

# **Risk Adjustment for Sociodemographic Status in 30-Day Hospital Readmissions**

**Methodology Report For:**  
**Acute Myocardial Infarction**  
**Congestive Heart Failure**  
**Pneumonia**  
**Chronic Obstructive Pulmonary Disease**  
**Total Hip and Knee Arthroplasty**  
**Hospital-Wide Readmissions**

Missouri Hospital Association  
Hospital Industry Data Institute

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**Background:**

Risk adjustment for publicly-reported health outcome measures is intended to allow for meaningful comparisons of measured quality differences between hospitals that are attributable to characteristics of the hospitals, as opposed to differing characteristics of the patients they care for or random variation.<sup>1</sup> Risk adjustment for patient-level clinical acuity and basic demographic factors such as age and gender are commonplace.<sup>2-7</sup> However, a growing body of research emerges around individual- and community-level social factors associated with hospital readmission risk.<sup>8-16</sup> Taken as a whole, evidence and associated theory suggest that relationships between social determinants and readmission risk are not often mediated by the effects of traditional hospital-based care. With these conditions, an expert panel convened by the National Quality Forum made recommendations in August 2014 suggesting that appropriate social determinant measures be included in risk-adjustment algorithms used for public reporting and other accountability applications.<sup>17</sup> This report provides details on the methodology used for the SDS-enriched risk standardized readmission measures reported by the Missouri Hospital Association's quality transparency initiative.

**Methods:**

Using the hierarchical generalized logistic methods and measures put forth by Krumholz et al., at Yale New Haven Health Services Corporation/Center for Outcomes Research & Evaluation under contract for the Centers for Medicare & Medicaid Services, MHA developed a blended clinical and SDS-enriched methodology to report 30-day risk standardized readmission rates and ratios for Missouri hospitals participating in the MHA quality transparency initiative. The measures are designed to account for patient-level risk associated with the comorbidities employed by CMS/Yale, as well as the effects of select social determinants indicated by patient Medicaid status and the poverty rate of a patient's home census tract. The SDS-enriched models additionally control for clustering of patients at the census-tract level to help account for differences in access to post-acute care amenities in patient's communities, such as transitional care, nutritional food outlets and access to transportation for follow-up care. Use of census tract as the geographic unit of analysis has been shown to more effectively account for the association between SDS and health outcomes than competing geographic levels, such as ZIP Codes or census block groups.<sup>17</sup>

**Data and Measures:**

30-day risk standardized readmission rates and ratios for any cause are calculated for Acute Myocardial Infarction (AMI), Congestive Heart Failure (CHF), Pneumonia (PN), Chronic Obstructive Pulmonary Disease (COPD), Total Hip and/or Total Knee Arthroplasty (THA/TKA) and Hospital-Wide Readmissions (HWR) for patients ages 18 and older with any payer using the most recent 36 months of Missouri hospital inpatient discharge data. The results provided in this analysis represent inpatient discharges in Missouri occurring between June 1, 2012, and May 31, 2015 — the most recent data available at the time of publication. Patient discharge records are geocoded to the census-tract level using the most recently reported address and Pitney-Bowes Precision Code software. The geocoded data are merged with census-tract level household poverty rate data from Nielsen-Claritas PopFacts Premier.

Qualifying index admissions for the condition- and procedure-specific measures are identified using the ICD-9-CM based cohorts defined by CMS/Yale (Table 1). The HWR measure is divided into five clinical

subgroups of patients: medical, surgical/gynecological, cardiorespiratory, cardiovascular and neurological (for more information on the HWR cohort definitions see Horwitz et al., 2012). The HWR method fits an individual model for each of the five clinical subgroups and uses a weighted geometric mean to derive overall, hospitalwide risk-adjusted performance metrics. The measures reported by the MHA quality transparency initiative will be updated quarterly using a moving 12-quarter study period of the most recently available 36 months of Missouri inpatient discharge data.

**Table 1: Model Cohorts**

**Measure    ICD-9-CM Codes Used to Signal Index Admissions**

<b>AMI</b>	Any 410.xx, excluding 410.x2
<b>CHF</b>	40201, 40211, 40291, 40401, 40403, 40411, 40413, 40491, 40493 or 428.xx
<b>PN</b>	4800, 4801, 4802, 4803, 4808, 4809, 481, 4820, 4821, 4822, 48230, 48231, 48232, 48239, 48240, 48241, 48249, 48281, 48282, 48283, 48284, 48289, 4829, 4830, 4831, 4838, 485, 486, 4870, 48242 or 48811
<b>COPD</b>	49121, 49122, 4918, 4919, 4928, 49320, 49321, 49322, 496, or 51881, 51882, 51884 or 7991 and 49121, 49122, 49321 or 49322
<b>THA/TKA</b>	8151 or 8154
<b>HWR</b>	Medical, surgical/gynecological, cardiorespiratory, cardiovascular and neurological (additional detail is provided in the appendix)

#### **Exclusions:**

Patient deaths, transfer patients, admissions with zero days to subsequent hospitalization, patients who leave against medical advice (AMA), obstetric and non-acute patients are excluded from the model cohorts, as are readmissions flagged by the CMS/Yale Planned Readmission Algorithm. Patient deaths are identified by discharge disposition codes of 20-Expired, 40-Expired at Home, 41-Expired in a Medical Facility, and 42-Expired in an Unknown Place. Transfer patients are identified by discharge disposition code 2-Short-Term General Hospital for Inpatient Care. Transfer patient records are removed from the transferring facility and assigned to the final receiving facility. Zero-day patients are identified if the admission date is equal to the previous discharge date. Self-discharges AMA are identified by discharge disposition code 7-Left Against Medical Advice or Discontinued Care. Non-acute patients are defined by inpatient place of services codes 2-Psychiatric Unit, 3-Medical Rehabilitation Unit, 4-Alternate Level of Care, 5-Alcohol Rehabilitation Unit, or 6-Drug Rehabilitation Unit. Major Diagnostic Codes (MDC) 19 and 20 also are omitted for psychiatric disorders and substance abuse. Obstetric patients are identified with MDC 14, pregnancy, childbirth and puerperium.

#### **Statistical Models:**

We use hierarchical logistic regression models to model readmission risk as a function of fixed and random effects measured at the patient and community levels. The fixed effects include all comorbidities and demographic factors currently specified by CMS/Yale methods, as well as patient-level Medicaid status and the poverty rate of the patient's census tract of residence. The random effects side of the models used to derive the expected rates were estimated by nesting the models at the

patient's census-tract level. Hierarchical logistic regression controls for naturally occurring data clustering (correlation among records from groups of observations nested together in settings such as hospitals or geographic areas) by simultaneously modeling individual- and group-level effects that contribute to the probability the modeled outcome will occur. The SDS-enriched models we employ draw from previous peer-reviewed work.<sup>8</sup> The SDS-enriched risk adjustment is designed to estimate and compare each hospital's performance controlling for the predicted risk of its patients using the fixed effects (case mix) and the expected risk for patients from similar census tracts in terms of clinical acuity, Medicaid status and poverty rate using the random effects (community mix).

For each hospital, the models derive estimates of the predicted readmission rate, the expected readmission rate, the risk-standardized readmission ratio (SRR) and the risk-standardized readmission rate (RSRR). The predicted rate estimates the hospital's performance controlling for its observed case mix (fixed effects). The expected rate is derived by random sampling from a normal distribution and estimates the expected readmission rate of patients from similar census tracts based on other hospitals' observed performance with these patients (random effects). The estimated coefficients from the fixed effects portion of the models are applied to the patient characteristics, transformed logarithmically and averaged to derive each hospital's overall predicted readmission rate based on its case mix. The expected rates are averaged across patients for each hospital to derive an overall expected readmission rate based on its community mix. The SRR is the ratio of predicted-to-expected readmission rates for each hospital. The SRR is analogous to an observed-to-expected ratio where a value below one indicates lower than expected readmissions and a value above one indicates higher than expected readmissions. The hospital RSRRs are standardized by scaling the SRR for each hospital by the observed readmission rate of the entire sample. Risk-adjusted measures for hospitals with fewer than 25 cases during the three-year study period are withheld.

#### **Inclusion of SDS Factors:**

Numerous SDS factors have been shown to influence patients' risk of readmission following an inpatient hospitalization.<sup>8-13, 15</sup> In light of the growing body of evidence around the causal role of SDS in determining health outcomes, the question of opportunities for mediation of the causal relationship by hospital quality and the underlying policy implications of the Hospital Readmission Reduction Program, beginning in April 2015, the National Quality Forum enacted a two-year trial period to further evaluate risk adjustment for SDS factors in national quality reporting and incentive programs.<sup>18</sup> The NQF historically prohibited the inclusion of SDS factors in its endorsement of risk-adjusted quality measures out of concerns surrounding the potential codification, or masking of health disparities, for SDS disadvantaged populations.

In a reversal stemming from the recommendations of an expert panel convened by NQF in 2014, measure developers now are required to test the effects of SDS factors in statistical models and provide a conceptual and empirical justification for the inclusion or exclusion of individual or contextual SDS factors. Conceptual evidence refers to the rationale and associated theory between the health outcome being measured and the patient's sociodemographic status or context, which may or may not be supported by existing literature. Empirical evidence refers to a known, observed and quantified statistical relationship between the measured outcome and SDS factor.<sup>17</sup> Table 2 includes the

conceptual and empirical bases for the individual and contextual SDS factors included in the MHA/HIDI SDS-enriched methods.

**Table 2: Conceptual and Empirical Basis for Included SDS Factors**

SDS Factor	Conceptual Basis	Empirical Basis
<b>Medicaid Status (Individual)</b>	Commonly used individual-level indicator of low SES. Patients with Medicaid are by default below certain low-income eligibility thresholds; however, not all low-income patients qualify for Medicaid in Missouri (such as childless adults). <sup>17</sup>	Large and statistically significant effects observed in the SDS-enriched models presented in the results section below.
<b>Census-Tract Poverty Rate (Contextual)</b>	Socioeconomic status is a key driver of health outcomes. Income and associated poverty is a core dimension of SES. In the absence of individual-level information, community-level proxy data are a tenable alternative. Census tracts are considered the preferred unit of geography in health outcomes modeling. <sup>8, 17, 22</sup>	Positive and predominantly significant observed association between poverty and readmission risk presented in the results section below and existing literature. <sup>8, 9, 20, 21</sup>
<b>Census-Tract Random Effect (Contextual)</b>	Intended to characterize the patient's environment and underlying risk associated with poverty and other community-based amenities such as access to post-acute care, nutritious food and transportation to follow-up care. <sup>9, 19-21</sup>	Large reductions in measured quality differences (between-hospital variation) observed in census-tract nested models compared with hospital-nested models presented in the results section below.

### Results:

Compared to the standard CMS/Yale model specifications, the SDS-enriched models produced significant reductions in the measured quality differences (between-hospital variation) in each of the six measures evaluated for Missouri hospitals with 25 or more cases during the 36 months ending in May 2015. Table 3 shows the minimum and maximum assessments for each condition measured under both the CMS/Yale and SDS-enriched methodological approaches. The percent change in variance represents the relative difference in the range for each assessment method. At a 35 percent relative reduction, the AMI measure was least sensitive to the included SDS factors, while total hip and knee arthroplasty was most sensitive with a relative variance reduction of more than 80 percent.

**Table 3: Reduction in Between-Hospital Variation**

Model	Observations		CMS/Yale SRR			SDS-Enriched SRR			% Change in Variance
	Admissions	Hospitals	Min	Max	Range	Min	Max	Range	
<b>AMI</b>	35,741	57	0.7490	1.1667	0.4177	0.8897	1.1621	0.2724	-34.8%
<b>HF</b>	59,058	113	0.6998	1.4355	0.7357	0.8945	1.1157	0.2212	-69.9%
<b>PN</b>	62,127	118	0.7019	1.5584	0.8566	0.9422	1.2129	0.2707	-68.4%
<b>COPD</b>	58,554	117	0.7242	1.5573	0.8331	0.8383	1.2389	0.4007	-51.9%
<b>TKA/THA</b>	73,418	81	0.6399	1.7917	1.1518	0.9457	1.1726	0.2269	-80.3%
<b>HWR</b>	1,322,483	125	0.7433	1.5717	0.8284	0.9202	1.2075	0.2873	-65.3%

Table 4 includes the distribution of impacted hospitals under each assessment method by the average poverty rate of patients' census tracts and the percentage of patients with Medicaid listed as primary payer on the discharge record. Hospitals with reduced (improved) assessments with the SDS-enriched models had higher rates of SDS-disadvantaged patients compared with hospitals receiving increased assessments. The relationship was more pronounced for hospitals with SRRs assessed over one (higher than expected) under the CMS/Yale models to under one (below expected) with SDS-enrichment.

**Table 4: Impact by SDS Factors**

	Hospitals With SRR Decrease With SDS-Enrichment (Improved Score)		Hospitals With SRR Increase With SDS-Enrichment (Worsened Score)		Hospitals Moving From Over Expected by CMS/Yale to Under Expected by SDS-Enriched	
	Avg. Census- Tract Poverty Rate	Percent Medicaid	Avg. Census- Tract Poverty Rate	Percent Medicaid	Avg. Census- Tract Poverty Rate	Percent Medicaid
<b>AMI</b>	10.9%	5.9%	10.6%	4.5%	11.5%	6.3%
<b>HF</b>	14.0%	6.9%	10.6%	4.7%	15.2%	8.5%
<b>PN</b>	12.1%	7.7%	12.0%	7.9%	11.9%	11.1%
<b>COPD</b>	13.3%	13.2%	11.6%	10.4%	14.0%	13.4%
<b>TKA/THA</b>	11.2%	6.9%	9.8%	3.9%	11.6%	8.5%
<b>HWR</b>	12.6%	12.0%	11.5%	9.6%	15.7%	11.0%

Medicaid status was a significant predictor of 30-day readmissions in each of the six measures evaluated. The poverty rate for families of the patient's census tract was positive in each model, while statistical significance was mixed (see model frequency and parameter estimates tables provided below). However, including census-tract poverty in the fixed effects side of the models may improve sensitivity of the expected rates by training the random effects on other provider's performance with patients from communities with similar levels of poverty. A common concern surrounding the inclusion of SDS factors in risk-adjustment models is explaining away actual variation in quality. The SDS-enriched models produced more statistically-significant assessments at the hospital level — high or low — than the CMS/Yale models in each of the six measures evaluated (see scatter plots provided below).

Histograms of the SRRs for the CMS/Yale models compared to the SDS-enriched models reveal a closer approximation of normal distribution for each measure with SDS factors included (see SRR histograms provided below). Compared to the CMS/Yale models, the SDS-enriched models also yielded enhanced calibration, or ability to correctly predict which patients have a higher risk of the modeled outcome as measured by observed readmission rates. The calibration charts provided below show patient SRR deciles (estimated risk) for each model and assessment method compared to the observed readmission rates (actual risk) for each patient decile. For each condition evaluated, the SDS-enriched models featured improved calibration compared to the CMS/Yale models as measured by Pearson's coefficients.

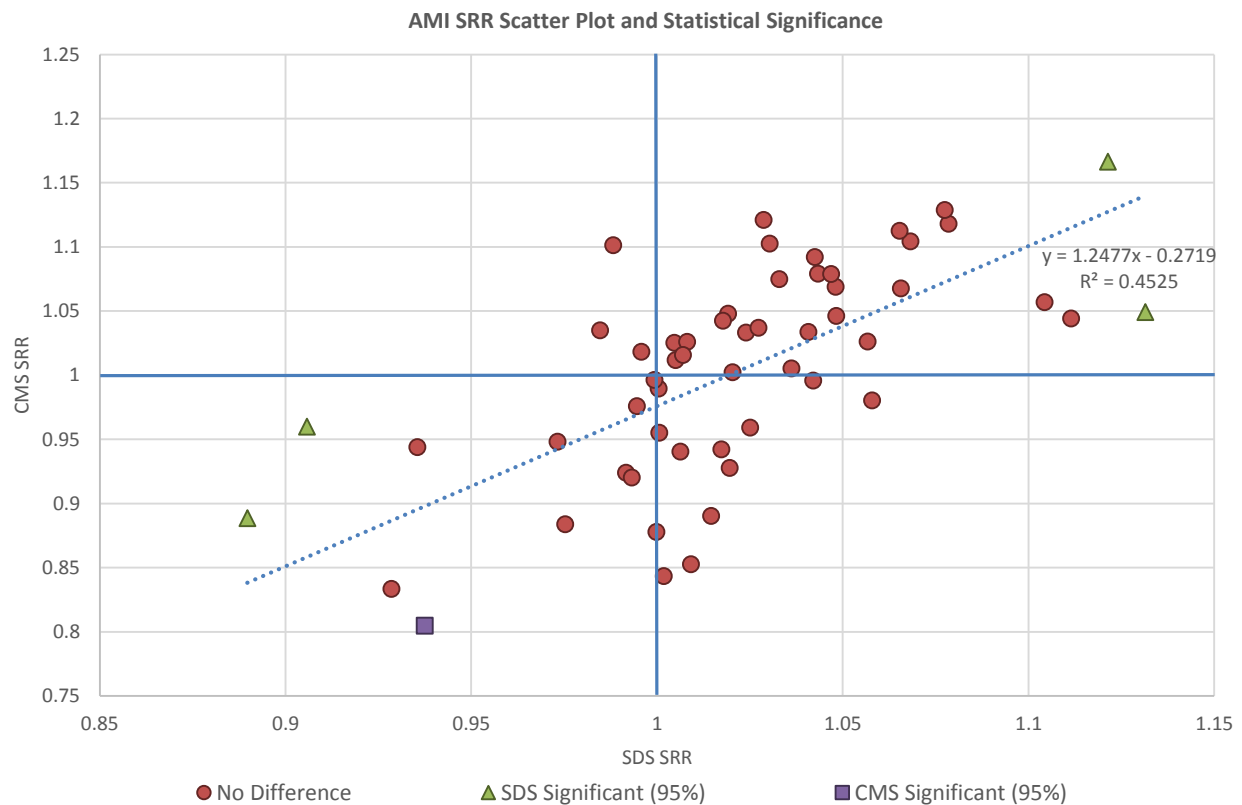
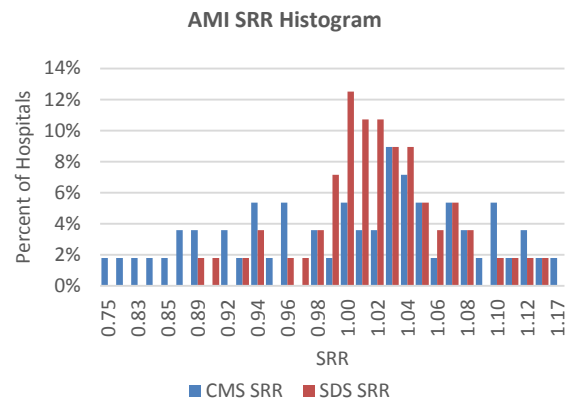
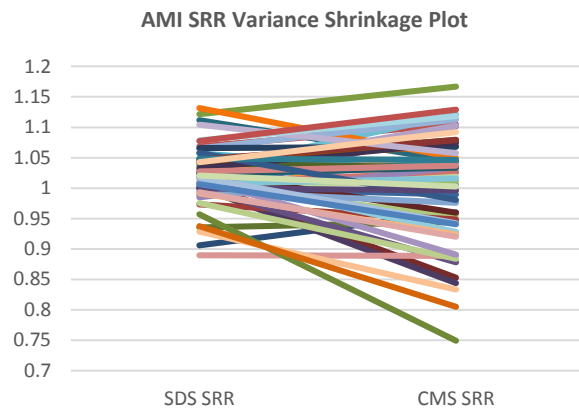
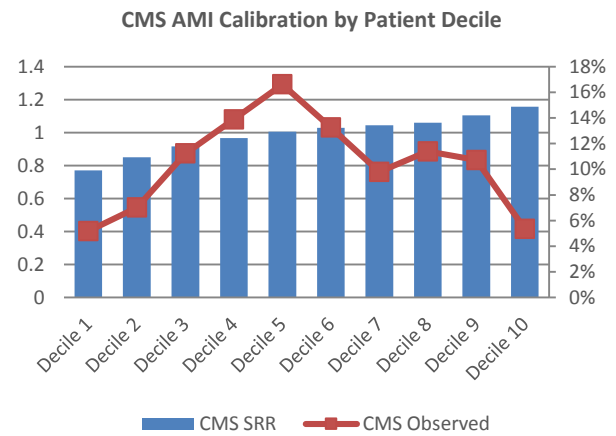
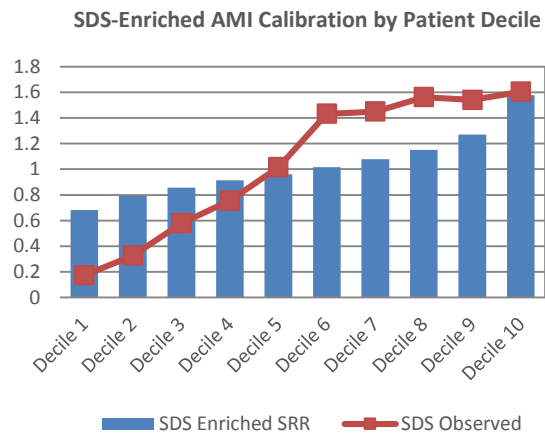
These results suggest that controlling for nonclinical SDS factors produces models that are comparatively more adept at predicting which patients actually will experience a readmission within 30 days of an acute hospitalization. This approach also subscribes to the recommendations put forth by NQF in terms of the conceptual and empirical constructs of sociodemographic determinants of 30-day hospital readmissions for each measure evaluated.

**AMI Model Results:****AMI Model Summary and Fit**

Index Admissions (n)	35,741
30-Day Readmissions	3,731
Observed Readmission Rate	10.4%
C-Statistic	0.872
Adjusted R <sup>2</sup>	0.296

**AMI Model Frequency and Parameter Estimates**

Parameter	Frequency	Odds Ratio	P-Value
Constant	-	0.014	<.0001
Age	66.5	1.000	0.8973
Male	61.4%	0.821	<.0001
History of CABG	12.7%	1.522	<.0001
History PTCA	28.6%	2.625	<.0001
Angina	26.2%	1.323	<.0001
CHF	24.5%	2.239	<.0001
Atherosclerosis	88.4%	1.333	<.0001
ACS	36.9%	1.509	<.0001
Arrhythmias	23.9%	1.418	<.0001
Valvular/rheumatic heart disease	16.1%	0.961	0.3361
Cerebrovascular disease	6.3%	1.115	0.0442
Stroke	2.1%	0.969	0.728
Vascular or circulatory disease	19.6%	1.466	<.0001
Functional disability	4.2%	1.009	0.8862
Diabetes	39.3%	0.930	0.0408
Renal failure	20.4%	1.402	<.0001
ESRD	2.1%	0.982	0.8153
Urinary tract disorders	7.9%	1.119	0.025
COPD	23.4%	1.094	0.016
Pneumonia	12.8%	1.301	<.0001
Asthma	3.6%	1.082	0.3073
Fluid disorders	23.5%	1.599	<.0001
History of infection	7.5%	1.251	<.0001
Metastatic cancer or leukemia	1.3%	1.158	0.2387
Cancer	5.4%	1.144	0.034
Iron deficiency	31.4%	1.327	<.0001
Decubitus ulcer	3.1%	1.090	0.2205
Dementia	7.8%	1.195	0.0012
Malnutrition	4.6%	1.095	0.1416
Anterior MI	9.3%	1.302	<.0001
Other location MI	16.3%	0.919	0.12
Census-Tract Poverty Rate	10.9%	1.002	0.3892
Medicaid Status	5.5%	1.261	0.0013



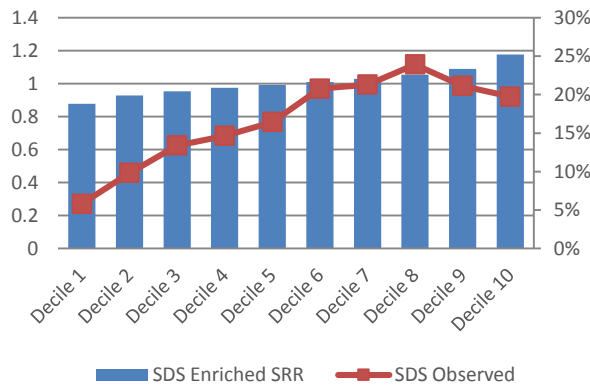
**CHF Model Results:****CHF Model Summary and Fit**

Index Admissions (n)	59,058
30-Day Readmissions	9,853
Observed Readmission Rate	16.7%
C-Statistic	0.791
Adjusted R <sup>2</sup>	0.221

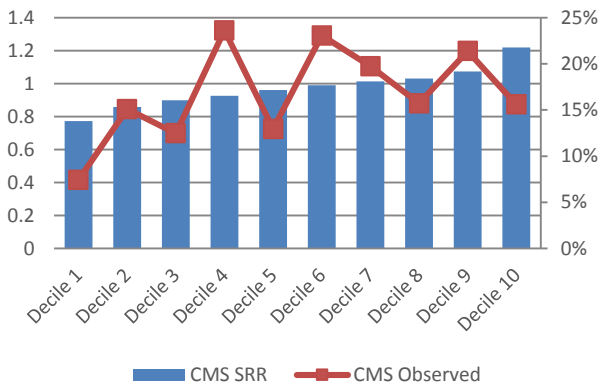
**CHF Model Frequency and Parameter Estimates**

Parameter	Frequency	Odds Ratio	P-Value
Constant	-	0.052	<.0001
Age	72.6	0.995	<.0001
Male	49.1%	0.912	0.0001
History of CABG	19.2%	0.968	0.2887
Diabetes	50.4%	1.023	0.3514
Fluid disorders	37.0%	1.614	<.0001
Iron deficiency	47.0%	1.092	0.0005
Cardio-respiratory failure	26.4%	1.517	<.0001
CHF	43.9%	0.894	<.0001
Vascular or circulatory disease	26.1%	1.335	<.0001
COPD	42.4%	1.275	<.0001
Pneumonia	26.0%	0.920	0.0013
Renal failure	37.9%	2.524	<.0001
Urinary tract disorders	12.9%	0.989	0.7315
Decubitus ulcer	7.7%	1.008	0.8309
Other GI disorders	45.9%	1.085	0.0008
ACS	8.8%	0.909	0.0066
Valvular/rheumatic heart disease	33.3%	0.961	0.0991
Arrhythmias	38.0%	2.071	<.0001
Asthma	4.9%	1.051	0.3134
Peptic ulcer, hemorrhage, GI	7.7%	0.982	0.6102
Cancer	7.9%	1.024	0.5594
Substance abuse/psychosis	19.4%	0.935	0.0282
Major psychiatric disorders	5.8%	1.098	0.0327
ESRD	3.5%	1.079	0.1287
Severe hematological	1.2%	1.207	0.0312
Nephritis	3.7%	1.003	0.9454
Liver or biliary disease	8.3%	1.097	0.0127
Metastatic cancer or leukemia	1.5%	1.215	0.0208
Stroke	2.0%	0.900	0.1301
Dementia	12.6%	1.131	0.0003
Atherosclerosis or angina	60.7%	1.086	0.0018
Other heart disease	7.7%	1.068	0.0921
Other psychiatric disorders	16.3%	1.178	<.0001
Functional disability	5.5%	1.071	0.1128
Fibrosis/chronic lung disorders	4.0%	0.981	0.7129
Malnutrition	7.8%	1.071	0.0658
Depression	20.6%	1.029	0.3093
Census-Tract Poverty Rate	11.9%	1.009	<.0001
Medicaid Status	6.8%	1.322	<.0001

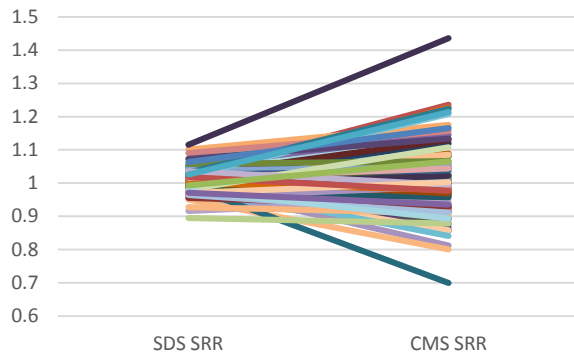
SDS-Enriched CHF Calibration by Patient Decile



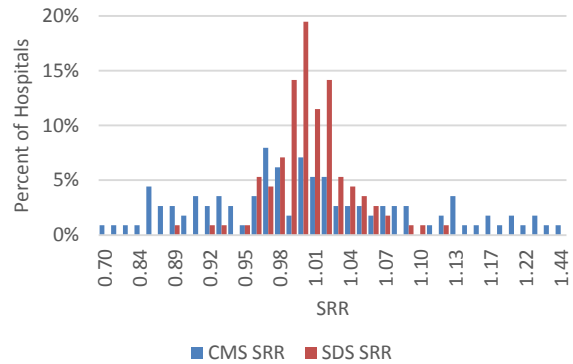
CMS CHF Calibration by Patient Decile



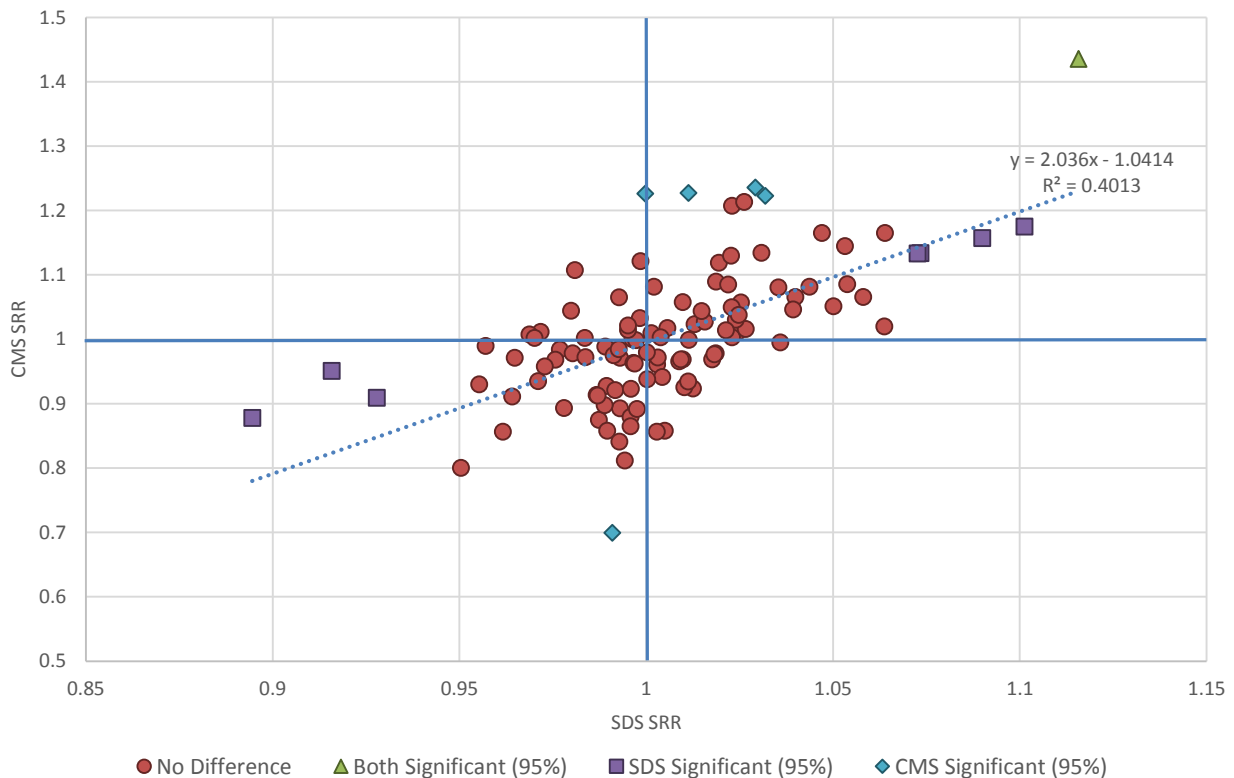
CHF SRR Variance Shrinkage Plot



CHF SRR Histogram



CHF SRR Scatter Plot and Statistical Significance



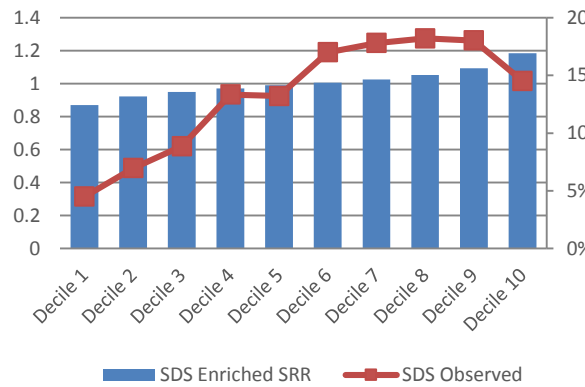
**PN Model Results:****PN Model Summary and Fit**

Index Admissions (n)	62,127
30-Day Readmissions	8,224
Observed Readmission Rate	13.2%
C-Statistic	0.824
Adjusted R <sup>2</sup>	0.252

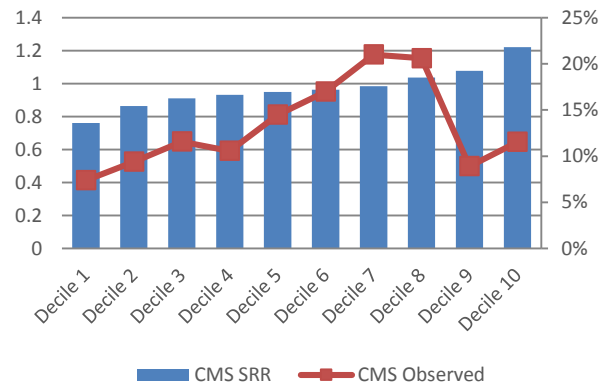
**PN Model Frequency and Parameter Estimates**

Parameter	Frequency	Odds Ratio	P-Value
Constant	-	0.029	<.0001
Age	68.9	1.001	0.309
Male	44.9%	1.149	<.0001
History of CABG	7.9%	0.895	0.016
History of infection	15.1%	1.331	<.0001
Septicemia/shock	7.2%	0.981	0.633
Metastatic cancer or leukemia	4.6%	1.202	0.002
Lung/upper digestive cancer	5.2%	1.427	<.0001
Other major cancers	7.3%	1.073	0.114
Diabetes	33.9%	0.975	0.340
Malnutrition	11.0%	1.136	0.000
Fluid disorders	36.4%	2.271	<.0001
Other GI disorders	51.2%	1.225	<.0001
Severe hematological	1.3%	1.353	0.001
Iron deficiency	41.2%	1.296	<.0001
Dementia	15.7%	1.113	0.002
Substance abuse/psychosis	26.5%	1.019	0.533
Major psychiatric disorders	9.5%	1.188	<.0001
Other psychiatric disorders	21.4%	1.280	<.0001
Functional disability	5.6%	1.231	<.0001
Cardio-respiratory failure	28.1%	2.291	<.0001
CHF	24.9%	1.643	<.0001
ACS	4.5%	0.974	0.585
Atherosclerosis or angina	32.8%	0.927	0.010
Valvular/rheumatic heart disease	10.8%	0.885	0.001
Arrhythmias	23.3%	1.470	<.0001
Stroke	1.8%	0.994	0.937
Vascular or circulatory disease	20.0%	1.202	<.0001
COPD	49.4%	1.226	<.0001
Fibrosis/chronic lung disorders	7.3%	1.184	<.0001
Asthma	7.9%	1.127	0.010
Pneumonia	33.6%	0.482	<.0001
Pleural effusion/pneumothorax	6.9%	1.639	<.0001
Other lung disorders	13.3%	1.061	0.070
ESRD	2.3%	1.069	0.276
Renal failure	22.8%	1.294	<.0001
Urinary tract infection	12.2%	1.003	0.921
Urinary tract disorders	9.8%	1.005	0.901
Decubitus ulcer	5.1%	1.148	0.002
Vertebral fractures	1.9%	1.138	0.079
Other injuries	15.5%	0.755	<.0001
Census-Tract Poverty Rate	11.1%	1.001	0.611
Medicaid Status	7.5%	1.186	0.0001

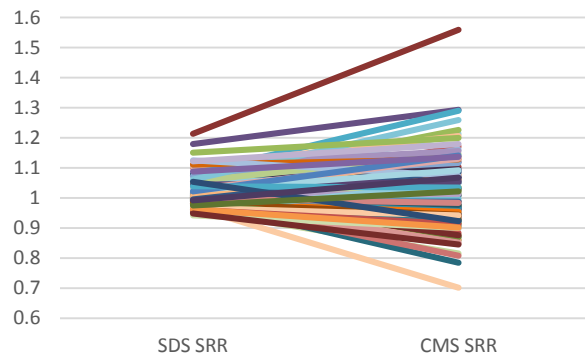
SDS-Enriched PN Calibration by Patient Decile



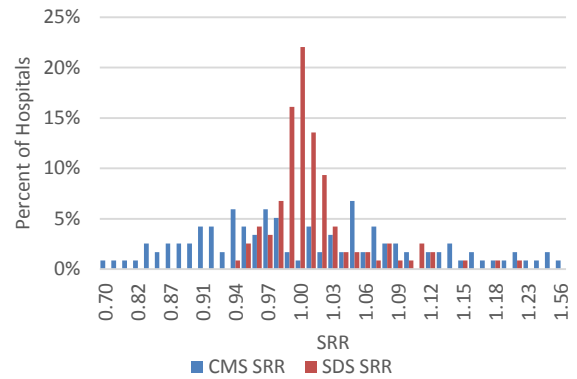
CMS PN Calibration by Patient Decile



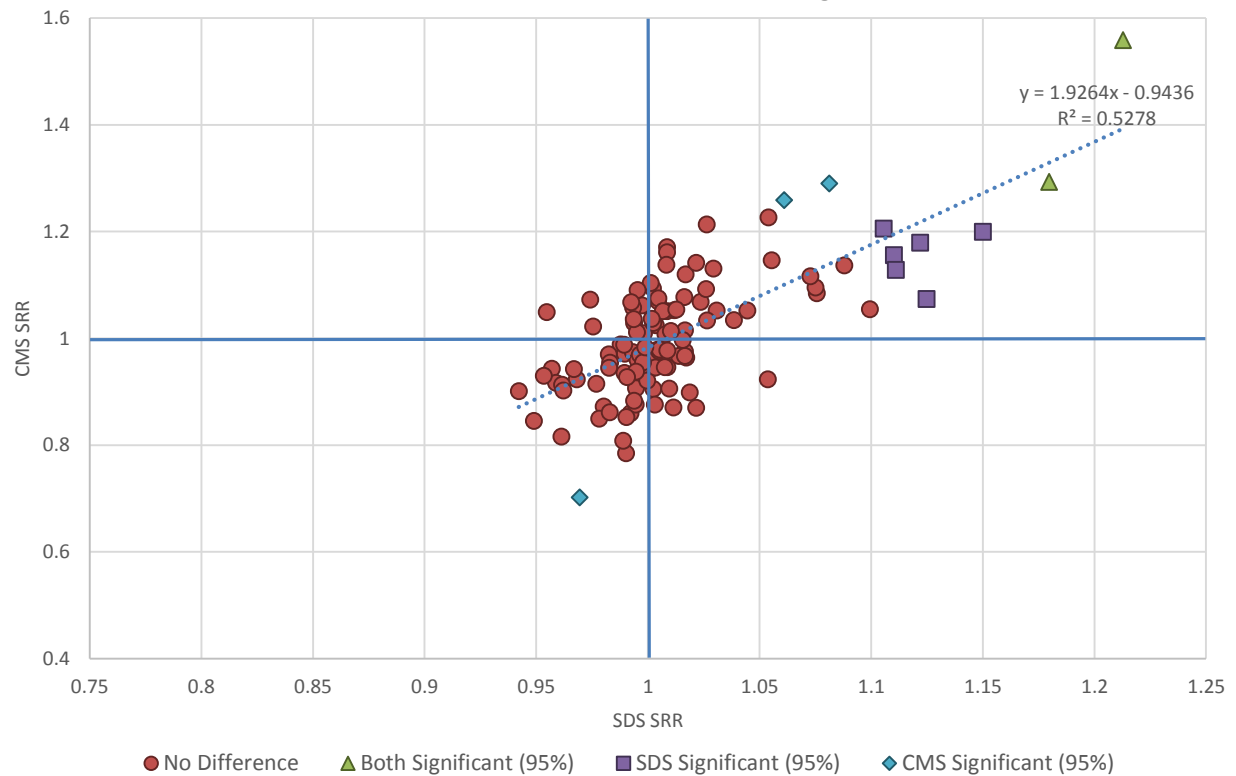
PN SRR Variance Shrinkage Plot



PN SRR Histogram



Pneumonia SRR Scatter Plot and Statistical Significance



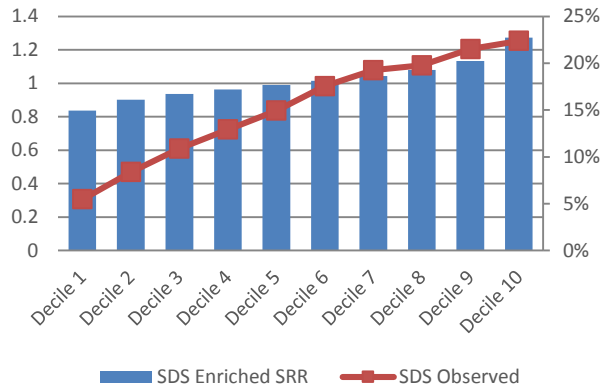
**COPD Model Results:****COPD Model Summary and Fit**

Index Admissions (n)	58,554
30-Day Readmissions	8,954
Observed Readmission Rate	15.3%
C-Statistic	0.717
Adjusted R <sup>2</sup>	0.106

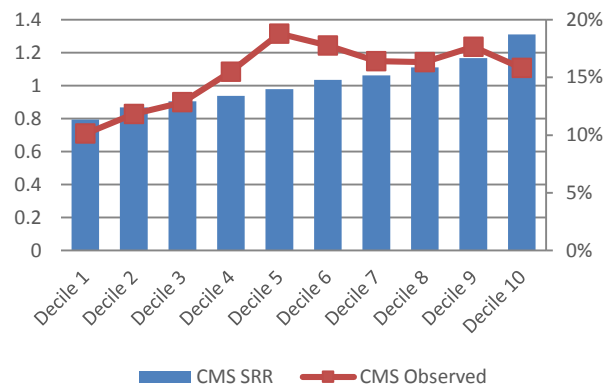
**COPD Model Frequency and Parameter Estimates**

Parameter	Frequency	Odds Ratio	P-Value
Constant	-	0.064	<.0001
Age	66.7	1.003	0.013
Fibrosis/chronic lung disorders	5.8%	1.050	0.291
Digestive/urinary neoplasms	1.2%	1.081	0.395
Renal failure	14.9%	1.049	0.243
Decubitus ulcer	3.0%	0.972	0.641
Cellulitis/skin infection	3.4%	0.979	0.714
Vertebral fractures	1.6%	1.341	0.000
Malnutrition	8.0%	1.148	0.001
Endocrine/metabolic/nutritional dis.	64.7%	0.982	0.520
Pancreatic disease	1.3%	1.146	0.126
Peptic ulcer, hemorrhage, GI	5.1%	1.321	<.0001
Other GI disorders	47.3%	1.172	<.0001
Severe hematological	0.5%	1.058	0.697
Iron deficiency	32.2%	1.268	<.0001
Depression	27.0%	1.083	0.004
Anxiety disorders	5.2%	1.220	<.0001
Other psychiatric disorders	27.7%	1.170	<.0001
Metastatic cancer or leukemia	1.8%	1.084	0.357
Polyneuropathy	8.1%	1.006	0.877
Cardio-respiratory failure	25.4%	1.166	<.0001
Lung/upper digestive/severe cancers	3.4%	1.330	<.0001
CHF	20.6%	1.490	<.0001
Hypertensive heart/renal disease	14.0%	0.994	0.874
Arrhythmias	16.1%	1.323	<.0001
Other heart disease	4.5%	1.010	0.853
History of infection	9.6%	1.154	0.000
Vascular or circulatory disease	14.2%	1.166	<.0001
Pneumonia	32.1%	1.144	<.0001
Diabetes	35.7%	1.079	0.004
Fluid disorders	24.2%	1.179	<.0001
Dementia	7.2%	0.930	0.101
Substance abuse/psychosis	4.5%	0.994	0.907
Major psychiatric disorders	9.9%	1.200	<.0001
Functional disability	2.6%	0.947	0.413
Respirator dependence	0.7%	1.206	0.077
ACS	3.8%	0.853	0.004
Coronary atherosclerosis/angina	33.5%	1.065	0.019
Other major cancers	3.6%	1.045	0.455
Stroke	1.2%	1.276	0.009
Sleep apnea	20.9%	1.053	0.087
History of mechanical ventilation	3.8%	2.105	<.0001
Census-Tract Poverty Rate	12.3%	1.005	0.002
Medicaid Status	12.3%	1.244	<.0001

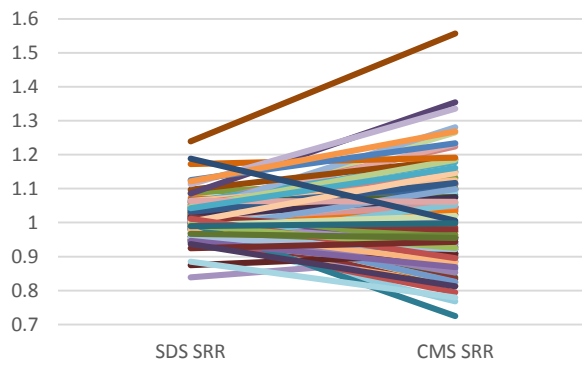
SDS-Enriched COPD Calibration by Patient Decile



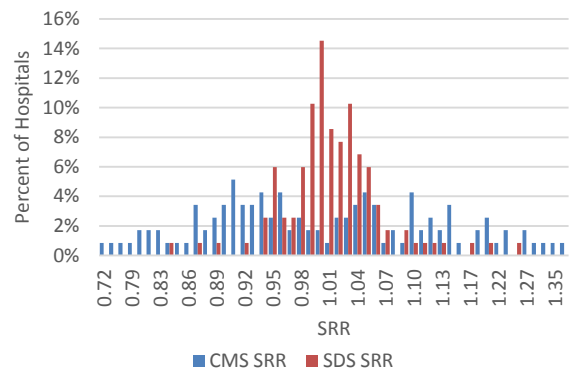
CMS COPD Calibration by Patient Decile



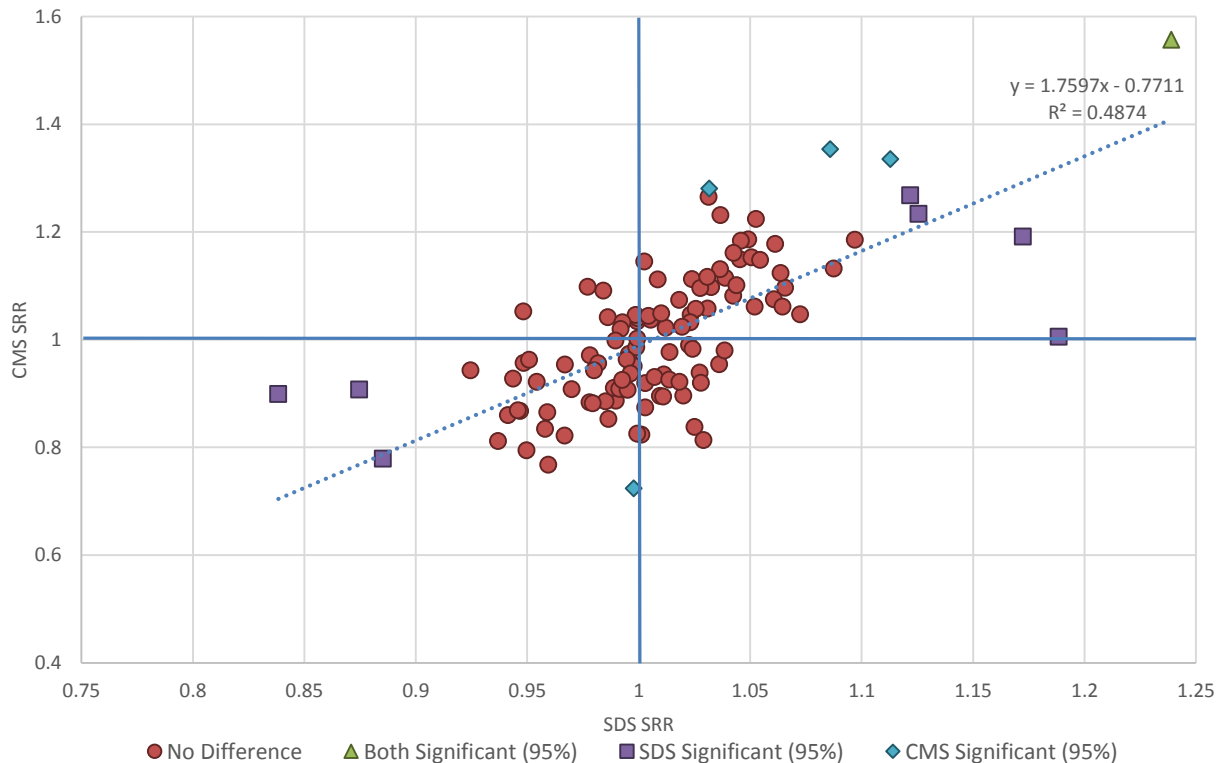
COPD SRR Variance Shrinkage Plot



COPD SRR Histogram



COPD SRR Scatter Plot and Statistical Significance



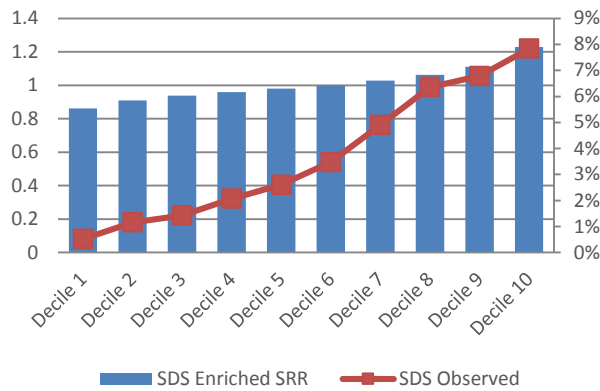
**THA/TKA Model Results:****THA/TKA Model Summary and Fit**

Index Admissions (n)	73,418
30-Day Readmissions	2,726
Observed Readmission Rate	3.7%
C-Statistic	0.732
Adjusted R <sup>2</sup>	0.072

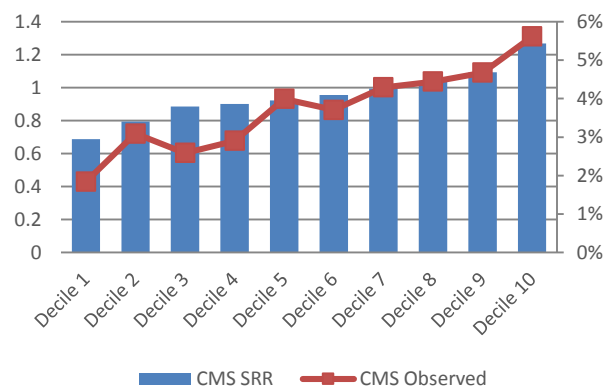
**THA/TKA Model Frequency and Parameter Estimates**

Parameter	Frequency	Odds Ratio	P-Value
Constant	-	0.005	<.0001
Age	65.7	1.026	<.0001
Male	40.1%	1.105	0.013
THA procedure	29.6%	1.025	0.564
Number of procedures	2.6%	1.057	0.660
History of infection	2.0%	1.582	<.0001
Metastatic cancer or leukemia	0.2%	0.535	0.120
Cancer	1.7%	1.147	0.225
Diabetes	20.6%	1.082	0.087
Malnutrition	0.5%	1.559	0.004
Fluid disorders	6.3%	1.387	<.0001
Rheumatoid arthritis	4.9%	1.309	0.000
Severe hematological	0.2%	2.621	0.001
Dementia	1.1%	1.124	0.370
Major psychiatric disorders	2.8%	1.261	0.012
Functional disability	0.5%	0.847	0.395
Polyneuropathy	3.5%	1.235	0.009
CHF	2.4%	1.178	0.065
Atherosclerosis or angina	13.3%	1.216	0.000
Hypertension	66.6%	1.287	<.0001
Arrhythmias	4.8%	1.025	0.735
Stroke	0.3%	1.274	0.306
Vascular or circulatory disease	4.3%	1.419	<.0001
COPD	8.7%	1.629	<.0001
Pneumonia	1.3%	1.307	0.009
ESRD	0.1%	0.949	0.894
Renal failure	3.6%	1.092	0.255
Decubitus ulcer	0.3%	0.732	0.149
Cellulitis/skin infection	0.9%	2.205	<.0001
Other injuries	4.4%	1.929	<.0001
Major symptoms, abnormalities	8.0%	1.389	<.0001
Morbid obesity	7.8%	1.405	<.0001
Congenital deformity of hip	0.4%	1.200	0.610
Post traumatic osteoarthritis	0.2%	1.031	0.934
Census-Tract Poverty Rate	9.1%	1.003	0.282
Medicaid Status	2.6%	1.896	<.0001

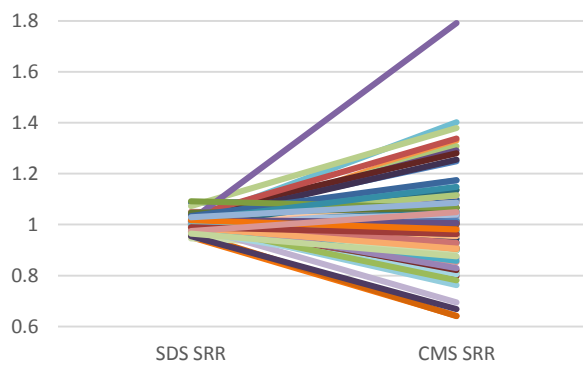
SDS-Enriched THA/TKA Calibration by Patient Decile



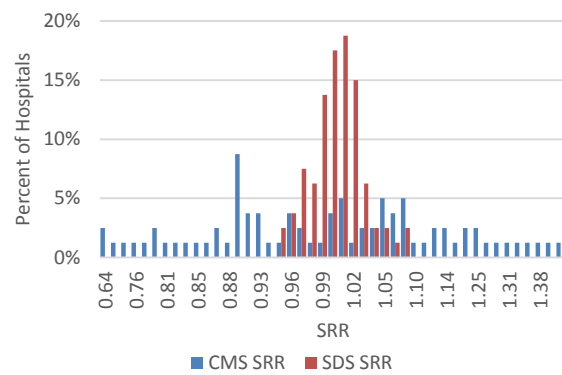
CMS THA/TKA Calibration by Patient Decile



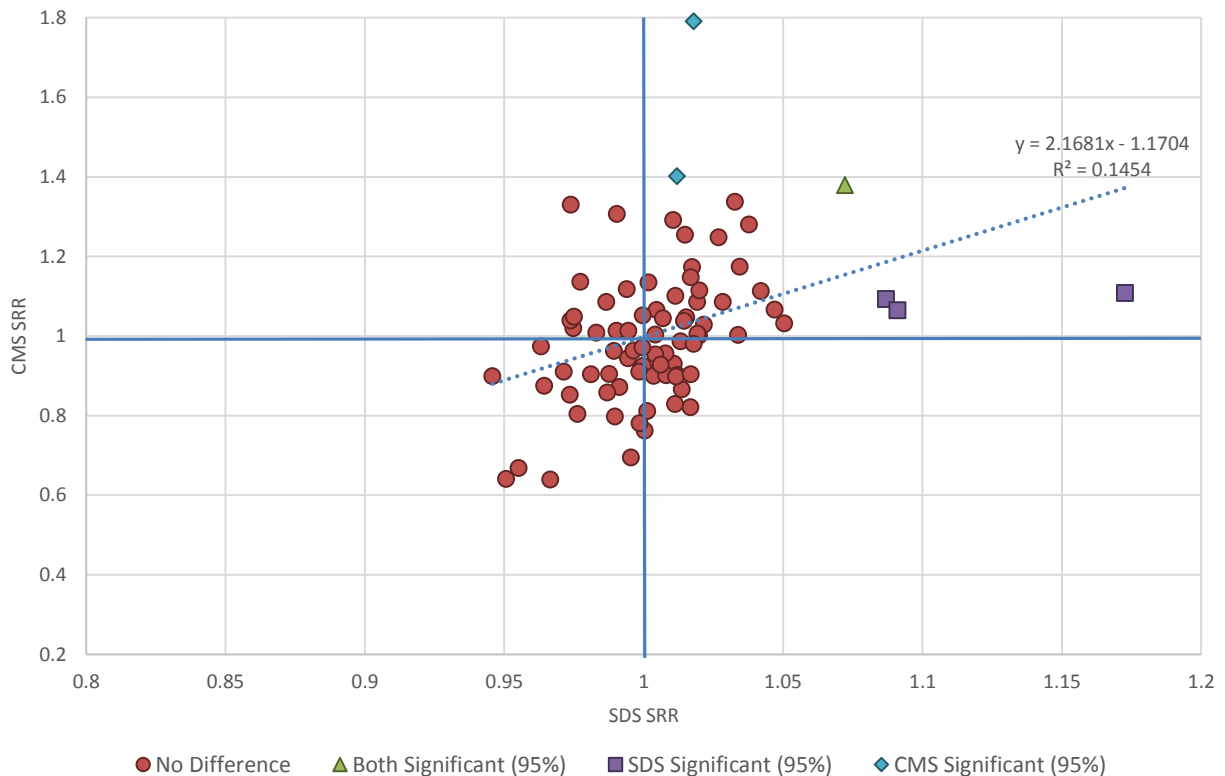
THA/TKA SRR Variance Shrinkage Plot



THA/TKA SRR Histogram



THA/TKA SRR Scatter Plot and Statistical Significance



## HWR Model Results:

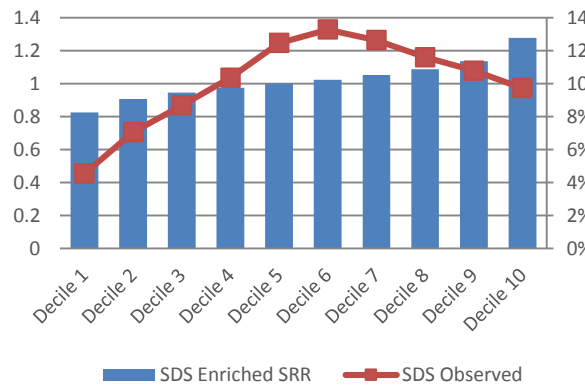
### HWR Weighted Model Summary and Fit

Index Admissions (n)	1,322,483
30-Day Readmissions	131,464
Observed Readmission Rate	9.9%
C-Statistic	0.856

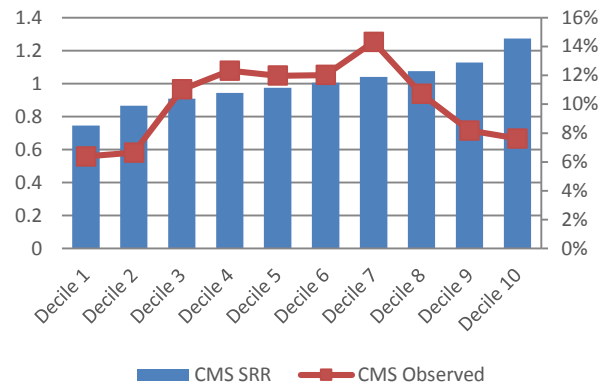
### HWR Model Frequency and Weighted Parameter Estimates

Parameter	Frequency	Odds Ratio	P-Value
Constant	-	0.019	<0.0001
Age	62.7	0.996	0.031
Metastatic cancer	3.2%	1.374	0.162
Severe cancer	4.3%	1.429	<0.0001
Other major cancers	5.8%	1.144	0.045
Other hematological disorders	0.8%	1.773	0.011
Coagulation/hematological	4.9%	1.033	0.073
Iron deficiency	32.8%	1.364	<0.0001
Liver or biliary disease	2.3%	1.339	0.019
Pancreatic disease	2.8%	1.492	0.003
Dialysis status	1.0%	2.079	<0.0001
Renal failure	14.1%	1.768	<0.0001
Transplants	0.8%	1.831	0.001
History of infection	1.5%	1.249	0.051
Other infectious disease	18.5%	1.799	<0.0001
Septicemia/Shock	5.7%	1.281	0.020
CHF	11.4%	2.255	<0.0001
Atherosclerosis/angina	41.9%	1.496	<0.0001
Specified arrhythmias	14.2%	1.685	<0.0001
Cardiorespiratory failure/shock	10.0%	1.090	0.052
COPD	21.4%	1.329	<0.0001
Fibrosis/chronic lung disorders	2.0%	1.079	0.096
Protein-calorie malnutrition	6.0%	1.071	0.207
Endocrine and metabolic disorders	24.2%	2.238	<0.0001
Rheumatoid arthritis	4.2%	1.250	0.001
Diabetes	30.8%	1.132	<0.0001
Decubitus ulcers	3.7%	1.158	0.003
Functional disability	4.6%	1.589	<0.0001
Seizures/convulsions	4.9%	1.425	<0.0001
Respirator/tracheostomy	0.3%	1.503	0.099
Substance abuse	3.7%	1.050	0.082
Psychological	30.8%	1.475	<0.0001
Hip fracture/dislocation	2.0%	1.017	0.057
Census-Tract Poverty Rate	11.1%	1.002	0.186
Medicaid Status	8.9%	1.353	<0.0001

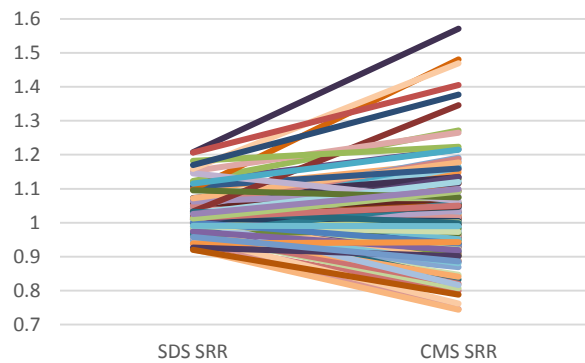
SDS-Enriched HWR Calibration by Patient Decile



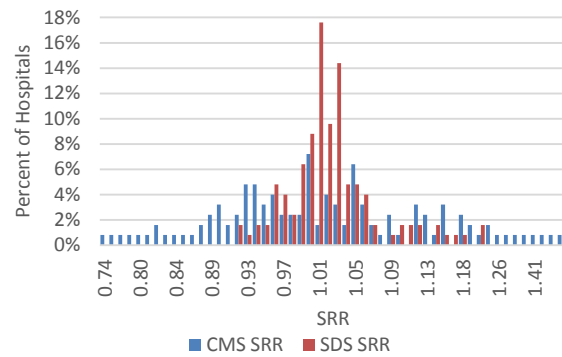
CMS HWR Calibration by Patient Decile



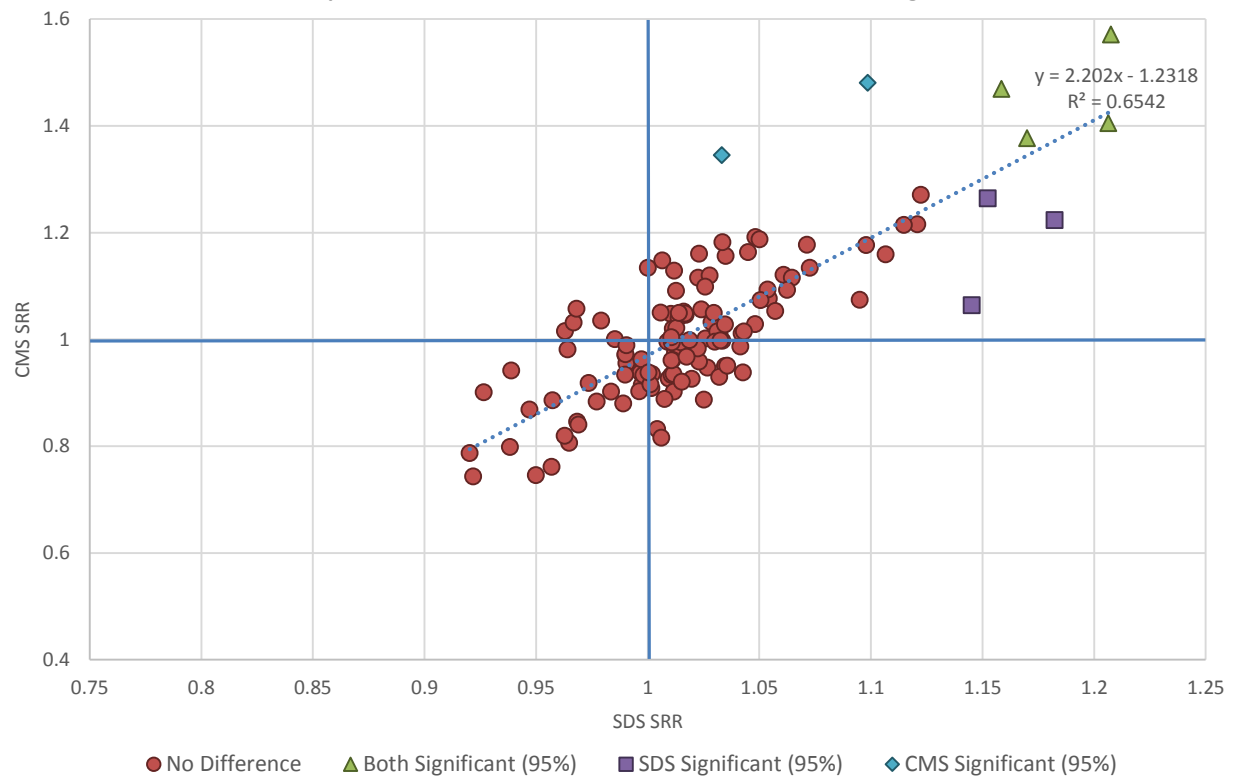
HWR SRR Variance Shrinkage Plot



HWR SRR Histogram



Hospital-Wide Readmissions SRR Scatter Plot and Statistical Significance



## Appendix:

### HWR Cardiorespiratory Cohort

#### AHRQ

##### Diagnosis

CCS	Description
56	Cystic fibrosis
103	Pulmonary heart disease
108	Congestive heart failure; nonhypertensive
122	Pneumonia (except that caused by tuberculosis or sexually transmitted disease)
125	Acute bronchitis
127	Chronic obstructive pulmonary disease and bronchiectasis
128	Asthma
131	Respiratory failure; insufficiency; arrest (adult)

### HWR Cardiovascular Cohort

96	Heart valve disorders
97	Peri-; endo-; and myocarditis; cardiomyopathy (except that caused by tuberculosis or sexually transmitted)
100	Acute myocardial infarction
101	Coronary atherosclerosis and other heart disease
102	Nonspecific chest pain
104	Other and ill-defined heart disease
105	Conduction disorders
106	Cardiac dysrhythmias
107	Cardiac arrest and ventricular fibrillation
114	Peripheral and visceral atherosclerosis
115	Aortic; peripheral; and visceral artery aneurysms
116	Aortic and peripheral arterial embolism or thrombosis
117	Other circulatory disease
213	Cardiac and circulatory congenital anomalies

### HWR Neurological Cohort

78	Other CNS infection and poliomyelitis
79	Parkinson`s disease
80	Multiple sclerosis
81	Other hereditary and degenerative nervous system conditions
82	Paralysis
83	Epilepsy; convulsions
85	Coma; stupor; and brain damage
95	Other nervous system disorders
109	Acute cerebrovascular disease
110	Occlusion or stenosis of precerebral arteries
111	Other and ill-defined cerebrovascular disease
112	Transient cerebral ischemia
113	Late effects of cerebrovascular disease
216	Nervous system congenital anomalies
227	Spinal cord injury
233	Intracranial injury

## HWR Surgical/Gynecological Cohort

AHRQ Procedure	
CCS	Description
1	Incision and excision of central nervous system
2	Insertion; replacement; or removal of extracranial ventricular shunt
3	Laminectomy; excision intervertebral disc
9	Other OR therapeutic nervous system procedures
10	Thyroidectomy; partial or complete
12	Other therapeutic endocrine procedures
13	Corneal transplant
14	Glaucoma procedures
15	Lens and cataract procedures
16	Repair of retinal tear; detachment
17	Destruction of lesion of retina and choroid
20	Other intraocular therapeutic procedures
21	Other extraocular muscle and orbit therapeutic procedures
22	Tympanoplasty
23	Myringotomy
24	Mastoidectomy
26	Other therapeutic ear procedures
28	Plastic procedures on nose
30	Tonsillectomy and/or adenoidectomy
33	Other OR therapeutic procedures on nose; mouth and pharynx
36	Lobectomy or pneumonectomy
42	Other OR Rx procedures on respiratory system and mediastinum
43	Heart valve procedures
44	Coronary artery bypass graft (CABG)
49	Other OR heart procedures
51	Endarterectomy; vessel of head and neck
52	Aortic resection; replacement or anastomosis
53	Varicose vein stripping; lower limb
55	Peripheral vascular bypass
56	Other vascular bypass and shunt; not heart
59	Other OR procedures on vessels of head and neck
60	Embolectomy and endarterectomy of lower limbs
66	Procedures on spleen
67	Other therapeutic procedures; hemic and lymphatic system
72	Colostomy; temporary and permanent
73	Ileostomy and other enterostomy
74	Gastrectomy; partial and total
75	Small bowel resection
78	Colorectal resection
79	Local excision of large intestine lesion (not endoscopic)
80	Appendectomy
84	Cholecystectomy and common duct exploration
85	Inguinal and femoral hernia repair
86	Other hernia repair
89	Exploratory laparotomy
90	Excision; lysis peritoneal adhesions
96	Other OR lower GI therapeutic procedures
99	Other OR gastrointestinal therapeutic procedures
101	Transurethral excision; drainage; or removal urinary obstruction
103	Nephrotomy and nephrostomy

## HWR Surgical/Gynecological Cohort

AHRQ	
Procedure	
CCS	Description
104	Nephrectomy; partial or complete
105	Kidney transplant
106	Genitourinary incontinence procedures
112	Other OR therapeutic procedures of urinary tract
113	Transurethral resection of prostate (TURP)
114	Open prostatectomy
118	Other OR therapeutic procedures; male genital
119	Oophorectomy; unilateral and bilateral
120	Other operations on ovary
121	Ligation or occlusion of fallopian tubes
122	Removal of ectopic pregnancy
123	Other operations on fallopian tubes
124	Hysterectomy; abdominal and vaginal
125	Other excision of cervix and uterus
126	Abortion (termination of pregnancy)
127	Dilatation and curettage (D&C); aspiration after delivery or abortion
129	Repair of cystocele and rectocele; obliteration of vaginal vault
131	Other non-OR therapeutic procedures; female organs
132	Other OR therapeutic procedures; female organs
133	Episiotomy
134	Cesarean section
135	Forceps; vacuum; and breech delivery
136	Artificial rupture of membranes to assist delivery
137	Other procedures to assist delivery
139	Fetal monitoring
140	Repair of current obstetric laceration
141	Other therapeutic obstetrical procedures
142	Partial excision bone
143	Bunionectomy or repair of toe deformities
144	Treatment; facial fracture or dislocation
145	Treatment; fracture or dislocation of radius and ulna
146	Treatment; fracture or dislocation of hip and femur
147	Treatment; fracture or dislocation of lower extremity (other than hip or femur)
148	Other fracture and dislocation procedure
150	Division of joint capsule; ligament or cartilage
151	Excision of semilunar cartilage of knee
152	Arthroplasty knee
153	Hip replacement; total and partial
154	Arthroplasty other than hip or knee
157	Amputation of lower extremity
158	Spinal fusion
160	Other therapeutic procedures on muscles and tendons
161	Other OR therapeutic procedures on bone
162	Other OR therapeutic procedures on joints
164	Other OR therapeutic procedures on musculoskeletal system
166	Lumpectomy; quadrantectomy of breast
167	Mastectomy
172	Skin graft
175	Other OR therapeutic procedures on skin and breast
176	Other organ transplantation

## HWR Medicine Cohort

### AHRQ

#### Diagnosis

CCS	Description
1	Tuberculosis
2	Septicemia (except in labor)
3	Bacterial infection; unspecified site
4	Mycoses
5	HIV infection
6	Hepatitis
7	Viral infection
8	Other infections; including parasitic
9	Sexually transmitted infections (not HIV or hepatitis)
10	Immunizations and screening for infectious disease
46	Benign neoplasm of uterus
47	Other and unspecified benign neoplasm
48	Thyroid disorders
49	Diabetes mellitus without complication
50	Diabetes mellitus with complications
51	Other endocrine disorders
52	Nutritional deficiencies
53	Disorders of lipid metabolism
54	Gout and other crystal arthropathies
55	Fluid and electrolyte disorders
57	Immunity disorders
58	Other nutritional; endocrine; and metabolic disorders
59	Deficiency and other anemia
60	Acute posthemorrhagic anemia
61	Sickle cell anemia
62	Coagulation and hemorrhagic disorders
63	Diseases of white blood cells
64	Other hematologic conditions
76	Meningitis (except that caused by tuberculosis or sexually transmitted disease)
77	Encephalitis (except that caused by tuberculosis or sexually transmitted disease)
84	Headache; including migraine
86	Cataract
87	Retinal detachments; defects; vascular occlusion; and retinopathy
88	Glaucoma
89	Blindness and vision defects
90	Inflammation; infection of eye (except that caused by tuberculosis or sexually transmitted disease)
91	Other eye disorders
92	Otitis media and related conditions
93	Conditions associated with dizziness or vertigo
94	Other ear and sense organ disorders
98	Essential hypertension
99	Hypertension with complications and secondary hypertension
118	Phlebitis; thrombophlebitis and thromboembolism
119	Varicose veins of lower extremity
120	Hemorrhoids
121	Other diseases of veins and lymphatics
124	Acute and chronic tonsillitis
126	Other upper respiratory infections
129	Aspiration pneumonitis; food/vomitus
130	Pleurisy; pneumothorax; pulmonary collapse

## HWR Medicine Cohort

### AHRQ

#### Diagnosis

CCS	Description
132	Lung disease due to external agents
133	Other lower respiratory disease
134	Other upper respiratory disease
135	Intestinal infection
136	Disorders of teeth and jaw
137	Diseases of mouth; excluding dental
138	Esophageal disorders
139	Gastroduodenal ulcer (except hemorrhage)
140	Gastritis and duodenitis
141	Other disorders of stomach and duodenum
142	Appendicitis and other appendiceal conditions
143	Abdominal hernia
144	Regional enteritis and ulcerative colitis
145	Intestinal obstruction without hernia
146	Diverticulosis and diverticulitis
147	Anal and rectal conditions
148	Peritonitis and intestinal abscess
149	Biliary tract disease
151	Other liver diseases
152	Pancreatic disorders (not diabetes)
153	Gastrointestinal hemorrhage
154	Noninfectious gastroenteritis
155	Other gastrointestinal disorders
156	Nephritis; nephrosis; renal sclerosis
157	Acute and unspecified renal failure
158	Chronic renal failure
159	Urinary tract infections
160	Calculus of urinary tract
161	Other diseases of kidney and ureters
162	Other diseases of bladder and urethra
163	Genitourinary symptoms and ill-defined conditions
164	Hyperplasia of prostate
165	Inflammatory conditions of male genital organs
166	Other male genital disorders
167	Nonmalignant breast conditions
168	Inflammatory diseases of female pelvic organs
169	Endometriosis
170	Prolapse of female genital organs
171	Menstrual disorders
172	Ovarian cyst
173	Menopausal disorders
174	Female infertility
175	Other female genital disorders
197	Skin and subcutaneous tissue infections
198	Other inflammatory condition of skin
199	Chronic ulcer of skin
200	Other skin disorders
201	Infective arthritis and osteomyelitis (except that caused by tuberculosis or sexually transmitted disease)
202	Rheumatoid arthritis and related disease
203	Osteoarthritis

## HWR Medicine Cohort

### AHRQ

#### Diagnosis

CCS	Description
204	Other non-traumatic joint disorders
205	Spondylosis; intervertebral disc disorders; other back problems
206	Osteoporosis
207	Pathological fracture
208	Acquired foot deformities
209	Other acquired deformities
210	Systemic lupus erythematosus and connective tissue disorders
211	Other connective tissue disease
212	Other bone disease and musculoskeletal deformities
214	Digestive congenital anomalies
215	Genitourinary congenital anomalies
217	Other congenital anomalies
225	Joint disorders and dislocations; trauma-related
226	Fracture of neck of femur (hip)
228	Skull and face fractures
229	Fracture of upper limb
230	Fracture of lower limb
231	Other fractures
232	Sprains and strains
234	Crushing injury or internal injury
235	Open wounds of head; neck; and trunk
236	Open wounds of extremities
237	Complication of device; implant or graft
238	Complications of surgical procedures or medical care
239	Superficial injury; contusion
240	Burns
241	Poisoning by psychotropic agents
242	Poisoning by other medications and drugs
243	Poisoning by nonmedicinal substances
244	Other injuries and conditions due to external causes
245	Syncope
246	Fever of unknown origin
247	Lymphadenitis
248	Gangrene
249	Shock
250	Nausea and vomiting
251	Abdominal pain
252	Malaise and fatigue
253	Allergic reactions
255	Administrative/social admission
256	Medical examination/evaluation
257	Other aftercare
258	Other screening for suspected conditions (not mental disorders or infectious disease)
259	Residual codes; unclassified
653	Delirium, dementia, and amnestic and other cognitive disorders
660	Alcohol-related disorders
661	Substance-related disorders
663	Screening and history of mental health and substance abuse codes

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