not result in transfer to another hospital, an in-hospital death, or a patient leaving the hospital against medical advice; (3) occurred prior to December 1\textsuperscript{st} 2014 (so that we could assess a 30-day outcomes); and (4) were not preceded by a 30-day “clean” period without a prior inpatient admission. We refer to these admissions as index admissions. The HRRP imposes a condition-specific version of this 30-day clean period by stipulating that readmissions for a condition targeted in the HRRP, following an admission for the same condition, cannot count as index admissions. In each study year and for each beneficiary, we sampled one index admission meeting these inclusion criteria, and assessed outcomes within 30 days of discharge from the index admission. In the analyses presented here, we sampled the patient’s first inpatient admission, although we found no appreciable difference in results when using a randomly sampled index admission.

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To ensure we had an adequate sample of index admissions per hospital to measure performance reliably, we limited our analyses to admissions occurring in hospitals with at least 200 index admissions in our 20% study sample of fee-for-service Medicare beneficiaries during the period 2013-2014. With this exclusion, our analysis included 2,215 hospitals. We selected the threshold of 200 or more index admissions based on exploratory analyses determining that lower-volume hospitals might provide an insufficient sample of index admissions to reliably assess between-hospital variation in readmission rates even when using hierarchical models to account for the contribution of sampling error to between-hospital variation.

Our inclusion criteria yielded a sample of 1,169,014 index admissions among 1,003,664 unique Medicare beneficiaries. The derivation of our analytic sample is illustrated in eFigure 1. Of the 2,215 hospitals in our sample, 1,107 (50%) had at least 631 index admissions and 1,661 (75%) had at least 376 index admissions during the study period.

In supplementary analyses that examined the combined outcome of 30-day readmission or mortality, we included index admissions in which patients died in the hospital but continued to exclude transfers and planned admissions. This supplementary analysis included 1,220,460 index admissions among 1,047,021 unique Medicare beneficiaries.
eFigure 1: Derivation of analytic cohort

Medicare beneficiaries ≥ age 65 in 2013 or 2014 with continuous fee-for-service (Part A & B) enrollment in current & prior year

9.73 million beneficiary-years

Excluded beneficiaries

Living in ZIP codes not linkable to area-level Census data 464,054 beneficiary-years

No inpatient admission in study year 8.03 million beneficiary-years

Medicare beneficiaries with ≥1 index admission

2.87 million admissions over 1.24 million beneficiary-years

Excluded admissions

525,379 admissions that were planned for cancer or psychiatric diseases

285,632 admissions in hospitals exempt from the HRRP

140,058 admissions in which the patient died in the hospital, was transferred to another hospital, or left the hospital against medical advice

30,486 admissions in December 2014

119,113 admissions in hospitals with fewer than 200 index admissions in 2013-14

Admission sample

1,773,423 admissions

Exclusions:

Final sample: sample first index admission per patient per year

1,169,014 index admissions among 1,003,664 unique beneficiaries in 2,215 hospitals

Notes: Frequencies based on a random 20% sample of fee-for-service Medicare beneficiaries.

* Per CMS definitions for the hospital-wide all-cause unplanned readmission measure, planned admissions include transplant surgeries, maintenance chemotherapy or immunotherapy, rehabilitation, and scheduled procedures.

* Per CMS definitions, excluded admissions for cancer are those with AHRQ Clinical Classification Software (CCS) codes 11-45; excluded admissions for psychiatric diseases are those with AHRQ CCS codes 650-659, 662, and 670.

* Hospitals exempt from Medicare’s Hospital Readmission Reduction Program include long-term, rehabilitation, children’s, psychiatric, and critical access hospitals, as well as all hospitals in Maryland.

* Excluding index admissions preceded within 30 days by a prior admission for the same patient.
II. Description of Covariates

This section describes the construction of clinical and social covariates that we added to our models.

a. Additional clinical measures

- **Hierarchical Condition Categories (HCCs):** We included indicators for 63 of 70 Hierarchical Condition Categories that are used by CMS to construct prospective patient-level HCC risk scores; HCC scores predict patient-level resource utilization in a year ($t$) based on diagnoses on inpatient and outpatient claims in the previous year ($t-1$). Hierarchical Condition Categories aggregate diagnosis codes into clinically similar groups of diseases by body system. We excluded 7 HCC indicators with low or no prevalence (<0.1%) in our sample.

- **Medicare Chronic Condition Data Warehouse (CCW) Conditions:** We used the CCW to characterize the cumulative chronic disease burden of Medicare beneficiaries through the year preceding the beneficiary’s index admission. We assessed the presence of 27 chronic conditions: Alzheimer’s disease, Alzheimer’s disease and related disorders or senile dementia, anemia, asthma, atrial fibrillation, benign prostatic hyperplasia, breast cancer, cataract, chronic kidney disease, chronic obstructive pulmonary disease, colorectal cancer, depression, diabetes, endometrial cancer, glaucoma, heart failure, hip or pelvic fracture, hyperlipidemia, hypertension, hypothyroidism, ischemic heart disease, lung cancer, osteoporosis, prostate cancer, acute myocardial infarction, rheumatoid arthritis, and stroke or transient ischemic attack. In our risk adjustment analyses, we included indicators for each of these conditions and for having $\geq 6$ or $\geq 9$ conditions.

- **Disability:** We assessed beneficiaries’ disability status using original reason for Medicare entitlement (OREC) codes in Medicare enrollment data in the Beneficiary Summary File.

- **End-stage renal disease:** We assessed the presence of end-stage renal disease using concurrent eligibility codes in the Beneficiary Summary File.
• **Long-term nursing home residence:** Employing a previously validated algorithm,\(^4\) we constructed an indicator for whether a beneficiary resided in a nursing home for \(\geq 2\) months of the study year without concomitant facility billing, indicating long-term nursing home residence beyond the 60-day period during which Medicare beneficiaries can receive post-acute care without per-diem coinsurance.

**b. Additional social measures**

• **Insurance coverage:** We used monthly Medicare-Medicaid dual eligibility and drug subsidy codes included in the Medicare Beneficiary Summary File to annually assess beneficiaries’ receipt of Medicaid, prescription drug subsidies, and prescription drug coverage. We constructed these variables sequentially, defining mutually exclusive subsidy and insurance coverage categories in the following order:

1. **Dual enrollment in Medicare and Medicaid:** This category consisted of Medicare beneficiaries with \(\geq 1\) month of full dual Medicaid coverage in the study year, whom we identified as beneficiaries with dual eligibility codes ‘02’ (QMB and full Medicaid coverage), ‘04’ (SLMB and full Medicaid coverage), or ‘08’ (other dual eligible with full Medicaid coverage).

2. **Recipient of a Medicare Savings Program (partial Medicaid enrollment):** This category consisted of beneficiaries with \(\geq 1\) month of enrollment in a Medicare Savings Program, encompassing the Qualified Medicare Beneficiary (dual eligibility code ‘01’), Specified Low-Income Medicare Beneficiary (dual eligibility code ‘03’), and Qualifying Individual programs (dual eligibility code ‘06’).

3. **Receipt of the Part D Low-Income Subsidy (LIS) among beneficiaries not automatically qualifying through Medicaid enrollment:** We included an indicator for beneficiaries receiving LIS subsidies for \(\geq 1\) month of the study year who did not automatically qualify for the LIS as a consequence of receiving full or partial Medicaid benefits.\(^5,6\) We identified
these LIS recipients from low-income cost share group codes in Medicare enrollment data (codes ‘04,’ ‘05,’ ‘06,’ ‘07,’ and ‘08’). (Beneficiaries with low-income cost share group codes ‘01,’ ‘02,’ and ‘03’ are “deemed” eligible for the Part D LIS because they receive full or partial Medicaid benefits, and thus are captured in the prior categories.)

4. **Prescription drug coverage without subsidies (reference group in regression models):**

   We constructed an indicator for beneficiaries who received prescription drug coverage through a Part D plan, through an employer receiving the Retiree Drug Subsidy, or through another creditable plan for ≥1 month of the study year, excluding beneficiaries receiving full or partial Medicaid benefits or the LIS in any month of the year. Using survey data on sources of supplemental sources of insurance coverage from the Consumer Assessment of Healthcare Providers and Systems (CAHPS) with linked Medicare claims data for fee-for-service beneficiaries, we determined that having a source of prescription drug coverage was strongly associated with having a source of supplemental coverage for medical care.

5. **No subsidies or prescription drug coverage:** This category consisted of Medicare beneficiaries who did not receive full or partial Medicaid benefits, the Part D LIS, or prescription drug coverage in any month of the study year. Based on our analysis of the CAHPS data, they were also unlikely to have supplemental medical coverage.

- **Area-level covariates:** We assessed several area-level measures of socioeconomic status for populations age 65 and older using linked ZIP-Code Tabulation Area (ZCTA) and Census Tract-level data from the American Community Survey 5-year (2010-2014) pooled estimates file: (1) the poverty rate; (2) the proportion of households with annual income <$50,000; (3) educational attainment (proportion of individuals with less than a high school education vs. a college education or higher [treating high school completion as the reference group]); and (4) the proportion of individuals living alone.

- **Interactions:** We included 2-way interactions between the following covariates: insurance coverage (categorized as dual Medicare and Medicaid enrollment, receipt of partial Medicaid
benefits via a Medicare Savings Program, LIS enrollment, and no subsidies/prescription drug coverage), disability, end-stage renal disease, age (continuous), count of CCW conditions, count of HCC indicators, and nursing home residence. To account for income differences among dual enrollees across states, we also interacted a patient-level indicator of dual status with the Medicaid income eligibility limit for aged, blind, and disabled persons in the beneficiary’s state.

III. Statistical analyses

a. Statistical analysis overview

We conducted two complementary analyses to quantify the effects of adjusting for several sets of patient characteristics, in addition to those CMS currently uses to risk adjust readmissions, on estimates of hospital performance and on penalties in programs structured like the HRRP. For both analyses, we used methods to adjust only for the within-hospital relationship between patient characteristics and readmissions, but not for differences between hospitals. In our first set of analyses, we examined changes in the distribution of hospitals’ risk-adjusted performance scores based on the covariances of hospitals’ scores before and after adjusting for additional patient characteristics. In the second set of analyses, we compared adjusted readmission rates of hospitals grouped in each of two ways: (1) by a measure of the average clinical and social risk of their Medicare patients, and (2) by the proportion of Medicare patients dually enrolled in Medicaid, before vs. after further adjustments. We repeated these analyses using a composite outcome of 30-day readmission or mortality. Both analyses used the following underlying approach for risk adjustment.

b. Adjusting hospitals’ readmission rates for differences in patient risk

We adjusted hospitals’ readmission rates for observed differences in patient characteristics, excluding from our adjustments between-hospital differences that may reflect variation in quality. To implement this adjustment, we fitted linear probability models with a pooled estimator of the coefficients of patient characteristics and a single additive parameter for each hospital (i.e., hospital fixed effects), which constituted each hospital’s specific effect on the probability of readmission. We excluded these hospital-
specific effects from adjustments in subsequent stages of our estimation. Specifically, for each patient $i$’s index admission in hospital $h$ during year $t$, we estimated the probability of readmission as a function of patient characteristics and hospital fixed effects:

<table>
<thead>
<tr>
<th>Risk Adjustment Model</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Base CMS adjustments</td>
<td>$Pr(\text{readmit}<em>{iht} = 1) = \alpha_1 + X</em>{iht}'\beta_1 + \varphi_1_{hospital_h} + \epsilon_{1,iht}$</td>
</tr>
<tr>
<td>(2) + clinical adjustments</td>
<td>$Pr(\text{readmit}<em>{iht} = 1) = \alpha_2 + X</em>{iht}'\beta_2 + H_{iht}'\gamma_2 + \varphi_2_{hospital_h} + \epsilon_{2,iht}$</td>
</tr>
<tr>
<td>(3) + social adjustments</td>
<td>$Pr(\text{readmit}<em>{iht} = 1) = \alpha_3 + X</em>{iht}'\beta_3 + S_{iht}'\theta_3 + \varphi_3_{hospital_h} + \epsilon_{3,iht}$</td>
</tr>
<tr>
<td>(4) + clinical &amp; social adjustments</td>
<td>$Pr(\text{readmit}<em>{iht} = 1) = \alpha_4 + X</em>{iht}'\beta_4 + H_{iht}'\gamma_4 + S_{iht}'\theta_4 + I_{iht}'\eta + \varphi_4_{hospital_h} + \epsilon_{4,iht}$</td>
</tr>
</tbody>
</table>

In the above equations, $X_{iht}$ denotes the base set of variables used by CMS for risk adjustment in the HRRP (gender, patient age in the study year, comorbidities, and clinical factors assessed for each patient’s admission). In addition to these CMS covariates, we included in the covariate vector $X_{iht}$ the year of the index admission (indicator variable for 2014 vs. 2013) and fixed effects for the calendar month of the index admission. In models 2-4, we added the following sets of covariates: clinical variables, $H_{iht}$, assessed annually for beneficiaries; social variables, $S_{iht}$; and pairwise interactions among clinical and social variables, $I_{iht}$. Controlling for hospital fixed effects ($hospital_h$), the coefficients on the patient-level variables represent the average within-hospital association between these characteristics and readmissions, pooled across all hospitals in our sample. This gave us a consistent estimator of the coefficients of each of the models in (1).

In supplementary analyses (discussed in Section IV, below) we assessed whether the within-hospital associations between patient characteristics and readmissions varied systematically with respect to the characteristics of hospitals’ Medicare patient populations. In addition, to illustrate the implications of our method of within-hospital adjustments, we repeated our analyses using hospital random effects in the first stage (thus not explicitly isolating the adjustment to between-hospital differences) and dropping hospital effects altogether (see eTable 7 of Section IV for a comparison of results).

Note that we estimated linear probability models rather than logistic regression models because of the computational efficiency and econometric advantages of fitting linear probability models with many
hospital fixed effects. However, we determined that predicted patient-level outcomes were highly correlated from the logistic and linear regression models (rho=0.989 for readmissions and 0.983 for the composite outcome of readmission or mortality), and found that the linear model did not produce extreme predictions outside the bounds of 0 and 1 for either outcome. In robustness checks (not shown), we determined that using a logistic regression model in the first stage of our estimation did not substantively change our findings of the variance reduction achieved by further adjustment for patient characteristics.

We predicted each patient’s likelihood of readmission based only on the within-hospital associations of observed patient factors with readmissions, as estimated from the pooled models in (1), excluding each hospital’s distinct contribution to readmissions (i.e., the estimates of the hospital fixed effects). Specifically, we constructed a vector of predicted values based on each of four sets of patient-level risk-adjustment predictors:

\[
\begin{align*}
\text{readmit}_{1,hti} &= \hat{X}_{iti}'\hat{\beta}_1 \\
\text{readmit}_{2,hti} &= \hat{X}_{iti}'\hat{\beta}_1 + H_{iti}'\hat{\gamma}_2 \\
\text{readmit}_{3,hti} &= \hat{X}_{iti}'\hat{\beta}_3 + S_{iti}'\hat{\theta}_3 \\
\text{readmit}_{4,hti} &= \hat{X}_{iti}'\hat{\beta}_4 + H_{iti}'\hat{\gamma}_4 + S_{iti}'\hat{\theta}_4 + I_{iti}'\hat{\eta}
\end{align*}
\]

To compare the performance of hospitals, net of the variation in readmission rates attributable to observed patient characteristics, we subtracted patient-level outcomes predicted from the within-hospital associations in (2) from observed outcomes, yielding the residuals $\hat{r}_{k,hti} = (\text{readmit}_{hti} - \text{readmit}_{k,hti})$, where $k$ indexes models 1-4. We refer to these residuals as “patient-level scores.” Aggregated to the hospital level by calculating means, these scores represent hospitals’ readmission rates adjusted for differences in performance attributable to observed differences in patient mix.

We estimated the hospital-level variances and covariances of the patient-level scores produced from the different predictions based on the different sets of patient predictors using a multilevel model with multivariate normally distributed hospital random effects to account for hospital sampling error and to quantify these associations among hospital performance estimates under the different risk-adjustment scenarios we analyzed and their sampling error distributions (see below for details). We fit analogous models for the composite outcome of 30-day readmission or mortality.
In eTable 1, we report estimates of the within-hospital associations between the clinical and social covariates and our two outcomes (readmission and the composite of readmission or mortality). For brevity, we report the average association between the HCC score and counts of CCW conditions rather than indicator variables for the constituent clinical indicators, although all risk adjustment analyses we present use the disaggregated condition indicators. We report the association of a unit change in the covariate with a percentage point change in the rate of readmission/composite rate of readmission or mortality.

### eTable 1: Within-hospital association between a unit change in patient characteristics and outcomes

<table>
<thead>
<tr>
<th>Patient characteristics:</th>
<th>Within-hospital association with readmission</th>
<th>Within-hospital association with readmission or mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimate</td>
<td>95% CI</td>
</tr>
<tr>
<td></td>
<td>95% CI</td>
<td></td>
</tr>
<tr>
<td>HCC score</td>
<td>0.393</td>
<td>0.331 - 0.455</td>
</tr>
<tr>
<td>Count of CCW conditions</td>
<td>0.129</td>
<td>0.105 - 0.152</td>
</tr>
<tr>
<td>Disabled</td>
<td>0.568</td>
<td>0.384 - 0.752</td>
</tr>
<tr>
<td>Long-term nursing home resident</td>
<td>0.015</td>
<td>-0.307 - 0.337</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Insurance characteristics:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enrolled in Medicaid</td>
</tr>
<tr>
<td>Enrolled in a Medicare Savings Program</td>
</tr>
<tr>
<td>Receives the Part D Low-Income Subsidy</td>
</tr>
<tr>
<td>No subsidies or prescription drug coverage</td>
</tr>
<tr>
<td>Poverty rate among residents ≥ 65 y in ZCTA</td>
</tr>
<tr>
<td>Poverty rate among residents ≥ 65 y in Census tract</td>
</tr>
<tr>
<td>HH income among residents ≥ 65 y in ZCTA &lt; $50,000</td>
</tr>
<tr>
<td>HH income among residents ≥ 65 y in Census tract &lt; $50,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Education among residents ≥ 65 y in ZCTA:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than a high school education</td>
</tr>
<tr>
<td>College or more</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Education among residents ≥ 65 y in Census tract:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than a high school education</td>
</tr>
<tr>
<td>College or more</td>
</tr>
<tr>
<td>Residents ≥ 65 y living alone in ZCTA</td>
</tr>
<tr>
<td>Residents ≥ 65 y living alone in Census tract</td>
</tr>
</tbody>
</table>

*Estimates are adjusted for the base sets of CMS covariates (age, sex, comorbidities, and primary diagnosis of the index admission), month of admission fixed effects, year of admission fixed effects, and hospital fixed effects. Estimates are reported as the association of a unit change in the covariate with a percentage point change in the rate of readmission/composite rate of readmission or mortality. Interactions between clinical and social covariates are not included in the adjustments used to produce these estimates.

*b Categorical variable; the omitted (reference) category is receiving prescription drug coverage without subsidies.

+c Both the ZCTA and Census tract-level variables are scaled as proportions (values in the 0-1 interval), such that the coefficient estimates represent the association of a 0% to 100% change in the prevalence of the characteristic with a percentage point change in the outcome, holding the other covariates constant.

*d The omitted category is the proportion of residents age 65 and over with a high school education.
Note that these estimates differ from those presented in the Box of the main manuscript, which shows the average within-hospital association between the outcome and these covariates added individually to models with hospital fixed effects.

c. Simulation analysis

We conducted a simulation analysis to quantify the impact of additional adjustments on hospitals’ readmission rates. Our simulation methods and results are detailed below.

Simulation methods:

To conduct the simulation, we first modeled the joint distribution of three quantities:

1) The unadjusted (i.e., observed) readmission rate, $\text{readmit}_{iht}$

2) A patient-level prediction of readmissions using base CMS adjustments, $\text{readmit}_{1,iht}$

3) A patient-level prediction of readmissions using one of our adjusted estimates, $\text{readmit}_{k,iht}$

(from model $k=2, 3, \text{or } 4$)

This multivariate distribution was described by the following equations:

$$\text{readmit}_{iht} = \phi_1 + \nu_{1,h} + \varepsilon_{1,iht}$$
$$\text{readmit}_{1,iht} = \phi_2 + \nu_{2,h} + \varepsilon_{2,iht}$$
$$\text{readmit}_{k,iht} = \phi_3 + \nu_{3,h} + \varepsilon_{3,iht}$$

with hospital-level model components, $\nu_{1,h}$, $\nu_{2,h}$ and $\nu_{3,h}$ assumed to have a trivariate normal distribution described by the variance-covariance matrix:

$$\Sigma = \begin{pmatrix}
\sigma_1^2 & \sigma_{12} & \sigma_{13} \\
\sigma_{21} & \sigma_2^2 & \sigma_{23} \\
\sigma_{31} & \sigma_{32} & \sigma_3^2
\end{pmatrix}$$

and by a 3x3 covariance matrix $\mathbf{E}$ of the sampling error components $(\varepsilon_{1,iht}, \varepsilon_{2,iht}, \varepsilon_{3,iht})$ with covariances

$$\left( \frac{1}{n_h} \right) \mathbf{E}.$$

We used multilevel models to estimate the hospital-level variance and covariance parameters in (4) net of sampling error using the “PROC MIXED” procedure in SAS 9.4 (with an unstructured covariance matrix).
matrix). To implement the estimation, we constructed a dataset in “long” format with three observations (denoted $yvar$) for each index admission per beneficiary $bene_id$. The three observations for $yvar$ were: $readmit_{iht}$, $readmit_{1,iht}$, and $readmit_{k,iht}$, which we indexed by a counter variable ($index = 1, 2, 3$) and linked to an identifier for the hospital of the index admission, $hospid$. Sample SAS syntax follows:

```sas
proc mixed covtest data=readmit_data_longfile;
class index bene_id hospid;
model yvar = index / solution noint;
random index / subject=hospid type=un;
repeated index / subject=bene_id(hospid) type=un; run;
```

This estimation routine enabled us to estimate the hospital-level variances and covariances of the unadjusted and predicted outcomes. Analogous models were fit for the composite outcome of readmission or mortality.

**Variance estimation results:**

In eTable 2, we calculate and interpret several quantities derived from this covariance matrix, which characterize the expected direction and magnitude of changes in hospitals’ scores following consecutive adjustments. The left column presents estimates for readmissions, and the right column presents results for the combined outcome of readmission or mortality. Standard deviation (variance) estimates are reported in percentage points (squared percentage points) of the readmission/readmission or mortality rate.

**eTable 2:** Hospital-level standard deviation and correlation of risk-adjusted readmissions/readmission or mortality, comparing base CMS adjustments vs. further adjustment for patients’ clinical and social characteristics

<table>
<thead>
<tr>
<th>Parameter Interpretation</th>
<th>SD (percentage points) or Correlation Estimate for Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Outcome: Readmission Readmission or mortality</td>
</tr>
<tr>
<td><strong>A. CMS adjustments vs. adjustments for additional clinical characteristics</strong></td>
<td></td>
</tr>
<tr>
<td>$SD(v_{1p} - v_{2p})$</td>
<td>Standard deviation of the score reflecting CMS adjustments</td>
</tr>
<tr>
<td>$SD(v_{1p} - v_{3p})$</td>
<td>Standard deviation of the score reflecting combined CMS and additional clinical adjustments</td>
</tr>
<tr>
<td>$SD(v_{2p} - v_{3p})$</td>
<td>Standard deviation of the incremental change in score after additional clinical adjustments</td>
</tr>
<tr>
<td>$Corr(v_{1p} - v_{2p}, v_{2p} - v_{3p})$</td>
<td>Correlation of score representing adjustments for base CMS variables with incremental change in score due to additional clinical adjustments</td>
</tr>
</tbody>
</table>

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$corr(v_{1p} - v_{2p}, v_{1p} - v_{3p})$ Correlation of scores adjusted only for CMS variables and for CMS variables with additional clinical characteristics 0.996 0.988

B. CMS adjustments vs. adjustments for additional social characteristics

<table>
<thead>
<tr>
<th>$SD(v_{1p} - v_{2p})$</th>
<th>Standard deviation of the score reflecting CMS adjustments [reproduced from Panel A]</th>
<th>1.222</th>
<th>1.548</th>
</tr>
</thead>
<tbody>
<tr>
<td>$SD(v_{1p} - v_{3p})$</td>
<td>Standard deviation of the score reflecting combined CMS and additional social adjustments</td>
<td>1.195</td>
<td>1.498</td>
</tr>
<tr>
<td>$SD(v_{2p} - v_{3p})$</td>
<td>Standard deviation of the incremental change in score after additional social adjustments</td>
<td>0.187</td>
<td>0.363</td>
</tr>
<tr>
<td>$corr(v_{1p} - v_{2p}, v_{2p} - v_{3p})$</td>
<td>Correlation of score representing adjustments for base CMS variables with incremental change in score due to additional social adjustments</td>
<td>-0.218</td>
<td>-0.252</td>
</tr>
<tr>
<td>$corr(v_{1p} - v_{2p}, v_{1p} - v_{3p})$</td>
<td>Correlation of scores adjusted only for CMS variables and for CMS variables with additional social characteristics</td>
<td>0.988</td>
<td>0.972</td>
</tr>
</tbody>
</table>

C. CMS adjustments vs. adjustments for additional clinical and social characteristics

<table>
<thead>
<tr>
<th>$SD(v_{1p} - v_{2p})$</th>
<th>Standard deviation of the score reflecting CMS adjustments [reproduced from Panel A]</th>
<th>1.222</th>
<th>1.548</th>
</tr>
</thead>
<tbody>
<tr>
<td>$SD(v_{1p} - v_{3p})$</td>
<td>Standard deviation of the score reflecting combined CMS and additional clinical and social adjustments</td>
<td>1.162</td>
<td>1.502</td>
</tr>
<tr>
<td>$SD(v_{2p} - v_{3p})$</td>
<td>Standard deviation of the incremental change in score after additional clinical and social adjustments</td>
<td>0.223</td>
<td>0.437</td>
</tr>
<tr>
<td>$corr(v_{1p} - v_{2p}, v_{2p} - v_{3p})$</td>
<td>Correlation of score representing adjustments for base CMS variables with incremental change in score due to additional clinical and social adjustments</td>
<td>-0.354</td>
<td>-0.243</td>
</tr>
<tr>
<td>$corr(v_{1p} - v_{2p}, v_{1p} - v_{3p})$</td>
<td>Correlation of scores adjusted only for CMS variables and for CMS variables with additional clinical and social characteristics</td>
<td>0.984</td>
<td>0.959</td>
</tr>
</tbody>
</table>

*The score is the difference between the observed and predicted outcome and thus can be interpreted as an adjusted rate. The quantities tabulated here concern hospital-level summaries of these scores and the covariance structure reflecting the association of these scores across adjustment models. The unadjusted standard deviation in readmission rates across hospitals (estimated net of sampling error) was 1.8%.

Summary of variance and correlation estimates:

The standard deviation of hospitals’ readmission rates (overall mean=11.9%) under CMS adjustments was 1.22 percentage points, implying a hospital-level variance of 1.49 percentage points (=1.22²). After additional clinical and social adjustments, the hospital variance was 1.35 percentage points (=1.16²). Thus, both sets of adjustments reduced the hospital-level variance by 9.6% (=1.35/1.49-1), relative to the variance under standard CMS adjustments.

With additional clinical and social adjustments, the standard deviation of the change in hospitals’ scores was 0.223 percentage points, indicating that, with further adjustments, 68% of hospitals’ adjusted...
readmission rates would change by as much as ±0.223 percentage points, and that 32% of hospitals’ adjusted
rates would shift by an even greater magnitude. The negative correlation of hospitals’ scores under CMS
adjustments with the change in scores expected from further clinical and social adjustments (-0.354)
indicates that, on net, these adjustments would tend to reduce the scores of hospitals with initially higher
rates (under CMS adjustments), and to increase scores among hospitals with initially lower rates.

For readmissions, both of the additional variable sets contributed to variance reduction, with clinical
characteristics contributing more. In particular, adjusting for additional clinical characteristics reduced the
variance of hospitals’ scores by approximately 8.7% (=1.168^2/1.222^2-1), adjusting for additional social
characteristics reduced the variance by approximately 4.3% (=1.195^2/1.222^2-1), and adjusting for both sets of
variables reduced the variance by 9.6%. The correlation of hospitals’ base adjusted scores with the change in
score after adjustment for social characteristics was -0.218, smaller in magnitude than the correlation of the
base scores with the change resulting from adjustment for additional clinical variables (-0.509). However,
both sets of adjustments contributed to changes in scores: the variance of score changes was 0.115^2 with
adjustment for additional clinical variables, 0.187^2 with adjustment for social variables, and 0.223^2 in the
model adjusting for both clinical and social variables. Together, these findings indicate that, even though
adjustment for the social variables did not substantially reduce the variance in scores beyond what
adjustment for the clinical variables achieved, the social adjustments led to substantial changes in scores in
directions that were orthogonal to hospitals’ initial scores.

The social variables contributed more to variance reduction for the composite outcome of
readmission or mortality (overall mean=20.5%) than they did for readmission alone. In particular, the model
adjusting for social covariates reduced the hospital-level variance by 6.3% (=1.498^2/1.548^2-1)—more than
the variance reduction achieved by adjusting for clinical variables (a 3.0% reduction [=1.524^2/1.548^2-1]) or
by adjusting for both clinical and social variables (a 5.8% reduction [=1.502^2/1.548^2-1]). The correlation of
hospitals’ base adjusted scores with scores adjusted for social variables was -0.252, considerably more
negative than the correlation of hospitals’ base scores with scores adjusted for the additional clinical
variables (-0.175). The greater contribution of the social adjustments to variance reduction for the composite

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vs. the readmission-only outcome reflects the fact that (holding clinical factors constant) social disadvantages like poverty, low income, and low education tend to be more strongly predictive of mortality or readmission than readmission alone (see eTable 1). This may reflect the fact that patients with social disadvantages have lower income, worse insurance coverage, or other attributes that may reduce the demand for care, thereby lowering rates of utilization (including readmissions), all else equal.

**Simulation methods and results:**

In simulation analyses, we used the covariance parameters from (4) to characterize the changes in hospitals’ readmission rates expected from the additional clinical and social adjustments. To conduct the simulation, we drew 5,000 1x3 vectors, \((C_1 \ C_2 \ C_3)\), from a trivariate normal distribution with covariances based on (4). We used these draws to construct 5,000 pairs of scores (adjusted readmission rates): (1) a score reflecting CMS adjustments \((v_{1p} − v_{2p})\), and (2) a score reflecting adjustments for clinical and social risk factors in addition to the base CMS variables \((v_{1p} − v_{3p})\). Results for readmissions are shown in manuscript Figure 1; analogous results for the composite outcome of readmission or mortality are shown in eFigure 2.

Consistent with the estimates in eTable 2, Figure 1 of the main manuscript shows that the additional adjustments resulted in a lower readmission rates for hospitals initially above the national median based on CMS adjustments, and a net increase in rates for hospitals initially below the median, contributing to a net reduction in the overall hospital-level variance. For example, among hospitals in the lowest decile of readmission rates based on CMS adjustments, further adjustments increased the average adjusted readmission rate by 0.15 percentage points, while among hospitals starting in the highest decile based on CMS adjustments, further adjustments reduced the average adjusted rate by 0.14 percentage points. Among hospitals above the national median of readmission rates based on standard CMS adjustments, 61.8% would be expected to have lower rates after accounting for additional clinical and social characteristics of their patients. Similarly, 62.2% of hospitals below the national median based on CMS adjustments would see their rates increase following further adjustments.
For the composite outcome of readmission or mortality, further adjustments increased rates among hospitals starting in the lowest decile by an average of 0.19 percentage points and reduced rates among hospitals starting in the highest decile by a similar magnitude points (eFigure 2). Again, further adjustments are expected to reduce rates, on average, for hospitals initially above the national median (based on CMS adjustments) and increase those for hospitals initially below the national median.

**eFigure 2:** Expected changes in the risk-adjusted rate of readmission or mortality after adjusting for additional clinical and social characteristics of patients

This figure shows the distribution of expected changes in hospitals’ risk-adjusted rate of readmission or mortality after adjusting for additional clinical and social risk factors from the Box of the main manuscript. Hospitals are grouped on the vertical axis by decile of their composite readmission/mortality rate, adjusting for patient age, gender, and recent comorbidities (i.e., standard HRRP adjustments for patient-level characteristics). Changes in the risk-adjusted readmission/mortality expected from further adjustments are displayed on the horizontal axis. The plotted distribution reflects 5,000 draws from the empirical covariances of hospitals’ unadjusted readmission/mortality rates with readmission rates predicted from the base CMS variables and the additional clinical and social characteristics listed in the manuscript Box. After additional adjustments in our analysis, approximately 9.4% of hospitals originally above the median would move below the median (plotted in green), while a similar proportion of hospitals below the median would be expected to move above the median (plotted in red).

**eFigure 3** provides additional detail on the distribution of readmission rate changes among hospitals following our additional clinical and social adjustments. For the most affected 5% of hospitals (i.e., those outside the 2.5th and 97.5th percentiles of the distribution plotted in the figure), further adjustments decreased or increased rates by ±0.44 to ±0.72 percentage points relative to rates under CMS adjustments. For the 5-
10% most affected hospitals, rates changed by ±0.37 to ±0.44 percentage points, and for the 10%-25% most affected hospitals, rates changed by ±0.26 to ±0.37 percentage points.

**eFigure 3:** Distribution of expected changes in hospital readmission rates following adjustment for additional patient characteristics

<table>
<thead>
<tr>
<th>Hospitals whose readmission rates are most affected by additional adjustments</th>
<th>Range of Changes ¹ (percentage points of readmission rate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5% most affected hospitals ²</td>
<td>±0.44% to ±0.72%</td>
</tr>
<tr>
<td>5-10% most affected hospitals ³</td>
<td>±0.37% to ±0.44%</td>
</tr>
<tr>
<td>10-25% most affected hospitals ⁴</td>
<td>±0.26% to ±0.37%</td>
</tr>
</tbody>
</table>

Note: Vertical lines in the graph depict percentiles of the change in adjusted readmission rates across hospitals after we adjusted for additional clinical and social characteristics of patients.

² The 5% of hospitals whose readmission rates would be expected to change the most with further adjustments are those below the 2.5th or above the 97.5th percentile of readmission rate changes (to the left and right of the outermost vertical lines in the figure).
³ The 5-10% of hospitals whose readmission rates would be expected to change the most with further adjustments are those between the 2.5th and 5th percentile or between the 95th and 97.5th percentile of readmission rate changes.
⁴ The 10-25% of hospitals whose readmission rates would be expected to change the most with further adjustments are those between the 5th and 12.5th percentile or between the 87.5th and 95th percentile of readmission rate changes.

Analogous results for the composite outcome of readmission and mortality are shown in eFigure 4, below. For the composite readmission/mortality measure, the additional adjustments would result in even larger changes in rates among hospitals, consistent with the larger estimated standard deviation of score changes (SD=0.437; see Panel C of eTable 2).
eFigure 4: Distribution of expected changes in the composite rate of readmission or mortality following adjustment for additional patient characteristics

Hospitals whose readmission rates are most affected by additional adjustments

<table>
<thead>
<tr>
<th>Range of Changes a (percentage points of readmission rate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5% most affected hospitals</td>
</tr>
<tr>
<td>5-10% most affected hospitals</td>
</tr>
<tr>
<td>10-25% most affected hospitals</td>
</tr>
</tbody>
</table>

Note: Vertical lines in the graph depict percentiles of the change in adjusted rates of readmission or mortality across hospitals after we adjusted for additional clinical and social characteristics of patients.

d. Simulated financial impacts

We simulated changes in readmission penalties expected from further clinical and social adjustments based on the empirical relationship between publicly reported hospital readmission rates and penalties and our estimates of the bivariate relationship between hospitals’ readmission rates under base CMS adjustments and our more fully adjusted models. By knowing the impact of the additional adjustments on the distribution of readmission rates, we can infer the impact on penalties by simulating the changes in penalties associated with the same distributional changes in the publicly reported rates.
We used public data on HRRP penalties for Fiscal Year 2018 for the 2,215 hospitals largest hospitals (by volume) reporting readmissions to recover the empirical relationship between readmission rates and penalties. Specifically, for each of these 2,215 hospitals, we constructed a case-weighted average “excess readmission ratio,” pooling across separate ratios reported for the most prevalent 5 targeted conditions (acute myocardial infarction, pneumonia, heart failure, COPD, and hip and knee replacement) and weighting by the number of index admissions for each condition. Excess readmission ratios compare hospitals’ performance, reflecting CMS adjustments, to the average performance of all hospitals with a comparable Medicare inpatient population, and are used to determine penalties in the HRRP. By construction, the ratios increase monotonically in hospitals’ readmission rates based on CMS adjustments. The size of HRRP penalties is proportional to this ratio (ranging from a minimum of 0% to a maximum penalty of 3%). Using the empirical distribution of the case-weighted excess readmission ratio, we assessed the relationship between the ratio (expressed in standard deviations relative to the average among all hospitals) and HRRP penalties. That is, for a case-weighted excess readmission ratio of $x$, we used observed FY 2018 penalties to calculate the HRRP penalty as a function of $x$, $P=p(x)$.

We then conducted a simulation to characterize changes in expected hospital penalties based on changes in the case-weighted excess readmission ratio expected from the changes in the rates in our analysis caused by the additional adjustments for clinical and social characteristics. To perform the simulation, we sampled (with replacement) 5,000 observations from the joint distribution of hospitals’ base and additionally adjusted case-weighted excess readmission ratios, based on the variances and covariances of readmission rates adjusted for base CMS variables and for all covariates, as reported in Panel C of eTable 2. Specifically, given the empirical case-weighted excess readmission ratio with mean $\mu^{obs}$ and standard deviation $\sigma^{obs}$, we drew 5,000 pairs of observations $(x, x')$ from the bivariate normal distribution:

$$
(\begin{pmatrix} x \\ x' \end{pmatrix}) \sim N \left( \begin{pmatrix} \mu^{obs} \\ \sigma^{obs} \end{pmatrix}, \begin{pmatrix} \sigma^{obs}^2 & \kappa \rho \sigma^{obs}^2 \\ \kappa \rho \sigma^{obs}^2 & \kappa^2 \sigma^{obs}^2 \end{pmatrix} \right)
$$

(5)

where $x$ is from the distribution of hospitals’ original case-weighted excess readmission ratios and $x'$ is a simulated ratio expected from additional clinical and social adjustments. In (6), we specified $\kappa =$

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1.162/1.222 (i.e., the ratio of the standard deviation of hospitals’ adjusted readmission rates [“scores”] reflecting standard CMS adjustments [denominator of the ratio] and our additional clinical and social adjustments [the numerator of the ratio], as reported in eTable 2), and \( \rho = 0.984 \) as the correlation of the two scores. The new simulated excess readmission ratio, \( x' \), reflects both the reduction in variance and reordering among hospitals expected from adjustment for additional characteristics of their patients.

We used these simulated data to simulate a new penalty for each hospital \( P' = p(x') \), from which we calculated the change in penalties, \( \Delta P = P' - P \). eTable 3 reports the mean of \( \Delta P \) for the 1%, 5%, and 10% of hospitals experiencing the greatest reduction in penalties. We estimate that the 1% of hospitals whose readmission penalties would be reduced the most because of additional adjustments would see their HRRP penalties fall, on average, by 1.20 percentage points—a 52% reduction in relative terms—while the 10% of hospitals whose readmission penalties would be reduced the most would see their HRRP penalties fall, on average, by 0.63 percentage points, a 41% relative reduction from an initial average penalty of 1.55 percentage points.

**eTable 3**: Simulated change in HRRP penalties after adjusting for additional clinical and social risk factors for readmission

<table>
<thead>
<tr>
<th>Percentile reduction in readmission penalties</th>
<th>Number of hospitals within percentile range ( ^a )</th>
<th>Mean initial penalty ( ^b ) (percentage points)</th>
<th>Mean change in penalty ( ^c ) (percentage points)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most affected 1% ( ^c )</td>
<td>23</td>
<td>2.29</td>
<td>-1.20</td>
</tr>
<tr>
<td>Most affected 5%</td>
<td>111</td>
<td>1.77</td>
<td>-0.81</td>
</tr>
<tr>
<td>Most affected 10%</td>
<td>220</td>
<td>1.55</td>
<td>-0.63</td>
</tr>
</tbody>
</table>

\( ^a \) Among hospitals subject to the HRRP with a sufficient number of index admissions to assess readmission rates for at least one of the HRRP’s core targeted conditions.

\( ^b \) Penalties reduce hospitals’ inpatient revenues from Medicare. For example, a hospital receiving a 2.29 percent penalty would receive 97.71 percent of the inpatient revenue that Medicare would have paid to a hospital receiving a 0 percent penalty.

\( ^c \) Change in penalties reported in percentage points. Negative numbers indicate a *reduction* in penalties.
e. Differences between hospitals serving patients with higher vs. lower clinical and social risk

We compared the performance of hospitals serving patients with higher vs. lower average clinical and social risk before and after adjusting for additional characteristics of their patients. For this analysis, we categorized hospitals into quintiles in one of two ways:

First, we categorized hospitals by an average risk score of their patients, which we constructed based on the within-hospital associations between readmission and the additional clinical and social characteristics we examined (listed in the manuscript Box); specifically, these patient risk scores are the fitted values $H_{it} \hat{\gamma}_4 + S_t \hat{\theta}_4 + I_{it} \hat{\eta}$ from the fourth model of equation (2). We used a hospital random effects model to estimate a hospital-level average risk score, and used the resulting estimates to categorize hospitals into quintiles.

Second, we categorized hospitals by the proportion of Medicare patients with dual Medicaid enrollment. For each hospital, we estimated the proportion of Medicare patients who were dual enrollees with a random effects model, and used these estimates to quintile hospitals. The proportions of Medicare beneficiaries with dual Medicaid enrollment in the first through the fifth quintiles were 8.8%, 13.8%, 17.8%, 23.0%, and 40.3%. We used random effects models for these categorizations to ensure that lower-volume hospitals were not categorized disproportionately in the lowest or highest quintiles as a result of random fluctuations in the proportion of dual-eligible or high-risk patients.

We assessed the mean difference in risk-adjusted readmissions between hospital quintiles for each of the four risk-adjustment models we fit (models indexed by $k$ [see equation (2)]). For each risk-adjusted “score”, $\tilde{r}_{k iht}$, we fit the following model:

$$\tilde{r}_{k iht} = v_k + \sum_{j=2}^5 \delta_k^j \cdot 1\{Q_h = j\} + \xi_{k iht}$$

Where $1\{Q_h = j\}$ is an indicator function that equals one if hospital $h$ was in the $j^{th}$ quintile of either high-risk or dually-enrolled patients (quintile 1 is omitted as the reference category). Thus, $\delta_k^j$ is the mean difference between hospitals in the $j^{th}$ vs. 1$^{st}$ quintile, adjusting for the variables in model $k$. We ran an analogous set of models for the composite outcome of readmission or mortality, quintiling hospitals based on their patients’ risk of readmission or mortality, as predicted from the variables in the manuscript Box.
Figure 2 of the manuscript plots the adjusted performance of the hospital quintiles for the readmission and composite readmission or mortality outcomes, which we centered at the grand means of the corresponding measures. As the figure shows, additional clinical and social adjustments narrowed the mean difference in readmission rates between hospitals in the top and bottom quintiles of high-risk patients by 54% and between hospitals in the top and bottom quintiles of dual patients by 83%.

For the composite outcome of readmission and mortality, changes in risk-adjusted performance between hospitals in the top and bottom quintiles of average patient risk even more pronounced (Figure 2 of the main manuscript). Under standard CMS adjustments, the rate of readmission or mortality was 0.88 percentage points higher in the top vs. bottom quintiles of hospitals. After further adjustments, hospitals in the top quintile had a 0.19 percentage point lower average rate of readmission or mortality vs. hospitals in the bottom quintile.

IV. Supplementary Analyses

We conducted four sets of supplementary analyses.

1) Testing for systematic relationship between A) the within-hospital associations between patients’ social characteristics and outcomes and B) the social risk of hospitals’ patient populations

An assumption of our risk adjustment models is that the coefficients of the covariates used in risk adjustment (as in Model (2)) are same in every hospital. We tested this assumption specifically for the social risk factors added to our models by examining whether the within-hospital association between these factors differed systematically between hospitals serving Medicare patients of higher- vs. lower average social risk. We used a two-stage procedure to compare the effects of the social adjustments when we based them on within-hospital associations estimated among hospitals serving patients of higher vs. lower social risk. If the within-associations were systematically stronger among hospitals serving higher-risk populations, we should see a greater impact of the additional adjustments if we base them on the within-hospital associations among hospitals serving higher-risk patients (rather than on the within-hospital association pooled across hospitals).
In the first stage of this procedure, we categorized hospitals into quintiles based on a composite “score” reflecting Medicare beneficiaries’ social risk. To construct this score, we fit a patient-level linear probability model predicting readmission as a function of socioeconomic characteristics from the manuscript Box ($S_{iht}$), adjusting for hospital fixed effects and observed differences in patients’ clinical risk ($X_{iht}$ and $H_{iht}$):

$$\Pr(\text{readmit}_{iht} = 1) = \beta_0 + S_{iht}' \beta_1 + X_{iht}' \beta_2 + H_{iht}' \beta_3 + \text{hospital}_h + \epsilon_{iht}$$

(6)

We generated a patient-level social risk score, $S_{iht}' \hat{\beta}_1$ using estimates from the social variables in this model. Using a hierarchical model with hospital random effects, we estimated a hospital-level average of this risk score, which we used to categorize hospitals into quintiles of social risk.

Second, for each quintile of hospitals, we fit a linear probability model predicting readmission as a function of the patient characteristics from the manuscript Box (excluding interactions) and hospital fixed effects:

$$\Pr(\text{readmit}_{iht} = 1|\text{quintile} = j) = \gamma_j^l + S_{iht}' \gamma_1^l + X_{iht}' \gamma_2^l + H_{iht}' \gamma_3^l + \text{hospital}_h + \epsilon_{iht}^l$$

(7)

where $j$ indexes the quintile of hospitals to which the model was fit ($j=1, \ldots, 5$). By fitting a separate model to each hospital quintile, we allowed estimates of the within-hospital association between patient variables and readmissions to vary across the quintiles. We used these estimates to construct 5 sets of patient-level predictions based on the within-hospital association of social factors with readmission (generating 1 prediction per quintile for each patient in our dataset):

$$\text{readmit}_{\text{social}}^l_{iht} = S_{iht}' \hat{\gamma}_1^l$$

(8)

We repeated both steps in separate analyses of the composite outcome of readmission or mortality.

We examined how patient-level predictions between quintiles of hospitals (grouped based on the average social risk of their Medicare patients) differed in the 5 sets of prediction models. Finding, for example, that the difference in predictions between hospitals in the top vs. the bottom quintile of patients’ social risk grew stronger in models fit to the top rather than the bottom quintile of hospitals would indicate a systematic difference in outcomes between patients of higher vs. lower social risk in hospitals serving higher-risk patients. On the other hand, finding that the difference in predictions between hospitals in the top
and bottom quintiles is not greater when models are fit to hospitals in higher quintiles of patient risk would suggest that our adjustment for average within-hospital associations (pooled across hospitals) does not reflect systematic differences in the outcomes of socially vulnerable patients between hospitals serving more vs. fewer such patients.

Results of these analyses are summarized in eTable 4. Rows in the table correspond to the quintile of hospitals used to estimate the within-hospital associations, and the columns indicate the quintile of hospitals to which the resulting estimates were applied to calculate predicted readmission rates. In the rightmost column, we calculate the difference in predictions between the 5th and 1st quintiles of hospitals when estimating the model to a given quintile of hospitals (i.e., model \( j = 1, \ldots, 5 \)),

\[
\delta_j = E[\text{readm} \mid \text{social}_{tht}^{j}]|\text{quintile} = 5] - E[\text{readm} \mid \text{social}_{tht}^{j}]|\text{quintile} = 1].
\]

We assess whether these between-quintile differences increase in models fit to higher quintiles of hospitals (down the row).

**eTable 4:** Differences in predicted within-hospital associations between social factors and outcomes between hospitals in the top and bottom quintiles based on Medicare patients’ social risk

<table>
<thead>
<tr>
<th>Quintile of hospital based on social risk score</th>
<th>1 (lowest social risk)</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5 (highest social risk)</th>
<th>Difference in mean predictions between hospitals in the top and bottom quintiles of social risk (column 5 – column 1) (( \delta_j ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Readmission</td>
<td>Predictions by quintile of social risk based on within-hospital associations estimated in quintile ( j )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Association between social factors and readmission in quintile ( j ):</td>
<td>4.13</td>
<td>4.27</td>
<td>4.37</td>
<td>4.43</td>
<td>4.59</td>
<td>0.46</td>
</tr>
<tr>
<td>1 (lowest social risk)</td>
<td>2.52</td>
<td>2.66</td>
<td>2.76</td>
<td>2.87</td>
<td>3.19</td>
<td>0.67</td>
</tr>
<tr>
<td>2</td>
<td>6.85</td>
<td>6.92</td>
<td>6.99</td>
<td>7.07</td>
<td>7.29</td>
<td>0.44</td>
</tr>
<tr>
<td>3</td>
<td>-1.40</td>
<td>-1.40</td>
<td>-1.30</td>
<td>-1.20</td>
<td>-1.00</td>
<td>0.40</td>
</tr>
<tr>
<td>4</td>
<td>3.94</td>
<td>3.94</td>
<td>3.95</td>
<td>3.99</td>
<td>4.12</td>
<td>0.18</td>
</tr>
<tr>
<td>5 (highest social risk)</td>
<td>12.70</td>
<td>13.00</td>
<td>13.10</td>
<td>13.20</td>
<td>13.50</td>
<td>0.80</td>
</tr>
<tr>
<td>2</td>
<td>8.59</td>
<td>8.89</td>
<td>9.06</td>
<td>9.24</td>
<td>9.60</td>
<td>1.01</td>
</tr>
<tr>
<td>3</td>
<td>4.36</td>
<td>4.70</td>
<td>4.88</td>
<td>5.08</td>
<td>5.47</td>
<td>1.11</td>
</tr>
<tr>
<td>4</td>
<td>8.45</td>
<td>8.77</td>
<td>8.96</td>
<td>9.14</td>
<td>9.53</td>
<td>1.08</td>
</tr>
<tr>
<td>5</td>
<td>11.70</td>
<td>11.90</td>
<td>12.10</td>
<td>12.30</td>
<td>12.60</td>
<td>0.90</td>
</tr>
</tbody>
</table>

*Estimates are reported in percentage points of the readmission or composite readmission/mortality rate (e.g., 4.13 can be interpreted as 4.13 percentage points of the readmission rate, or 4.13 readmissions per 100 index admissions).*

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b Hospitals grouped into quintiles of social risk based on the predicted association of social factors with readmission (readmission/mortality), conditioning on clinical characteristics, base CMS adjustments, and hospital fixed effects. As one moves down the right-most column of estimates, the difference in predicted risk between hospitals in the highest vs. lowest quintile of risk does not increase systematically when we use hospitals with higher-risk patients to estimate the within-hospital associations. In fact, the between-quintile difference in predicted readmissions is smallest when we use hospitals in the highest quintile of risk to estimate the within-hospital associations, and does not increase monotonically for the composite outcome of readmission or mortality. Thus, these results demonstrate that the within-hospital association between patients’ social characteristics and outcomes was not systematically higher in hospitals serving more socially vulnerable patients vs. fewer.

In supplementary analyses (not shown) we also found no systematic differences in the within-hospital association of Medicare patients’ clinical and social risk factors between hospitals serving patients with higher average clinical and social risk.

2) Impact of adjustments for rates of readmission following index admissions for conditions targeted by the HRRP

Next, we examined the impact of adjustments on hospital-level differences in readmission rates, focusing on readmissions after index admissions for conditions targeted by the HRRP (acute myocardial infarction, chronic obstructive pulmonary disease, heart failure, and pneumonia). For each patient, we included the first annual admission among any of the four HRRP-targeted conditions, and assessed whether the patient was readmitted within 30 days for any condition. To assess the effects of adjustments on a sufficient number of hospitals, we included hospitals with 100 or more index admissions for the targeted conditions (n=817 hospitals and 132,841 index admissions). We obtained similar results among a smaller subset of hospitals with at least 200 index admissions for HRRP-targeted conditions (n=173 hospitals and 45,578 index admissions; not shown).

As reported in eTable 5 (next page), adjustment for additional clinical and social variables reduced the hospital variance of readmissions by 16.6% (=1.117^2/1.223^2-1), considerably greater than the 9.6%
reduction in the hospital variance in our primary readmission measure. The standard deviation of score changes due to the additional adjustments was also larger than in our main analysis (0.344 vs. 0.223).

**eTable 5:** Hospital-level standard deviation and correlation of risk-adjusted readmissions following index admissions for HRRP-targeted conditions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Interpretation</th>
<th>SD (percentage points) or Correlation Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>$SD(v_{1p} - v_{2p})$</td>
<td>Standard deviation of the score reflecting CMS adjustments</td>
<td>1.223</td>
</tr>
<tr>
<td>$SD(v_{1p} - v_{3p})$</td>
<td>Standard deviation of the score reflecting additional clinical adjustments</td>
<td>1.117</td>
</tr>
<tr>
<td>$SD(v_{2p} - v_{3p})$</td>
<td>Standard deviation of the change in score after additional clinical adjustments</td>
<td>0.344</td>
</tr>
<tr>
<td>$Corr(v_{1p} - v_{2p}, v_{2p} - v_{3p})$</td>
<td>Correlation of change in score (before vs. after additional clinical adjustments) with score adjusted for base CMS variables</td>
<td>-0.436</td>
</tr>
<tr>
<td>$Corr(v_{1p} - v_{2p}, v_{1p} - v_{3p})$</td>
<td>Correlation of scores adjusted for CMS variables and for additional clinical characteristics</td>
<td>0.961</td>
</tr>
</tbody>
</table>

*The score is the difference between the observed and predicted outcome and thus can be interpreted as an adjusted rate.

**eFigure 5** (next page) summarizes the distribution of changes in readmission rates for the HRRP-targeted subset of index admissions that we would expect from further clinical and social adjustments. These adjustments would be expected to decrease or increase readmission rates for the most affected 5% of hospitals by ±0.66 to ±1.14 percentage points relative to their rates under CMS adjustments. For the 5-10% most affected hospitals, rates would change by ±0.56 to ±0.66 percentage points. The additional adjustments would reduce the adjusted readmission rates of approximately 64% of hospitals initially above the national median (based on CMS adjustments) and shift approximately 9% of hospitals from above to below the national median.
**Figure 5**: Distribution of expected changes in readmissions following admissions for HRRP-targeted conditions

<table>
<thead>
<tr>
<th>Hospitals whose readmission rates are most affected by additional adjustments</th>
<th>Range of Changes <em>a</em> (percentage points of readmission rate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5% most affected hospitals</td>
<td>±0.66% to ±1.14%</td>
</tr>
<tr>
<td>5-10% most affected hospitals</td>
<td>±0.56% to ±0.66%</td>
</tr>
<tr>
<td>10-25% most affected hospitals</td>
<td>±0.40% to ±0.66%</td>
</tr>
</tbody>
</table>

Note: Vertical lines in the graph depict percentiles of the change in adjusted readmission rates for HRRP-targeted conditions across hospitals after we adjusted for additional clinical and social characteristics of their patients.

3) **Changes in hospitals’ risk-adjusted readmission rates including an indicator of dual Medicare and Medicaid enrollment in the base set of risk adjustment variables**

Finally, we repeated our analyses for the hospital-wide measure of readmission, including a patient-level indicator for dual enrollment in Medicare and Medicaid in the base set of adjustments. This approach reflects planned changes to the HRRP that will account for patients’ dual enrollment but differs from the stratification approach CMS will take. As noted in our manuscript, stratification may be inappropriate to the extent that hospitals serving different patient populations differ in their quality of care, as a stratified adjustment would cause hospitals serving different patient populations to be held to different standards. Our approach avoids this problem by adjusting only for within-hospital associations between patient risk and...
outcomes. We then assess the independent impact of adjustment for additional social and clinical characteristics, incremental to a base model including dual enrollment.

Results of this analysis are reported in eTable 6, below. After including patients’ dual enrollment status in the initial set of risk adjustment variables, the other additional adjustments reduced the hospital variance in readmission rates by 6.8 percentage points ($=1.158^2/1.199^2-1$), affected rates for 32% of hospitals by at least ±0.124 percentage points. Relative to a base model including dual enrollment status, further adjustments changed rates for the most affected 10% of hospitals’ readmission rates by ±0.20-0.42 percentage points. Thus, dual enrollment explained only part of the effects of the additional adjustments, and adjustment for patient characteristics distinct from dual enrollment would be expected to contribute to further changes in hospital scores.

**eTable 6:** Hospital-level standard deviation and correlation of risk-adjusted readmissions, comparing adjustment for standard CMS variables plus dual enrollment versus adjustments for additional clinical and social characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Interpretation</th>
<th>SD (percentage points) or Correlation Estimate for Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>$SD(v_{1p} - v_{2p})$</td>
<td>Standard deviation of the score reflecting CMS adjustments plus dual enrollment $^a$</td>
<td>1.199</td>
</tr>
<tr>
<td>$SD(v_{1p} - v_{3p})$</td>
<td>Standard deviation of the score reflecting combined CMS adjustments (plus dual enrollment) and additional clinical and social adjustments $^b$</td>
<td>1.158</td>
</tr>
<tr>
<td>$SD(v_{2p} - v_{3p})$</td>
<td>Standard deviation of the incremental change in score after additional clinical and social adjustments (relative to a base score adjusted for CMS variables and dual enrollment)</td>
<td>0.124</td>
</tr>
<tr>
<td>$Corr(v_{1p} - v_{2p}, v_{2p} - v_{3p})$</td>
<td>Correlation of score representing adjustments for base CMS variables plus dual enrollment with incremental change in score due to additional clinical and social adjustments)</td>
<td>-0.380</td>
</tr>
<tr>
<td>$Corr(v_{1p} - v_{2p}, v_{1p} - v_{3p})$</td>
<td>Correlation of scores adjusted for CMS variables plus dual enrollment and for CMS variables with additional clinical and social characteristics</td>
<td>0.995</td>
</tr>
</tbody>
</table>

$^a$ Adjusted for age, sex, comorbidities on recent hospital claims, principal diagnosis of the index admission, and the main effect of dual enrollment in Medicare and Medicaid.

$^b$ Reflects adjustments for all additional clinical and social factors from the manuscript Box, including 2-way interactions between dual enrollment and other clinical and social covariates.

We repeated our comparisons of adjusted readmission rates for hospitals grouped into quintiles, alternately by their Medicare patients’ readmission risk or dual enrollment in Medicaid, to assess the extent to which further adjustments would reduce differences in average rates of readmission between hospitals.
relative to a base model that included patients’ dual enrollment status. Results are plotted in eFigure 6 (next page). Relative to a base model that included dual enrollment status (in addition to standard CMS covariates), further adjustments reduced the mean difference in readmission rates between hospitals in the top and bottom quintiles of high-risk Medicare patients from 0.71 percentage points to 0.45 percentage points—a 36% reduction in relative terms. Further adjustments reduced the mean difference between hospitals in the top and bottom quintiles of dual-eligible patients from 0.21 percentage points to 0.10 percentage points—a 52% relative reduction. Thus, we would continue to expect appreciable changes in hospital performance assessments after accounting for additional patient characteristics, even when patients’ dual enrollment status is included in the base set of risk adjustment variables.
4) Adjusting for within- vs. within- and between-hospital relationships between patient characteristics and outcomes

In our main analyses, we adjusted for the average within-hospital association between patient characteristics and outcomes (pooled across hospitals) using hospital fixed effects in the first stage of our estimation. This approach excluded between-hospital differences from our adjustments, e.g., differences in hospital quality that might be correlated with differences in their patient populations (see Section II.A).
This section compares results from our main analyses to results from two alternate analyses, in which we replaced the first-stage model using hospital fixed effects with: (1) a hospital random effects model, which is analogous to CMS risk-adjustment methods for the HRRP, and (2) a model without hospital fixed or random effects in the first stage. Using estimates from these alternate approaches, we predicted outcomes and constructed risk-adjusted scores using CMS variables and after adding clinical and social variables from the manuscript Box. While our preferred method of hospital fixed effects adjusts only for the within-hospital association between patient characteristics and outcomes (leaving intact any hospital-level differences that contribute to outcomes), the random effects model adjusts for within- and some between-hospital effects, while the model without hospital effects allows both within- and between-hospital differences to contribute to the adjustments.

Using these alternate models in lieu of hospital fixed effects had an appreciable effect on estimates of the relationship between the patient characteristics in the manuscript Box—particularly the added social characteristics—and our outcomes. For example, when adjusting for the full set of variables from the manuscript Box, predicted readmission rates differed by at least 0.09 percentage points for 10% hospitals when comparing the hospital fixed effects vs. random effects models (mean difference of 0.12 percentage points, or 19.0% of the hospital level SD in the predictions using our full set of adjustments [0.63 percentage points]), and by at least 0.13 percentage points (mean 0.18 percentage points, or 29.0% of the SD) for 10% of hospitals when comparing the model with hospital fixed effects to the model without any hospital effects. For the composite outcome of readmission or mortality, predicted rates (under our full set of adjustments) differed by at least 0.11 percentage points among 10% of hospitals (mean 0.15 percentage points, or 10.8% of the SD under our full set of adjustments [1.42 percentage points]) when comparing hospital random effects vs. fixed effects models and by 0.18 percentage points for 10% of hospitals (mean 0.24 percentage points, or 16.8% of the SD) when comparing hospital-level predictions from the fixed effects model to predictions from the model omitting hospital effects.

These differences in predictions contribute to differences in hospitals’ risk-adjusted scores (differences between observed and predicted outcomes). Below, eTable 7 compares the hospital-level
standard deviations scores under standard CMS adjustments and after our additional adjustments, from first-stage models with hospital fixed effects (Panel A), hospital random effects (Panel B), and no hospital effects (Panel C). The standard deviation of hospitals’ scores are expectedly smaller when we allow between-hospital differences to contribute to the adjustments and additional adjustments reduced the hospital-level variance in scores by more when we allowed between-hospital differences to contribute fully to the adjustments (Panel C) than when we did not (Panel A). For example, in Panel C, further clinical and social adjustments reduced the hospital-level variance of scores for readmissions by 14.4% (=1.113²/1.203² – 1), compared to a variance reduction of 9.6% when we adjusted only for within-hospital effects.

cTable 7: Hospital-level scores, comparing adjustment for within-hospital vs. within- and between-hospital associations between patient characteristics and outcomes

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Interpretation</th>
<th>SD (percentage points) for Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Outcome:</td>
<td>Readmission</td>
</tr>
<tr>
<td>A. First stage adjustments use a hospital fixed effects model (i.e., adjustment for within-hospital differences; reproduced from eTable 2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$SD(v_{1p} - v_{2p})$</td>
<td>Standard deviation of the score reflecting CMS adjustments</td>
<td>1.222</td>
</tr>
<tr>
<td>$SD(v_{1p} - v_{3p})$</td>
<td>Standard deviation of the score reflecting combined CMS and additional clinical and social adjustments</td>
<td>1.162</td>
</tr>
<tr>
<td>B. First stage adjustments use a hospital random effects model</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$SD(v_{1p} - v_{2p})$</td>
<td>Standard deviation of the score reflecting CMS adjustments</td>
<td>1.170</td>
</tr>
<tr>
<td>$SD(v_{1p} - v_{3p})$</td>
<td>Standard deviation of the score reflecting combined CMS and additional clinical and social adjustments</td>
<td>1.138</td>
</tr>
<tr>
<td>C. First stage adjustments do not adjust for any hospital effects</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$SD(v_{1p} - v_{2p})$</td>
<td>Standard deviation of the score reflecting CMS adjustments</td>
<td>1.203</td>
</tr>
<tr>
<td>$SD(v_{1p} - v_{3p})$</td>
<td>Standard deviation of the score reflecting combined CMS and additional clinical and social adjustments</td>
<td>1.113</td>
</tr>
</tbody>
</table>
APPENDIX REFERENCES


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