

Hospital 30-Day Heart Failure Readmission Measure

Methodology

Submitted By Yale University/Yale-New Haven Hospital Center for Outcomes Research & Evaluation (YNHH-CORE):

Harlan Krumholz, M.D., S.M.
Sharon-Lise Normand, Ph.D.*
Patricia Keenan, Ph.D., M.H.S.
Zhenqiu Lin, Ph.D.
Elizabeth Drye, M.D., S.M.
Kanchana Bhat, M.P.H.
Yongfei Wang, M.Sc.
Joseph Ross, M.D., M.H.S.
Jeremiah Schuur, M.D.
Brett Stauffer, M.D.
Susannah Bernheim, M.D., M.H.S.
Andrew Epstein, Ph.D., M.P.P.
Jeph Herrin, Ph.D.
Jessica Federer, B.S.
Jennifer Mattera, M.P.H.
Yun Wang, Ph.D.
Gregory Mulvey, B.A.
Geoffrey Schreiner, B.S.

*Harvard Medical School, Department of Health Care Policy

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1. INTRODUCTION

1.1 Overview of Measure

Hospital readmission rates reflect quality and efficiency of care. The Deficit Reduction Act (DRA) of 2005 requires that the Centers for Medicare & Medicaid Services (CMS) publicly report outcomes and efficiency measures on the consumer Web site, Hospital Compare. CMS began publicly reporting acute myocardial infarction (AMI) and heart failure (HF) 30-day mortality measures as outcome measures in June 2007, and expects to report a pneumonia 30-day mortality measure in addition to these measures in July 2008. In accordance with the DRA, CMS has developed this HF 30-day all-cause readmission measure as a potential publicly reported efficiency measure.

We developed hospital-specific, risk-standardized, 30-day all-cause readmission rates for Medicare fee-for-service (FFS) patients discharged from the hospital with a principal diagnosis of HF. To account for the clustering of observations within hospitals and differences in number of admissions across hospitals, we used hierarchical regression to estimate risk-adjusted rates. The model uses administrative claims data from each index HF hospitalization, and from inpatient and outpatient Medicare claims from the 12 months prior to the hospitalization. We validated the claims-based model with a model using medical record data. The model is aligned with the American Heart Association (AHA) published standards for publicly reported outcomes measures (Krumholz et al., 2005).

1.2 Purpose of the Measure

Readmission of patients who were recently discharged after hospitalization with HF represents an important, expensive, and often preventable adverse outcome. The risk of readmission can certainly be modified by the quality and type of care provided to these patients. Improving readmission rates is the joint responsibility of hospitals and clinicians. Measuring readmission will create incentives to invest in interventions to improve hospital care, better assess the readiness of patients for discharge and facilitate transitions to outpatient status. This measure is also responsive to the recent call by Medicare Payment Advisory Commission (MedPAC) to develop readmission measures, with HF as a priority condition.

1.3 Why HF Readmission

HF is the most common principal discharge diagnosis among Medicare beneficiaries and the third highest for hospital reimbursements in 2005 (CMS/OIS, 2006). All-cause 30-day readmission rates per thousand patients discharged with HF increased by 11 percent between 1992 and 2001 (CMS/MQMS, 2006).

Readmission rates are influenced by the quality of inpatient and outpatient care, availability and use of effective disease management programs, and the bed capacity

of the local health care system. Some of the variation in readmissions may be attributable to delivery system characteristics (Fisher, Wennberg et al., 1994). Also, interventions during and after a hospitalization can be effective in reducing readmission rates in geriatric populations (Benbassat and Taragin, 2000; Naylor et al., 1999; Coleman et al., 2006) and for elderly HF patients particularly (Phillips et al., 2004; Naylor et al., 2004; Koelling et al., 2005; Krumholz et al., 2002; Nohria et al., 2002; Rich et al., 1995). Such interventions can be cost saving (Coleman et al., 2006; Naylor et al., 1999; Krumholz et al., 2002; Naylor et al., 2004; Rich et al., 1995; Koelling et al., 2005; Phillips et al., 2004). Tracking readmissions also emphasizes improvement in care transitions and care coordination. Although discharge planning is required by Medicare as a condition of participation for hospitals, transitional care focuses more broadly on “hands-off” of care from one setting to another, and may have implications for quality and costs (Coleman, 2005). Despite positive results in disease management studies, many post-hospital HF management programs have been discontinued, most often due to financial considerations (Seow, 2006).

MedPAC has called for hospital-specific public reporting of readmission rates, identifying HF as a priority condition (MedPAC, 2007). MedPAC finds that readmissions are common, costly, and often preventable. Based on 2005 Medicare data, MedPAC estimates that about 12.5% of Medicare HF admissions were followed by a readmission within 15 days, accounting for more than 90,000 admissions at a cost of \$590 million.

1.4 Relationship to Mortality Measures

Measuring hospital readmission rates will build on and complement CMS’s 30-day mortality measures for AMI, HF and pneumonia (Krumholz et al. 2004; Krumholz et al., 2006). The mortality measures and CMS’s core process measures reflect hospital quality of care. Readmission rates reflect quality and have implications for the cost of care. Adding an HF readmission measure to existing measures will provide a more complete picture of hospitals’ HF care, including the transition to outpatient status.

1.5 Core Values for Hospital Outcomes Models Suitable for Public Reporting

Regardless of data source, risk-adjustment models that are suitable for public reporting should have specific attributes. We developed a model using an approach that is consistent with the rationale articulated in the AHA Scientific Statement, “Standards for Statistical Models Used for Public Reporting of Health Outcomes” (Krumholz et al., 2005). First, a description of the methodological development of the model, the model components, and its performance should be publicly available. Second, each model should have a clear and justifiable strategy for developing the sample of patients to be included, exclude those unlikely to have the condition, and account for transfers and other applicable factors. Third, the model should include comorbidities, but not complications or clinical conditions that develop during hospitalization, and evaluate the outcomes of a hospitalization using a pre-specified, standardized follow-up time, rather than a non-standardized period of assessment

(such as during the hospitalization). Fourth, if administrative data are used, then there need to be strategies to incorporate the more than 15,000 International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) codes into a clinically coherent framework, reflecting condition-specific risk-adjustment methodologies, and to develop and validate the model in different populations—including, when available, against medical record-based models. Fifth, the model should incorporate design features to account for patient clustering. Finally, the results should be presented in an understandable and informative way.

The methodological approach to develop the readmission measure is designed to reflect all of these attributes. We use Medicare administrative datasets that contain FFS HF hospitalizations, as well as administrative data for each patient in the year before each index admission. To consolidate the 15,000+ ICD-9-CM codes into clinically coherent groupings, we use the Condition Categories (CCs) from CMS's Hierarchical Condition Category (HCC) methodology, a publicly available diagnostic grouping system (Pope et al., 2000). To calculate risk-standardized readmission rates, we use hierarchical logistic regression models, a statistical approach that takes into account the clustering of patients within hospitals and differences in sample size across hospitals. We derive the model using risk adjustment variables that exclude potential complications. We compute indices that describe model performance in terms of predictive ability, discriminant ability, and overall fit. We validate the results with additional administrative claims data and through comparison of administrative and chart data models.

2. METHODS

2.1 Overview

We sought to develop a measure that could be calculated from CMS claims data, validated with models using medical chart data, and aligned with the published AHA standard discussed above.

We use a hierarchical logistic regression model to account for the clustering of patients within a hospital and the different number of observations per hospital. We use inpatient and outpatient claims information from the 12 months prior to admission for risk adjustment.

We use Medicare administrative datasets that contain HF FFS hospitalizations for patients discharged in 2003 and 2004. The datasets also contain administrative data for each patient in the year before each index admission and the 30 days following the index admission. The administrative model is derived using a randomly selected half of the hospitalizations in 2004 (“derivation sample”). The performance of the model is then evaluated using patients contained in the other half of the 2004 administrative dataset and 2003 data and in a sample of patients for which there are both medical record-based and administrative data.

For further validation, we determine whether the administrative model produces readmission rate results that can be considered a surrogate for a model derived from medical chart-based data. Thus, we develop a linked dataset with chart-based data and administrative data. Then, we develop a medical chart (“gold standard”) model. We subsequently compare the results of the administrative model, using the same approach taken in the CMS mortality models (Normand, 2007).

For all validation efforts, we compute indices that describe their respective performance in terms of predictive ability, discriminant ability, and overall fit.

2.2 Outcome

The outcome evaluated is HF 30-day all-cause readmission, as measured from the date of discharge of the index HF admission.

2.2.1 30-Day Timeframe

We chose 30 days because it is a clinically meaningful timeframe for hospitals, in collaboration with their medical communities, to take actions to reduce readmissions, such as: ensure patients are clinically ready at discharge; reduce risk of infection; reconcile medications; improve communication among providers in transitions of care; encourage strategies that promote disease management principles and educate patients on what symptoms to monitor, who to contact with

questions, and where and when to seek follow-up care. Deaths that occur at home within the 30-day period are considered a “zero” readmission.

2.2.2 All-Cause Readmission

We use all-cause readmission for several reasons. First, from the patient perspective, readmission for any cause is a key concern. Second, limiting the measure to HF readmissions may make it susceptible to gaming. Moreover, it is often hard to exclude quality issues and accountability based on the documented cause of readmission. For example, a patient with heart failure who develops a hospital-acquired infection may ultimately be readmitted for sepsis. We would consider it inappropriate to treat this readmission as unrelated to the care the patient received for HF. Another patient might have a complication leading to renal failure, resulting in readmission for renal failure, and yet quality of care during the HF admission could have reduced the risk of the complication. Finally, while the measure does not presume that each readmission is preventable, interventions have generally shown reductions in non-HF as well as HF readmissions.

2.3 Admissions Sample

2.3.1 HF Codes

Patients must have had a principal hospital discharge diagnosis of one of the codes listed in Table 1. These codes define the universe of heart failure codes.

Table 1 – ICD-9-CM Codes that Define HF

ICD-9-CM	Description
402.01	Malignant hypertensive heart disease with congestive heart failure (CHF)
402.11	Benign hypertensive heart disease with CHF
402.91	Hypertensive heart disease with CHF
404.01	Malignant hypertensive heart and renal disease with CHF
404.03	Malignant hypertensive heart and renal disease with CHF & renal failure (RF)
404.11	Benign hypertensive heart and renal disease with CHF
404.13	Benign hypertensive heart and renal disease with CHF & RF
404.91	Unspecified hypertensive heart and renal disease with CHF
404.93	Hypertension and non-specified heart and renal disease with CHF & RF
428.xx	Heart failure codes

2.3.2 Exclusion Criteria

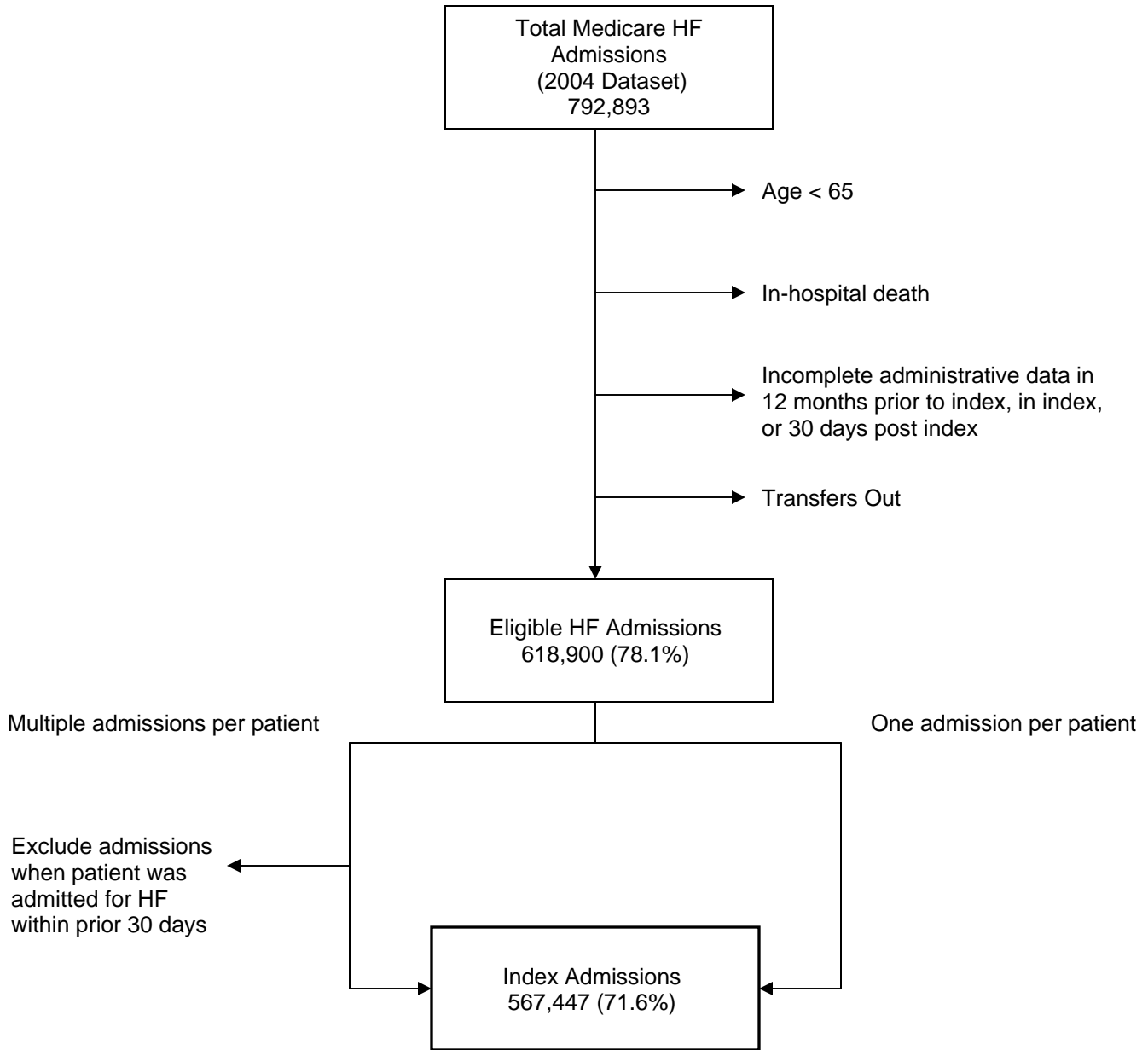
An “index admission” is one in which we evaluate the 30 days after discharge for a readmission. One patient may have more than one index admission in the study year. The algorithm used to derive the set of index admissions is documented in Figure 1. The following HF hospitalizations are excluded as index admissions from the measure calculation:

- 1) Age <65. HF admissions for patients less than 65 years old at the time of an index admission are excluded.
Rationale: Admissions of patients under age 65, who qualify for Medicare due to disability, are excluded because they represent a distinct population, and we had few of these patients in the medical record database for validation purposes.
- 2) In-hospital deaths. Admissions for patients with in-hospital deaths are excluded.
Rationale: Patients who die during the initial hospitalization are not eligible for readmission.
- 3) Incomplete data. The measure excludes HF admissions for:
 - a. Beneficiaries without FFS Medicare Part A at the time of the index admission;
 - b. Beneficiaries without 12 full months of enrollment in parts A and B FFS prior to the index admission;
 - c. Beneficiaries without one full month of enrollment in Parts A and B FFS post discharge.*Rationale:* We limit the sample to FFS Medicare beneficiaries because claims data are not made available for Medicare health plan enrollees. We exclude individuals who are not enrolled in Part B because they lack physician claims history for use in risk adjustment.

- 4) Transfers-out. Admissions for patients having a principal diagnosis during the index hospitalization and subsequently transferred to an acute care setting.
Rationale: We exclude hospitalizations that result in a transfer to another acute care facility because the measure's focus is on hospitals that discharge patients to a non-acute setting (e.g. to home or a skilled nursing facility).

- 5) Additional HF admissions within 30 days. If a patient has one or more additional HF admissions *within 30 days of discharge from an index HF admission*, we do not consider the additional HF admissions as index admissions (they are considered as potential readmissions). Thus, any HF admission is either an index admission or a readmission, but not both.
Rationale: Additional HF admissions within 30 days are excluded as index admissions because they are part of the outcome and we choose not to count a single admission as an index admission and a readmission for another index admission.

Figure 1 – HF Admissions Included in Measure Calculation



Note: Exclusion categories are not mutually exclusive.

2.4 Observational Period

We assessed hospital performance over the period of 1 calendar year.

2.5 Data Sources

The datasets are described below and summarized in Table 2. We also used National Heart Failure chart data along with the corresponding administrative data for the validation. These data were provided by the CMS National Heart Care (NHC) Project and the Research Data Assistance Center (ResDAC).

1) Part A (inpatient) data

Part A inpatient data refers to claims paid for Medicare inpatient hospital care, skilled nursing facility care, some home health agency services, and hospice care. For purposes of this project, Part A is used to refer to inpatient services only and includes data from 2 time periods:

- a. *Index admission*: Index admission data are based on the inclusion/exclusion criteria for the condition, and comorbidities (if any) are identified from the secondary diagnoses associated with the index admission.
- b. *Pre-index*: 12 months prior to the index admission (“pre-index”).

2) Hospital outpatient data – 12 months pre-index

Hospital outpatient refers to Medicare claims paid for the facility component of surgical or diagnostic procedures, emergency room care, and other non-inpatient services performed in a hospital outpatient department or ambulatory surgical/diagnostic center.

3) Part B data – 12 months pre-index

Part B data refers to Medicare claims for the services of physicians (regardless of setting) and other outpatient care, services, and supplies. For purposes of this project, Part B services included only face-to-face encounters between a care provider and patient. We thus do not include services such as laboratory tests, medical supplies, or other ambulatory services.

4) Medicare Enrollment Database

This database contains Medicare beneficiary demographic, benefit/coverage, and vital status information.

5) National Heart Failure Chart Abstracted Data

The NHC Project is a CMS initiative designed to assess and improve the quality of care for Medicare beneficiaries hospitalized with HF (Masoudi et al., 2000). Medicare FFS beneficiaries hospitalized with a principal discharge diagnosis of HF ICD-9-CM codes 402.01, 402.11, 402.91, 404.01, 404.91, or 428) between April 1998 and March 1999 or July 2000 and June 2001, inclusive, were identified. In each sampling period, discharges were grouped by state, sorted by age, sex, race, and treating hospital, and up to 800 discharges were randomly selected from each state (Havranek et al., 2002).

All records were included if fewer than 800 hospitalizations occurred in a state during a sampling period (Alaska, Hawaii, Idaho, Utah, Vermont, and Wyoming in both samples). Medical records of selected discharges were obtained from the treating hospital and underwent detailed review by trained data abstractors in central data abstraction centers. Patients with invalid social security numbers, those receiving long-term hemodialysis, those transferred to another hospital or those who left against medical advice based upon administrative data or during chart abstraction were excluded. The NHC sample thus consists of 78,882 records, of which 39,477 were from 1998-99 and 39,405 from 2000-01.

2.6 Administrative Model Development

2.6.1 Model Overview

We use Medicare administrative datasets that contain FFS hospitalizations for each condition, as well as administrative data for each patient in the year before each index admission. The administrative model is derived using a randomly selected half of the hospitalizations in 2004 (“derivation sample”). The performance of the model is then evaluated using patients contained in the other half of the 2004 administrative dataset and in a sample of patients for which there are both medical record-based and administrative data (“validation sample”). In order to assess variability of the model over time, we also evaluate the model using administrative datasets of hospitalizations for 2003. We compute indices that describe model performance in terms of predictive ability, discriminant ability, and overall fit. We then develop a medical record model and compare the ability of the administrative and medical record models to classify performance.

Figure 2 shows the overall approach to HF readmission model development and validation, as summarized in the Overview. Specific information about each step in the process is described below. The datasets used are listed in Table 2.

Figure 2 – Heart Failure Readmission Model Development and Validation

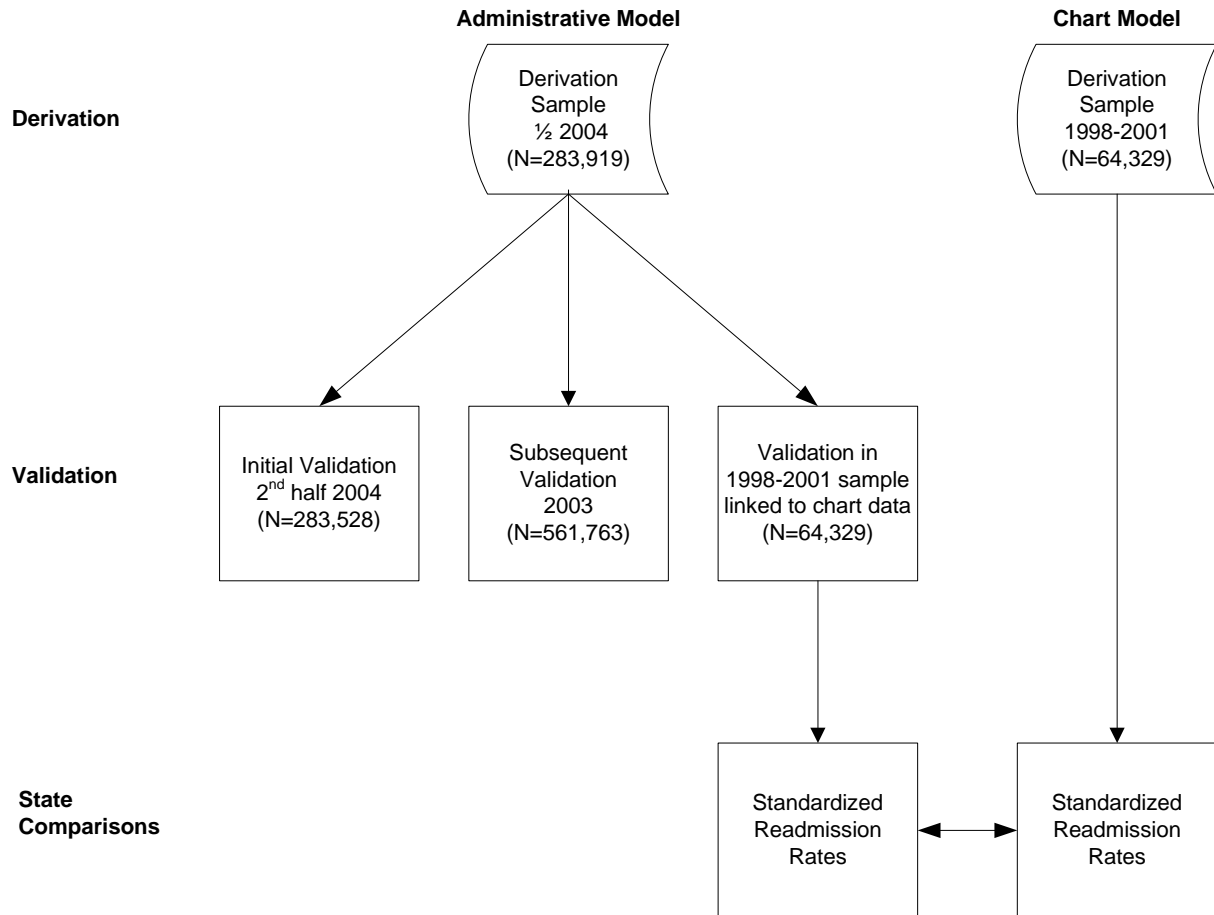


Table 2 – Datasets Used for HF Readmission Administrative Model Development and Validation

Step	Dataset	Pre-Index (Prior 12 Months)	Index Admission	Post-Index
1. Administrative Model Development (Derivation Sample)	Administrative 50% sample, randomly selected, from: • 2004 (N=283,919; 4,669 hospitals) ¹	<ul style="list-style-type: none"> • Hospital inpatient, (any condition) – principal and secondary diagnoses 	<ul style="list-style-type: none"> • Hospital inpatient (Pre-existing conditions identified from the index admission) 	<ul style="list-style-type: none"> • Hospital inpatient (any condition) – principal and secondary diagnoses (30 days within discharge of index admission)
2. Administrative Model Validation in Administrative Datasets	Administrative 50% sample after randomly selecting for first 50%: • 2004 (N=283,528; 4,680 hospitals) ¹ • 100% sample for 2003 (N=561,763; 4,741 hospitals)	<ul style="list-style-type: none"> • Hospital outpatient • Clinician data 		<ul style="list-style-type: none"> • Medicare enrollment database mortality data (30 days within discharge from index admission)
3. Administrative Model Validation in Medical Record Sample	Linked Medical Record Sample • 1998-2001 (N=64,329) ²	<ul style="list-style-type: none"> • Hospital inpatient, (any condition) – principal and secondary diagnoses³ 	<ul style="list-style-type: none"> • Medical record data (national inpatient abstraction sample) • Hospital inpatient (Pre-existing conditions identified from the index admission)³ 	<ul style="list-style-type: none"> • Hospital inpatient (any condition) – principal and secondary diagnoses (30 days within discharge of index admission)
4. Develop Medical Record Model		<ul style="list-style-type: none"> • Hospital outpatient³ • Clinician data³ 		<ul style="list-style-type: none"> • Medicare enrollment database mortality data (30 days within discharge of index admission)³
5. Comparison of Administrative Model and Medical Record Model				

¹ There were 4,730 hospitals in the full 2004 dataset. For the 50% of cases randomly selected for the derivation sample, there were 4,669 hospitals with at least 1 case. For the 50% of cases randomly selected for the validation sample, there were 4,680 hospitals with at least 1 case.

² Comparison between the administrative and medical record models was undertaken at state level (i.e., the 50 states, plus the District of Columbia and Puerto Rico).

³ For steps 3 and 4, the administrative datasets listed are linked to the medical record-abstracted cases.

2.7 Developmental Dataset

We use Medicare HF admissions for 2004 and 2003. Table 3 presents the total number of HF admissions, the number excluded in each year, and the number included in the final samples as index admissions. We use a randomly selected half of the 2004 cohort for the derivation sample. The derivation sample consisted of 283,919 index admissions at 4,669 hospitals, with an overall unadjusted 30-day readmission rate of 23.6%. In 12,569 index cases (4.4%) the patient died within 30 days without being readmitted.

Table 3 – Heart Failure Readmission 2003 and 2004 Datasets

Data year	Total*	Exclusion (%)					Final Sample	
		Age <65	In-hospital deaths	Incomplete information	Transfers out**	Hospitalizations within 30 days	N	%
2003	786,506	11.8%	4.5%	11.7%	1.1%	6.5%	561,763	71.4%
2004	792,893	12.0%	4.3%	11.3%	1.1%	6.5%	567,447	71.6%

*Transfer pairs were not included in the study sample if the first admission was in 2003 or if one of the pairs did not have a qualifying diagnosis.

**Transfers must have occurred within one day or less (or they were considered as separate admissions)

2.8 Candidate and Final Variables

We sought to develop a model that included key variables that were clinically relevant and based on strong relationships with the outcomes and that was parsimonious, using a grouper for the 15000+ ICD-9-CM codes that is in the public domain. The candidate variables for the model were derived from the index admission, with comorbidities identified from the index admission secondary diagnoses (excluding potential complications); 12-month pre-index inpatient Part A (for any condition); outpatient hospital; and Part B physician data. We developed candidate variables for the model from the claims codes.

For administrative model development, we started with the 189 diagnostic groups included in the Hierarchical Condition Category (HCC) clinical classification system (Pope et al, 2000). The HCC clinical classification system was developed for CMS in preparation for all-encounter risk adjustment for Medicare Advantage (managed care) plans and represented a refinement of an earlier risk-adjustment method based solely on principal inpatient diagnosis. The HCC model makes use of all physician and hospital encounter diagnoses and was designed to predict a beneficiary's expenditures based on the total clinical profile represented by all of his/her assigned HCCs. Under the HCC algorithm, the 15,000+ ICD-9-CM diagnosis codes are first assigned to one of 804 mutually exclusive groupings ("DxGroups") and then subsequently aggregated into 189 condition categories (CCs). We adopted a modified approach to the HCC classification system, using the 189 CCs, but not the hierarchical logic that converts the CCs into HCCs.

To select candidate variables, a team of physicians began with a review of all 189 CC variables (see Appendix). A total of 154 CCs determined to be clinically relevant to the readmission outcome were included for consideration. Some CCs were then combined into clinically coherent groupings of CCs. Our set of candidate variables (see Table 4) therefore included 95 CC-based variables, two demographic variables (age and gender) and two procedure codes relevant to readmission risk (history of percutaneous coronary intervention [PCI] and history of coronary artery bypass graft [CABG]). The final risk adjustment variables were selected by a team of physicians and analysts primarily based on their clinical relevance but with knowledge of their strength of association with the readmission outcome.

To inform variable selection, a modified approach to stepwise logistic regression was performed. The developmental dataset was used to create 200 bootstrap samples. For each sample, we ran a logistic stepwise regression, with both backward and forward selection, that included the 99 candidate variables. The results were summarized to show the percent of times that each of the candidate variables was significantly associated with readmission ($p < 0.001$) in each of the 200 repeated samples (e.g. 80 percent would mean that the candidate variable was selected as significant at $p < 0.001$ in 80 percent of the estimations). We also assessed the direction and magnitude of the regression coefficients.

The physician team reviewed these results and decided to retain all risk adjustment variables above a 70% cutoff since all demonstrated a relatively strong association with readmission and were clinically relevant (25 variables). Variables selected in less than 70% of the bootstrap samples were also included in the final model if:

- 1) They were markers for end of life/frailty (metastatic cancer, dementia, protein-calorie malnutrition, liver and biliary disease, age-65, stroke, hemiplegia/paraplegia/paralysis/functional disability); or
- 2) They were on the same clinical spectrum as a variable above the 70% cutoff and were clinically important for HF patients (e.g. asthma and COPD and depression and other psychiatric disorders; or
- 3) Certain hospitals might have a disproportionate share of patients with the condition (e.g. metastatic cancer, cancer).

Gender was also included in the model. This resulted in a final risk-adjustment model that included 37 variables. Table 5 shows the list of final variables.

Table 4 – HF Model Candidate Variables

Category	Variable	Code(s)
Demographic	Age-65 (years above 65, continuous)	
	Male	
Cardiovascular	History PCI	
	History CABG	
	Congestive heart failure	CC 80
	Acute coronary syndrome	CC 81, 82
	Chronic atherosclerosis	CC 83, 84
	Cardio-respiratory failure and shock	CC 79
	Hypertensive heart disease	CC 90
	Valvular and rheumatic heart disease	CC 86
	Arrhythmias	CC 92, 93
Comorbidity	History of Infection	CC 1, 3-6
	Septicemia/shock	CC 2
	Metastatic cancer and acute leukemia	CC 7
	Cancer	CC 8-12
	Other neoplasms	CC 13
	Benign neoplasms of skin, breast, eye	CC 14
	Diabetes and DM complications	CC 15-20, 119, 120
	Protein-calorie malnutrition	CC 21
	Disorders of fluid/electrolyte/acid-base	CC 22, 23
	Obesity/disorders of thyroid, cholesterol, lipids	CC 24
	Liver and biliary disease	CC 25-30
	Intestinal obstruction/perforation	CC 31
	Pancreatic disease	CC 32
	Inflammatory bowel disease	CC 33
	Peptic ulcer, hemorrhage, other specified gastrointestinal disorders	CC 34
	Appendicitis	CC 35
	Other gastrointestinal disorders	CC 36
	Bone/joint/muscle infections/necrosis	CC 37
	Rheumatoid arthritis and inflammatory connective tissue disease	CC 38
	Disorders of vertebrae and spinal discs	CC 39
	Osteoarthritis of hip and knee	CC 40
	Osteoporosis and other bone/cartilage disease	CC 41
	Congenital/developmental skeletal and connective tissue disorders	CC 42
	Other musculoskeletal and connective tissue	CC 43
	Severe hematological disorders	CC 44
	Disorders of immunity	CC 45
	Coagulation defects and other specified hematological disorders	CC 46
	Iron deficiency and other/unspecified anemias and blood disease	CC 47
	Delirium and encephalopathy	CC 48
	Dementia and senility	CC 49, 50
	Drug/alcohol abuse/dependence/psychosis	CC 51-53
	Major psych disorders	CC 54-56
	Personality disorders	CC 57
	Depression	CC 58
	Anxiety disorders	CC 59
	Other psychiatric disorders	CC 60
	Mental retardation or developmental disability	CC 61-65
	Hemiplegia, paraplegia, paralysis, functional disability	CC 67-69, 100-102, 177, 178
	Muscular dystrophy	CC 70
	Polyneuropathy	CC 71

Category	Variable	Code(s)
	Multiple sclerosis	CC 72
	Parkinson's and Huntington's diseases	CC 73
	Seizure disorders and convulsions	CC 74
	Coma, brain compressions/anoxic damage	CC 75
	Mononeuropathy, other neurologic conditions/injuries	CC 76
	Respiratory arrest	CC 78
	Heart infection/inflammation, except rheumatic	CC 85
	Congenital cardiac/circulatory defect	CC 87, 88
	Hypertension	CC 89, 91
	Other and unspecified heart disease	CC 94
	Stroke	CC 95, 96
	Cerebrovascular disease	CC 97-99, 103
	Vascular or circulatory disease	CC 104-106
	Cystic fibrosis	CC 107
	COPD	CC 108
	Fibrosis of lung or other chronic lung disorders	CC 109
	Asthma	CC 110
	Pneumonia	CC 111-113
	Pleural effusion/pneumothorax	CC 114
	Other lung disorders	CC 115
	Major eye infections/inflammations	CC 117
	Retinal detachment	CC 118
	Retinal disorders, except detachment and vascular retinopathies	CC 121
	Glaucoma	CC 122
	Cataract	CC 123
	Other eye disorders	CC 124
	Significant ear, nose, and throat disorder	CC 125
	Other ear, nose, throat, and mouth disorder	CC127
	Kidney transplant status	CC 128
	End-stage renal disease or dialysis	CC 129, 130
	Renal failure	CC 131
	Nephritis	CC 132
	Urinary obstruction and retention	CC 133
	Urinary tract infection	CC 135
	Other urinary tract disorders	CC 136
	Pelvic inflammatory disease	CC 138
	Other female genital disorders	CC 139
	Male genital disorders	CC 140
	Decubitus ulcer or chronic skin ulcer	CC 148, 149
	Extensive burns	CC 150, 151
	Cellulitis, local skin infection	CC 152
	Other dermatological disorders	CC 153
	Trauma	CC 154-156, 158-161
	Vertebral fractures	CC 157
	Other injuries	CC 162
	Major organ transplant	CC 173
	Major organ transplant status	CC 174
	Other organ transplant/replacement	CC 175

Notes:

- All CC variables represent “or” conditions from all sources.
- Potential index admission complications and clinically irrelevant CCs are not included.

Table 5 – Included HF Model Variables

Category	Variable	Code(s)
Demographic	Age-65 (years above 65, continuous) Male	
Cardiovascular	History of CABG Congestive heart failure Acute coronary syndrome Arrhythmias Cardio-respiratory failure and shock Valvular and rheumatic heart disease Vascular or circulatory disease Chronic atherosclerosis Other and unspecified heart disease	CC 80 CC 81, 82 CC 92, 93 CC 79 CC 86 CC 104-106 CC 83, 84 CC 94
Comorbidity	Hemiplegia, paraplegia, paralysis, functional disability Stroke Renal failure COPD Diabetes and DM complications Disorders of fluid/electrolyte/acid-base Other urinary tract disorders Decubitus ulcer or chronic skin ulcer Other gastrointestinal disorders Peptic ulcer, hemorrhage, other specified gastrointestinal disorders Severe hematological disorders Nephritis Dementia and senility Metastatic cancer and acute leukemia Cancer Liver and biliary disease End-stage renal disease or dialysis Asthma Iron deficiency and other/unspecified anemias and blood disease Pneumonia Drug/alcohol abuse/dependence/psychosis Major psych disorders Depression Other psychiatric disorders Fibrosis of lung and other chronic lung disorders Protein-calorie malnutrition	CC 67-69, 100-102, 177, 178 CC 95, 96 CC 131 CC 108 CC 15-20, 119, 120 CC 22, 23 CC 136 CC 148, 149 CC 36 CC 34 CC 44 CC 132 CC 49, 50 CC 7 CC 8-12 CC 25-30 CC 129, 130 CC 110 CC 47 CC 111-113 CC 51-53 CC 54-56 CC 58 CC 60 CC 109 CC 21

We gather these variables for each HF hospitalization from inpatient and outpatient claims data in the 12 months prior to the hospitalization. Because the source of the diagnostic information (e.g. inpatient or outpatient claims, principal or secondary diagnosis) and the timing of the diagnostic information (e.g. prior to the index admission or during the index admission) may represent different clinical burdens, we define 5 sets of CC variables to include the most extensive claims-based list of patient comorbidities (Table 6). For each CC code, we first develop 5 variables derived

respectively from the following sources of information: (1) Part A secondary diagnoses from the index admission (the primary diagnosis being the condition under consideration), (2) Part A principal diagnosis from any hospitalization in the 12 months before the index admission, (3) Part A secondary diagnoses from any hospitalization in the 12 months prior to the index admission, (4) diagnoses from hospital outpatient services in the 12 months before the index admission, and (5) diagnoses from Part B physician encounters in the 12 months before the index admission. The variables are then grouped as a single variable for each CC using an “or” condition across the data sources. Thus, a code in any of the data sources produces an indicator for that CC.

Table 6 – Data Sources and Timing

Original Data Source	Time Period	Comment
1. Part A (inpatient) – secondary diagnosis/es	Index admission	A sub-dataset of pre-existing conditions present at the index admission was created based on this file
2. Part A (inpatient) – principal diagnosis	12 months pre-index admission	These CC variables were entered into the model using an “or” condition from all data sources.
3. Part A (inpatient) – secondary diagnosis/es		
4. Hospital outpatient		
5. Part B physician		

The physician team also identified a subset of CC variables that when coded as secondary diagnosis codes could represent complications of care (see Appendix). As recommended in the AHA statement, we do not adjust for these variables where they may represent complications of care (Krumholz et al, 2005). Specifically for a given HF admission, if these risk factors appear only as secondary diagnosis codes in the index admission and not prior to the index hospitalization, we do not include them in the coding of the covariate.

2.9 Statistical Model

Because of the natural clustering of the observations within hospitals, we estimated hierarchical generalized linear models (HGLM). We modeled the log-odds of readmission within 30 days of discharge from an index HF admission as a function of patient demographic and clinical characteristics, and a random hospital-specific intercept. This strategy accounts for within-hospital correlation of the observed outcomes, and models the assumption that underlying differences in quality among the health care groups being evaluated lead to systematic differences in outcomes.

We then calculate hospital-specific readmission rates. These rates are obtained as the ratio of predicted to expected readmissions, multiplied by the national unadjusted rate. The expected number of readmissions in each hospital is estimated using its

patient mix and the average hospital-specific intercept. The predicted number of readmissions in each hospital is estimated given the same patient mix but the hospital-specific intercept. Operationally, the expected number of readmissions for each hospital is obtained by regressing the risk factors on the readmission using all hospitals in our sample, applying the subsequent estimated regression coefficients to the patient characteristics observed in the hospital, adding the average of the hospital-specific intercepts, summing over all patients in the hospital, and then transforming to get a count. This is a form of indirect standardization. The predicted hospital outcome is the number of expected readmissions in the “specific” hospital and not at a reference hospital. Operationally this is accomplished by estimating a hospital-specific intercept that represented baseline readmission risk within the hospital, applying the estimated regression coefficients to the patient characteristics in the hospital, summing over all patients in the hospital, and then transforming to get a count. To assess hospital performance in any given year, we re-estimate the model coefficients using that year’s data.

More specifically, we estimate 2 types of regression models using the administrative data (Table 7). First, we fit a generalized linear model (GLM) linking the outcome to the risk factors (McCullagh and Nelder, 1989). Let Y_{ij} denote the outcome (equal to 1 if patient is readmitted within 30-days, zero otherwise) for the j^{th} patient discharged from the i^{th} hospital; \mathbf{Z}_{ij} denotes a set of risk factors based on the administrative data. Let I denote the total number of hospitals and n_i the number of index admissions to hospital i . We assume the outcome is related linearly to the covariates via a known linked function, h , where

$$\text{GLM} \quad h(Y_{ij}) = \alpha + \beta \mathbf{Z}_{ij} \quad (1)$$

and $\mathbf{Z}_{ij} = (Z_{1ij}, Z_{2ij}, \dots, Z_{pij})$ is a set of p patient-specific covariates. In our case, $h =$ the logit link.

To account for the natural clustering of observations within hospitals, we estimate an HGLM that links the risk factors to the same outcomes and a hospital-specific random effect,

$$\text{HGLM} \quad h(Y_{ij}) = \alpha_i + \beta \mathbf{Z}_{ij} \quad (2)$$

$$\alpha_i = \mu + \omega_i; \omega_i \sim N(0, \tau^2) \quad (3)$$

where α_i represents the hospital-specific intercept, \mathbf{Z}_{ij} is defined as above, μ the adjusted average outcome over all hospitals in the sample, and τ^2 the between-hospital variance component (Daniels and Gatsonis, 1999). This model separates within-hospital variation from between-hospital variation. Both HGLMs and GLMs are estimated using the SAS software system (GLIMMIX and LOGISTIC procedures respectfully).

We first fit the GLM described in Equation (1) using the logit link.

Having identified the covariates that remained, we next fit the HGLM described in Equations (2) and (3), again using the logit link function; e.g.,

$$\begin{aligned}\text{Logit}(P(Y_{ij} = 1)) &= \alpha_i + \beta \mathbf{Z}_{ij} \\ \alpha_i &= \mu + \omega_i \quad \omega_i \sim N(0, \tau^2)\end{aligned}$$

where \mathbf{Z}_{ij} consisted of the covariates retained in the GLM model. As before, $Y_{ij} = 1$ if patient j treated at hospital i had the event; 0 otherwise.

2.10 Hospital Performance Reporting

Using the set of risk factors in the GLM, we fit the HGLM defined by Equations (2) - (3) and estimate the parameters, $\hat{\mu}$, $\{\hat{\alpha}_1, \hat{\alpha}_2, \dots, \hat{\alpha}_I\}$, $\hat{\beta}$, and $\hat{\tau}^2$. We calculate a standardized outcome, s_i , for each hospital by computing the ratio of the predicted to expected mean outcomes multiplied by the unadjusted national mean readmission rate. Specifically, we calculate

$$\text{Predicted} \quad \hat{y}_{ij}(Z) = h^{-1}(\hat{\alpha}_i + \hat{\beta} \mathbf{Z}_{ij}) \quad (4)$$

$$\text{Expected} \quad \hat{e}_{ij}(Z) = h^{-1}(\hat{\mu} + \hat{\beta} \mathbf{Z}_{ij}) \quad (5)$$

$$\hat{s}_i(Z) = \frac{\sum_{j=1}^{n_i} \hat{y}_{ij}(Z)}{\sum_{j=1}^{n_i} \hat{e}_{ij}(Z)} \times \bar{y} \quad (6)$$

If more (fewer) cases than “expected” have the outcome in a hospital, then \hat{s}_i will be higher (lower) than the unadjusted average, \bar{y} . For each hospital, we compute interval estimates of s_i and the probability that hospital is a good performer. For example, if Y is an adverse outcome, then $\hat{P}(s_i(Z) < C)$ with a relatively small C would quantify the probability that a hospital had a low adverse outcome.

2.10.1 Creating Interval and Probability Estimates

Because the statistic described in Equation (6) is a complex function of parameter estimates, we use re-sampling techniques, bootstrapping, to derive an interval estimate. The bootstrap has the advantage of avoiding unnecessary distributional assumptions.

2.10.2 Algorithm

Let I denote the total number of hospitals in the sample. We repeat steps 1 – 4 for $b = 1, 2, \dots, B$ times:

1. Sample I hospitals with replacement.

2. Fit the HGLM using all patients within each sampled hospital. We use as starting values the parameter estimates obtained by fitting the model to all hospitals. If some hospitals are selected more than once in a bootstrapped sample, we treat them as distinct so that we have I random effects to estimate the variance components. At the conclusion of Step 2, we have:

- a. $\hat{\beta}^{(b)}$ (the estimated regression coefficients of the risk factors).
- b. The parameters governing the random effects, hospital adjusted outcomes, distribution, $\hat{\mu}^{(b)}$ and $\hat{\tau}^{2(b)}$.
- c. The set of hospital-specific intercepts and corresponding variances, $\{\hat{\alpha}_i^{(b)}, \text{var}(\hat{\alpha}_i^{(b)})\}; i = 1, 2, \dots, I\}$.

3. We generate a hospital random effect by sampling from the distribution of the hospital-specific distribution obtained in Step 2c. We approximate the distribution for each random effect by a normal distribution. Thus, we draw $\alpha_i^{(b*)} \sim N(\hat{\alpha}_i^{(b)}, \text{var}(\hat{\alpha}_i^{(b)}))$ for the unique set of hospitals sampled in Step 1.

4. Within each unique hospital i sampled in Step 1, and for each case j in that hospital, we calculate $\hat{y}_{ij}^{(b)}$, $\hat{e}_{ij}^{(b)}$, and $\hat{s}_i(Z)^{(b)}$ where $\hat{\beta}^{(b)}$ and $\hat{\mu}^{(b)}$ are obtained from Step 2 and $\hat{\alpha}_i^{(b*)}$ is obtained from Step 3.

Ninety-five percent interval estimates (or alternative interval estimates) for the hospital-standardized outcomes can be computed by identifying the 2.5th and 97.5th percentiles of the B standardized estimates (or the percentiles corresponding to the alternative desired intervals).

Table 7 – Analysis Steps

Step	Risk Factors Based on: Administrative Data
1	Compute bivariate and univariate summaries \mathbf{Z} & Y
2	Generalized Linear Model $h(Y_{ij}) = \alpha^A + \beta^A \mathbf{Z}_{ij}$ Obtain R^2 , residuals, etc.
3	Hierarchical Generalized Linear Model $h(Y_{ij}) = \alpha_i^A + \beta^A \mathbf{Z}_{ij}$ $\alpha_i^{(A)} \sim N(\mu_A, \tau_A^2)$
4	Hospital-Specific Predicted Outcomes $\hat{y}_i^A(\mathbf{Z}) = \frac{1}{n_i} \sum_{j=1}^{n_i} h^{-1}(\hat{\alpha}_i^A + \hat{\beta}^A \mathbf{Z}_{ij})$ Hospital-Specific Expected Outcomes $\hat{e}_i^A(\mathbf{Z}) = \frac{1}{n_i} \sum_{j=1}^{n_i} h^{-1}(\hat{\mu}_A + \hat{\beta}^A \mathbf{Z}_{ij})$ Hospital-Specific Standardized Outcomes $\hat{s}_i^A(\mathbf{Z}) = \frac{\hat{y}_i^A(\mathbf{Z})}{\hat{e}_i^A(\mathbf{Z})} \times \bar{y}$

2.10.3 Administrative Model Results (GLM)

The variables and the associated codes, standardized regression coefficients, and standard errors are shown in Table 8. The standardized regression coefficients are regression coefficients expressed in units of standard deviations and can range between -1 and 1, with ± 1 indicating a perfect linear relationship and 0 indicating no linear relationship.⁴

⁴ Standardized regression coefficients are like correlation coefficients. We compute them in order to compare the size of the coefficients by standardizing the coefficients to be unitless.

2.10.4 Model Performance

We computed 6 summary statistics for assessing model performance (Harrell, 2001): over-fitting indices⁵, percent of variation explained by the risk factors, predictive ability, area under the receiver operating characteristic (ROC) curve, distribution of residuals, and model χ^2 (see Table 11)⁶.

The derivation model has modest discrimination ($R^2 = 0.034$), calibration, and fit. The patient-level predicted readmission rate ranges from 15% in the lowest predicted decile to 37% in the highest predicted decile, a range of 22%. The area under the ROC curve is 0.601. For comparison, a model with age and gender had an ROC of 0.516 and a model with all candidate variables had an ROC equal to 0.604.

The discrimination and the explained variation of the model at the patient-level are consistent with the few published models of readmission after HF that report predictive ability (Philbin and DiSalvo, 1999; Yamokoski et al, 2007). We excluded covariates such as potential complications, certain patient demographics (e.g., race, socioeconomic status), and patients' admission path and discharge disposition (e.g. admit from, or discharge to, a skilled nursing facility). These characteristics may be associated with readmission and thus could increase the model performance to predict patient readmissions. However, these variables may be related to quality or supply factors that should not be included in an adjustment that seeks to control for patient clinical characteristics. For example, if hospitals with a higher share of a particular ethnic group have higher readmission rates, then including ethnic group in the model will attenuate this difference and obscure differences that are important to identify. With regard to non-clinical variables, the hospitals are expected to do well with the patients they have. Thus, the choice was to focus on adjustment for clinical differences in the populations among hospitals.

⁵ Over-fitting refers to the phenomenon in which a model well describes the relationship between predictive variables and outcome in the derivation dataset, but fails to provide valid predictions in new patients.

⁶ Chi-Square – A test of statistical significance usually employed for categorical data to determine whether there is a good fit between the observed data and expected values; i.e., whether the differences between observed and expected values are attributable to true differences in characteristics or instead the result of chance variation. The formula for computing the chi-square is as follows:

$$\sum \frac{(O-E)^2}{E}$$

where O = observed value

E = expected value, and

degrees of freedom (df) = (rows-1)(columns-1)

Table 8 – HF Readmission Administrative Model (50% 2004 Derivation Sample-Results from the GLM)

Variable	Mean (std) or percent	Estimate	SE	OR	95% CI	
Intercept		-1.89	0.02			
Age-65 (years above 65, continuous)	14.9 (7.8)	0.00	0.00	1.00	1.00	1.00
Male	42.21	0.01	0.01	1.01	0.99	1.03
History of CABG	13.45	-0.07	0.01	0.93	0.91	0.96
Congestive heart failure (CC 80)	75.59	0.09	0.01	1.09	1.07	1.12
Acute coronary syndrome (CC 81, 82)	20.85	0.12	0.01	1.12	1.10	1.15
Arrhythmias (CC 92, 93)	59.65	0.06	0.01	1.06	1.04	1.08
Cardio-respiratory failure and shock (CC 79)	18.54	0.08	0.01	1.08	1.06	1.11
Valvular and rheumatic heart disease (CC 86)	47.05	0.08	0.01	1.08	1.06	1.10
Vascular or circulatory disease (CC 104-106)	45.39	0.07	0.01	1.07	1.05	1.09
Chronic atherosclerosis (CC 83, 84)	73.71	0.08	0.01	1.09	1.06	1.11
Other and unspecified heart disease (CC 94)	35.71	0.05	0.01	1.05	1.03	1.08
Hemiplegia, paraplegia, paralysis, functional disability (CC 67-69, 100-102, 177, 178)	6.69	0.04	0.02	1.04	1.01	1.08
Stroke (CC 95, 96)	10.66	0.03	0.01	1.03	1.00	1.07
Renal failure (CC 131)	26.15	0.14	0.01	1.15	1.13	1.18
COPD (CC 108)	46.87	0.15	0.01	1.17	1.14	1.19
Diabetes and DM complications (CC 15-20, 119, 120)	49.40	0.08	0.01	1.08	1.06	1.11
Disorders of fluid/electrolyte/acid-base (CC 22, 23)	36.28	0.11	0.01	1.12	1.09	1.14
Other urinary tract disorders (CC 136)	40.61	0.12	0.01	1.12	1.10	1.15
Decubitus ulcer or chronic skin ulcer (CC 148, 149)	11.86	0.10	0.01	1.10	1.07	1.13
Other gastrointestinal disorders (CC 36)	51.12	0.06	0.01	1.06	1.04	1.08
Peptic ulcer, hemorrhage, other specified gastrointestinal disorders (CC 34)	15.94	0.07	0.01	1.07	1.05	1.10
Severe hematological disorders (CC 44)	3.28	0.14	0.02	1.15	1.10	1.21
Nephritis (CC 132)	3.88	0.07	0.02	1.08	1.03	1.12
Dementia and senility (CC 49, 50)	18.94	0.01	0.01	1.01	0.99	1.03
Metastatic cancer and acute leukemia (CC 7)	2.13	0.13	0.03	1.14	1.07	1.21
Cancer (CC 8-12)	19.58	0.01	0.01	1.01	0.99	1.03

Liver and biliary disease (CC 25-30)	7.64	0.06	0.02	1.06	1.02	1.09
End-stage renal disease or dialysis (CC 129, 130)	2.98	0.15	0.03	1.16	1.11	1.22
Asthma (CC 110)	8.15	0.06	0.02	1.06	1.03	1.10
Iron deficiency and other/unspecified anemias and blood disease (CC 47)	45.43	0.08	0.01	1.09	1.06	1.11
Pneumonia (CC 111-113)	37.49	0.09	0.01	1.09	1.07	1.11
Drug/alcohol abuse/dependence/psychosis (CC 51-53)	8.68	0.07	0.02	1.07	1.04	1.10
Major psych disorders (CC 54-56)	8.48	0.02	0.02	1.02	0.99	1.06
Depression (CC 58)	13.03	0.02	0.01	1.02	0.99	1.05
Other psychiatric disorders (CC 60)	9.31	0.08	0.02	1.08	1.05	1.12
Fibrosis of lung and other chronic lung disorders (CC 109)	13.03	0.05	0.01	1.05	1.02	1.08
Protein-calorie malnutrition (CC 21)	4.52	0.05	0.02	1.05	1.01	1.09

2.11 Administrative Model Validation

We compared the model performance in the derivation sample with its performance in the sample from the 2004 data that was not selected for the derivation set, representing 283,528 cases discharged from the 4,680 hospitals with at least 1 case in the 2004 validation dataset. The validation data had a raw readmission rate of 23.7%; and in 4.4% of index admissions patients died within 30 days after discharge without being readmitted. The model was recalibrated in the validation set and the same approach to defining the set of hospitalizations was applied.

The standardized regression coefficients and standard errors for the 2004 validation dataset are shown in Table 9, and the performance metrics are shown in Table 11. The performance was not substantively different in this validation sample ($R^2 = 0.04$ and ROC area = 0.60).

The model variables were then tested in HF readmissions in 2003. Unadjusted readmission was 23.8% in 2003 and the mortality rate within 30 days without being readmitted was 4.4%. Model performance using 2003 is consistent with and similar to the derivation set (see Table 11). The percent explained variation is 0.038, while the area under the ROC curve is 0.61. The models appear well calibrated, with the overfitting indices of 0.089, 1.05.

We also examined the temporal variation of the standardized regression coefficients and frequencies of the variables in the final administrative model. Table 10 provides the standardized regression coefficients and standard errors for the full 2004 dataset. Tables 12 and 13 compare these results for 2003 and 2004. The frequencies and regression coefficients are fairly consistent over the 2 years of data (see Tables 12 and 13).

Table 9 – HF Readmission Administrative Model (50% 2004 Validation Sample – Results from the GLM)

Variable	Estimate	Standard Error	Standardized Reg. Coeff.	Odds Ratio	95% CI	
Intercept	-1.914	0.018				
Age-65 (years above 65, continuous)	-0.001	0.001	-0.0032	0.999	0.998	1.001
Male	0.012	0.010	0.0032	1.012	0.993	1.031
History of CABG	-0.091	0.014	-0.0170	0.913	0.889	0.938
Congestive heart failure (CC 80)	0.103	0.012	0.0243	1.108	1.081	1.136
Acute coronary syndromes (CC 81, 82)	0.114	0.011	0.0255	1.121	1.096	1.146
Arrhythmias (CC 92, 93)	0.069	0.010	0.0186	1.071	1.05	1.093
Cardio-respiratory failure and shock (CC 79)	0.077	0.012	0.0164	1.08	1.055	1.106
Valvular and rheumatic heart disease (CC 86)	0.096	0.009	0.0263	1.1	1.08	1.12
Vascular or circulatory disease (CC 104-106)	0.076	0.010	0.0209	1.079	1.059	1.1
Chronic atherosclerosis (CC 83, 84)	0.088	0.012	0.0213	1.092	1.067	1.116
Other and unspecified heart disease (CC 94)	0.062	0.010	0.0164	1.064	1.044	1.085
Hemiplegia, paraplegia, paralysis, functional disability (CC 67-69, 100-102, 177, 178)	0.054	0.018	0.0074	1.055	1.019	1.093
Stroke (CC 95, 96)	0.039	0.015	0.0066	1.04	1.01	1.07
Renal failure (CC 131)	0.137	0.012	0.0332	1.147	1.121	1.174
COPD (CC 108)	0.131	0.010	0.0360	1.14	1.118	1.161
Diabetes and DM complications (CC 15-20, 119, 120)	0.108	0.010	0.0296	1.114	1.093	1.135
Disorders of fluid/electrolyte/acid-base (CC 22, 23)	0.133	0.010	0.0353	1.142	1.119	1.166
Other urinary tract disorders (CC 136)	0.105	0.010	0.0284	1.111	1.089	1.133
Decubitus ulcer or chronic skin ulcer (CC 148, 149)	0.092	0.014	0.0164	1.096	1.067	1.126
Other gastrointestinal disorders (CC 36)	0.043	0.010	0.0118	1.044	1.024	1.064
Peptic ulcer, hemorrhage, other specified gastrointestinal disorders (CC 34)	0.047	0.013	0.0095	1.048	1.022	1.075
Severe hematological disorders (CC 44)	0.130	0.024	0.0128	1.139	1.087	1.193
Nephritis (CC 132)	0.081	0.022	0.0086	1.084	1.038	1.132
Dementia and senility (CC 49, 50)	0.002	0.012	0.0004	1.002	0.978	1.026
Metastatic cancer and acute leukemia (CC 7)	0.120	0.031	0.0096	1.128	1.062	1.198
Cancer (CC 8-12)	0.026	0.012	0.0057	1.027	1.003	1.051
Liver and biliary disease (CC 25-30)	0.049	0.016	0.0072	1.05	1.017	1.085
End-stage renal disease or dialysis (CC 129, 130)	0.119	0.025	0.0113	1.126	1.073	1.182
Asthma (CC 110)	0.035	0.016	0.0053	1.036	1.003	1.069
Iron deficiency and other/unspecified anemias and blood disease (CC 47)	0.075	0.010	0.0205	1.077	1.057	1.099
Pneumonia (CC 111-113)	0.070	0.010	0.0187	1.073	1.052	1.094
Drug/alcohol abuse/dependence/psychosis (CC 51-53)	0.107	0.016	0.0168	1.113	1.079	1.148
Major psych disorders (CC 54-56)	0.017	0.016	0.0026	1.017	0.985	1.05
Depression (CC 58)	0.022	0.014	0.0041	1.022	0.995	1.05
Other psychiatric disorders (CC 60)	0.106	0.015	0.0171	1.112	1.079	1.145
Fibrosis of lung and other chronic lung disorders (CC 109)	0.045	0.013	0.0083	1.046	1.019	1.073
Protein-calorie malnutrition (CC 21)	0.083	0.020	0.0096	1.087	1.044	1.131

Table 10– HF Readmission Administrative Model (2004 Full Sample –
Results from the GLM)

Variable	Estimate	Standard Error	Standardized Reg. Coeff.	Odds Ratio	95% CI	
Intercept	-1.902	0.013				
Age-65 (years above 65, continuous)	-0.001	0.0005	-0.0039	0.999	0.998	1.000
Male	0.012	0.007	0.0033	1.012	0.999	1.026
History of CABG	-0.081	0.010	-0.0152	0.922	0.905	0.940
Congestive heart failure (CC 80)	0.096	0.009	0.0227	1.100	1.082	1.120
Acute coronary syndrome (CC 81, 82)	0.116	0.008	0.0258	1.123	1.105	1.140
Arrhythmias (CC 92, 93)	0.062	0.007	0.0168	1.064	1.049	1.079
Cardio-respiratory failure and shock (CC 79)	0.079	0.008	0.0169	1.082	1.064	1.100
Valvular and rheumatic heart disease (CC 86)	0.086	0.007	0.0236	1.090	1.076	1.104
Vascular or circulatory disease (CC 104-106)	0.073	0.007	0.0200	1.076	1.061	1.090
Chronic atherosclerosis (CC 83, 84)	0.085	0.008	0.0205	1.088	1.071	1.106
Other and unspecified heart disease (CC 94)	0.058	0.007	0.0152	1.059	1.045	1.074
Hemiplegia, paraplegia, paralysis, functional disability (CC 67-69, 100-102, 177, 178)	0.048	0.013	0.0066	1.049	1.023	1.076
Stroke (CC 95, 96)	0.036	0.011	0.0061	1.037	1.016	1.058
Renal failure (CC 131)	0.139	0.008	0.0337	1.149	1.131	1.168
COPD (CC 108)	0.142	0.007	0.0390	1.152	1.137	1.168
Diabetes and DM complications (CC 15-20, 119, 120)	0.094	0.007	0.0260	1.099	1.084	1.113
Disorders of fluid/electrolyte/acid-base (CC 22, 23)	0.122	0.007	0.0322	1.129	1.113	1.146
Other urinary tract disorders (CC 136)	0.110	0.007	0.0299	1.117	1.101	1.132
Decubitus ulcer or chronic skin ulcer (CC 148, 149)	0.094	0.010	0.0168	1.099	1.078	1.120
Other gastrointestinal disorders (CC 36)	0.050	0.007	0.0139	1.052	1.038	1.066
Peptic ulcer, hemorrhage, other specified gastrointestinal disorders (CC 34)	0.058	0.009	0.0116	1.060	1.041	1.078
Severe hematological disorders (CC 44)	0.137	0.017	0.0134	1.146	1.109	1.185
Nephritis (CC 132)	0.077	0.016	0.0082	1.080	1.047	1.113
Dementia and senility (CC 49, 50)	0.005	0.009	0.0011	1.005	0.988	1.022
Metastatic cancer and acute leukemia (CC 7)	0.126	0.022	0.0100	1.134	1.087	1.183
Cancer (CC 8-12)	0.017	0.008	0.0038	1.017	1.001	1.034
Liver and biliary disease (CC 25-30)	0.052	0.012	0.0077	1.054	1.030	1.078
End-stage renal disease or dialysis (CC 129, 130)	0.135	0.018	0.0128	1.145	1.106	1.185
Asthma (CC 110)	0.049	0.011	0.0074	1.050	1.027	1.074
Iron deficiency and other/unspecified anemias and blood disease (CC 47)	0.078	0.007	0.0215	1.081	1.067	1.096
Pneumonia (CC 111-113)	0.078	0.007	0.0208	1.081	1.066	1.096
Drug/alcohol abuse/dependence/psychosis (CC 51-53)	0.087	0.011	0.0135	1.090	1.067	1.115
Major psych disorders (CC 54-56)	0.021	0.012	0.0032	1.021	0.998	1.044
Depression (CC 58)	0.021	0.010	0.0038	1.021	1.002	1.040
Other psychiatric disorders (CC 60)	0.093	0.011	0.0149	1.097	1.075	1.121
Fibrosis of lung and other chronic lung disorders (CC 109)	0.047	0.009	0.0087	1.048	1.029	1.067
Protein-calorie malnutrition (CC 21)	0.065	0.015	0.0074	1.067	1.037	1.098

Table 11– HF Readmission Administrative Model Performance: Results Based on the GLM

Model	Calibration	Adjusted $R^{2[*]}$	Discrimination		Residuals Lack of Fit (Pearson Residual Fall %)				Model χ^2 [Number of Covariates] ^{#[}
	$(\gamma_0, \gamma_1)^7$		Predictive Ability [†] (lowest decile, highest decile)	ROC	<-2	[-2, 0)	[0, 2)	[2+	
With Clinical Data and Outpatient Hospital									
Derivation Sample									
2004 (1 st half) N=283,919	(0,1)	0.03	0.15-0.37	0.60	0	76.40	17.62	5.98	6,462 (37)
Validation Sample									
2004 (2 nd half) N=283,528	(-0.02,1.01)	0.04	0.15-0.37	0.60	0	76.29	17.83	5.88	6,632 (37)
2003 N=561,763	(0.09, 1.05)	0.04	0.15-0.38	0.61	0	76.21	17.9	5.89	14,038 (37)

* Max-rescaled r-squared

Wald chi-squared

† Measure by observed rates

⁷ Over-Fitting Indices (γ_0, γ_1) provide evidence of over-fitting and require several steps to calculate. Let b denote the *estimated vector* of regression coefficients. *Predicted Probabilities* $(\hat{p}) = 1/(1+\exp\{-Xb\})$, and $Z = Xb$ (e.g., the linear predictor that is a scalar value for everyone). A new logistic regression model that includes only an intercept and a slope by regressing the logits on Z is fitted in the validation sample; e.g., $\text{Logit}(P(Y=1|Z)) = \gamma_0 + \gamma_1 Z$. Estimated values of γ_0 far from 0 and estimated values of γ_1 far from 1 provide evidence of over-fitting.

Table 12 – HF Readmission Administrative Model (GLM) – Standardized Estimates
Stratified by Year of Discharge (2003-2004)

Variable	2003	2004
Age-65 (years above 65, continuous)	-0.007	-0.004
Male	0.003	0.003
History of CABG	-0.017	-0.015
Congestive heart failure (CC 80)	0.032	0.023
Acute coronary syndrome (CC 81, 82)	0.024	0.026
Arrhythmias (CC 92, 93)	0.018	0.017
Cardio-respiratory failure and shock (CC 79)	0.021	0.017
Valvular and rheumatic heart disease (CC 86)	0.022	0.024
Vascular or circulatory disease (CC 104-106)	0.019	0.020
Chronic atherosclerosis (CC 83, 84)	0.023	0.021
Other and unspecified heart disease (CC 94)	0.017	0.015
Hemiplegia, paraplegia, paralysis, functional disability(CC 67-69, 100-102, 177, 178)	0.009	0.007
Stroke (CC 95, 96)	0.004	0.006
Renal failure (CC 131)	0.033	0.034
COPD (CC 108)	0.035	0.039
Diabetes and DM complications (CC 15-20, 119, 120)	0.027	0.026
Disorders of fluid/electrolyte/acid-base (CC 22, 23)	0.034	0.032
Other urinary tract disorders (CC 136)	0.027	0.030
Decubitus ulcer or chronic skin ulcer (CC 148, 149)	0.016	0.017
Other gastrointestinal disorders (CC 36)	0.020	0.014
Peptic ulcer, hemorrhage, other specified gastrointestinal disorders (CC 34)	0.011	0.012
Severe hematological disorders (CC 44)	0.010	0.013
Nephritis (CC 132)	0.011	0.008
Dementia and senility (CC 49, 50)	0.002	0.001
Metastatic cancer and acute leukemia (CC 7)	0.008	0.010
Cancer (CC 8-12)	0.006	0.004
Liver and biliary disease (CC 25-30)	0.008	0.008
End-stage renal disease or dialysis (CC 129, 130)	0.009	0.013
Asthma (CC 110)	0.008	0.007
Iron deficiency and other/unspecified anemias and blood disease (CC 47)	0.021	0.022
Pneumonia (CC 111-113)	0.027	0.021
Drug/alcohol abuse/dependence/psychosis (CC 51-53)	0.011	0.014
Major psych disorders (CC 54-56)	0.004	0.003
Depression (CC 58)	0.004	0.004
Other psychiatric disorders (CC 60)	0.014	0.015
Fibrosis of lung and other chronic lung disorders (CC 109)	0.008	0.009
Protein-calorie malnutrition (CC 21)	0.008	0.007

Table 13 – HF Readmission Administrative Model– Risk Factor Frequency Stratified by Year of Discharge (2003-2004)

Variable	2003	2004
Age-65 (years above 65, continuous)	14.8 (7.8)	14.9 (7.8)
Male	41.49	42.21
History of CABG	13.57	13.45
Congestive heart failure (CC 80)	74.86	75.59
Acute coronary syndrome (CC 81, 82)	21.04	20.85
Arrhythmias (CC 92, 93)	57.90	59.65
Cardio-respiratory failure and shock (CC 79)	18.04	18.54
Valvular and rheumatic heart disease (CC 86)	45.58	47.05
Vascular or circulatory disease (CC 104-106)	43.65	45.39
Chronic atherosclerosis (CC 83)	72.71	73.71
Other and unspecified heart disease (CC 94)	35.98	35.71
Hemiplegia, paraplegia, paralysis, functional disability (CC 67-69, 100-102, 177, 178)	6.71	6.69
Stroke (CC 95, 96)	10.62	10.66
Renal failure (CC 131)	23.59	26.15
COPD (CC 108)	46.04	46.87
Diabetes and DM complications (CC 15-20, 119, 120)	48.60	49.40
Disorders of fluid/electrolyte/acid-base (CC 22, 23)	34.92	36.28
Other urinary tract disorders (CC 136)	38.03	40.61
Decubitus ulcer or chronic skin ulcer (CC 148, 149)	11.34	11.86
Other gastrointestinal disorders (CC 36)	50.30	51.12
Peptic ulcer, hemorrhage, other specified gastrointestinal disorders (CC 34)	15.68	15.94
Severe hematological disorders (CC 44)	3.12	3.28
Nephritis (CC 132)	4.17	3.88
Dementia and senility (CC 49, 50)	18.28	18.94
Metastatic cancer and acute leukemia (CC 7)	2.14	2.13
Cancer (CC 8-12)	19.19	19.58
Liver and biliary disease (CC 25-30)	7.44	7.64
End-stage renal disease or dialysis (CC 129, 130)	2.79	2.98
Asthma (CC 110)	8.05	8.15
Iron deficiency and other/unspecified anemias and blood disease (CC 47)	43.97	45.43
Pneumonia (CC 111-113)	36.21	37.49
Drug/alcohol abuse/dependence/psychosis (CC 51-53)	8.27	8.68
Major psych disorders (CC 54-56)	8.35	8.48
Depression (CC 58)	12.81	13.03
Other psychiatric disorders (CC 60)	9.38	9.31
Fibrosis of lung and other chronic lung disorders (CC 109)	12.81	13.03
Protein-calorie malnutrition (CC 21)	4.24	4.52

2.12 Administrative Model Results (HGLM)

Table 14 shows the point estimates, standard errors, and associated t values for the HGLM, based on the SAS GLIMMIX procedure based on the full 2004 dataset. The estimated between-hospital variance in the adjusted log-odds of readmission is 0.0207, based on the 2004 full dataset. This result implies that the odds of readmission for a high readmission hospital (+ 1 SD) are 1.33 times that in a low readmission hospital (-1 SD). If there were no differences between hospitals, the between-hospital variance would be 0 and the odds would be 1.0.

Table 14 – HGLM Results (100% of 2004 Administrative Dataset)

Effect	Estimate	Standard Error	t Value	Pr > t
Intercept	-1.898	0.013	-144.66	<.0001
Age-65 (years above 65, continuous)	-0.001	0.000	-1.93	0.0542
Male	0.017	0.007	2.47	0.0136
History of CABG	-0.082	0.010	-8.45	<.0001
Congestive heart failure (CC 80)	0.094	0.009	10.63	<.0001
Acute coronary syndrome (CC 81, 82)	0.110	0.008	13.69	<.0001
Arrhythmias (CC 92, 93)	0.065	0.007	9.16	<.0001
Cardio-respiratory failure and shock (CC 79)	0.080	0.008	9.37	<.0001
Valvular and rheumatic heart disease (CC 86)	0.096	0.007	14.38	<.0001
Vascular or circulatory disease (CC 104-106)	0.071	0.007	10.37	<.0001
Chronic atherosclerosis (CC 83, 84)	0.082	0.008	10.03	<.0001
Other and unspecified heart disease (CC 94)	0.057	0.007	8.20	<.0001
Hemiplegia, paraplegia, paralysis, functional disability (CC 67-69, 100-102, 177, 178)	0.046	0.013	3.64	0.0003
Stroke (CC 95, 96)	0.034	0.011	3.19	0.0014
Renal failure (CC 131)	0.140	0.008	16.75	<.0001
COPD (CC 108)	0.139	0.007	20.31	<.0001
Diabetes and DM complications (CC 15-20, 119, 120)	0.091	0.007	13.44	<.0001
Disorders of fluid/electrolyte/acid-base (CC 22, 23)	0.121	0.007	16.49	<.0001
Other urinary tract disorders (CC 136)	0.114	0.007	15.94	<.0001
Decubitus ulcer or chronic skin ulcer (CC 148, 149)	0.094	0.010	9.71	<.0001
Other gastrointestinal disorders (CC 36)	0.051	0.007	7.39	<.0001
Peptic ulcer, hemorrhage, other specified gastrointestinal disorders (CC 34)	0.055	0.009	6.10	<.0001
Severe hematological disorders (CC 44)	0.140	0.017	8.30	<.0001
Nephritis (CC 132)	0.074	0.016	4.68	<.0001
Dementia and senility (CC 49, 50)	0.001	0.009	0.09	0.9273
Metastatic cancer and acute leukemia (CC 7)	0.125	0.022	5.76	<.0001
Cancer (CC 8-12)	0.017	0.008	2.06	0.0391
Liver and biliary disease (CC 25-30)	0.051	0.012	4.40	<.0001
End-stage renal disease or dialysis (CC 129, 130)	0.136	0.018	7.67	<.0001
Asthma (CC 110)	0.044	0.011	3.87	0.0001
Iron deficiency and other/unspecified anemias and blood disease (CC 47)	0.078	0.007	11.02	<.0001
Pneumonia (CC 111-113)	0.075	0.007	10.59	<.0001
Drug/alcohol abuse/dependence/psychosis (CC 51-53)	0.090	0.011	8.04	<.0001
Major psych disorders (CC 54-56)	0.018	0.012	1.55	0.1209
Depression (CC 58)	0.022	0.010	2.33	0.0201
Other psychiatric disorders (CC 60)	0.090	0.011	8.42	<.0001
Fibrosis of lung and other chronic lung disorders (CC 109)	0.049	0.009	5.18	<.0001
Protein-calorie malnutrition (CC 21)	0.066	0.015	4.49	<.0001

- 4,730 hospitals in the full 2004 administrative dataset
- Between-hospital variance = 0.0207, standard error of variance estimate = 0.0015

2.13 Readmission Rate Distribution – With and Without Risk-Adjustment

Figures 3-6 display the frequency distributions of the hospital-specific 30-day readmission rates, with and without risk-adjustment for 2004. Figures 4 and 6 display these results by hospital volume quartiles for the unadjusted and adjusted rates respectively. Without adjustment, there is substantial variation, particularly among the low volume hospitals. Even with risk adjustment, however, there are clinically important differences in the rates among hospitals.

The observed readmission rate ranged from 0% to 100% across the 4,730 hospitals in the complete 2004 dataset. The 25th, 50th, and 75th percentiles for unadjusted readmission were 18.8%, 23.1%, and 27.3%, respectively. The distribution of standardized readmission rates, however, ranged from 18.2% to 29.4%, with 25th, 50th, and 75th percentiles of 23.0%, 23.6%, and 24.3%, respectively.

Figure 3 – Distribution of Hospital-level Unadjusted 30-Day Heart Failure Readmission Rates (Full 2004 Sample)

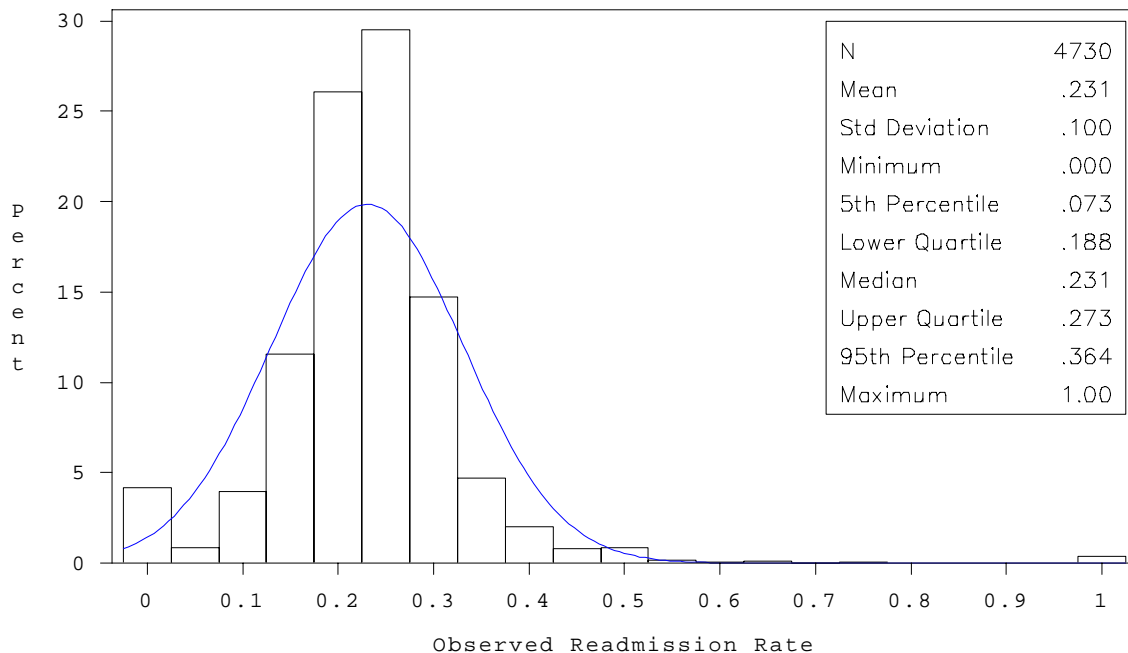
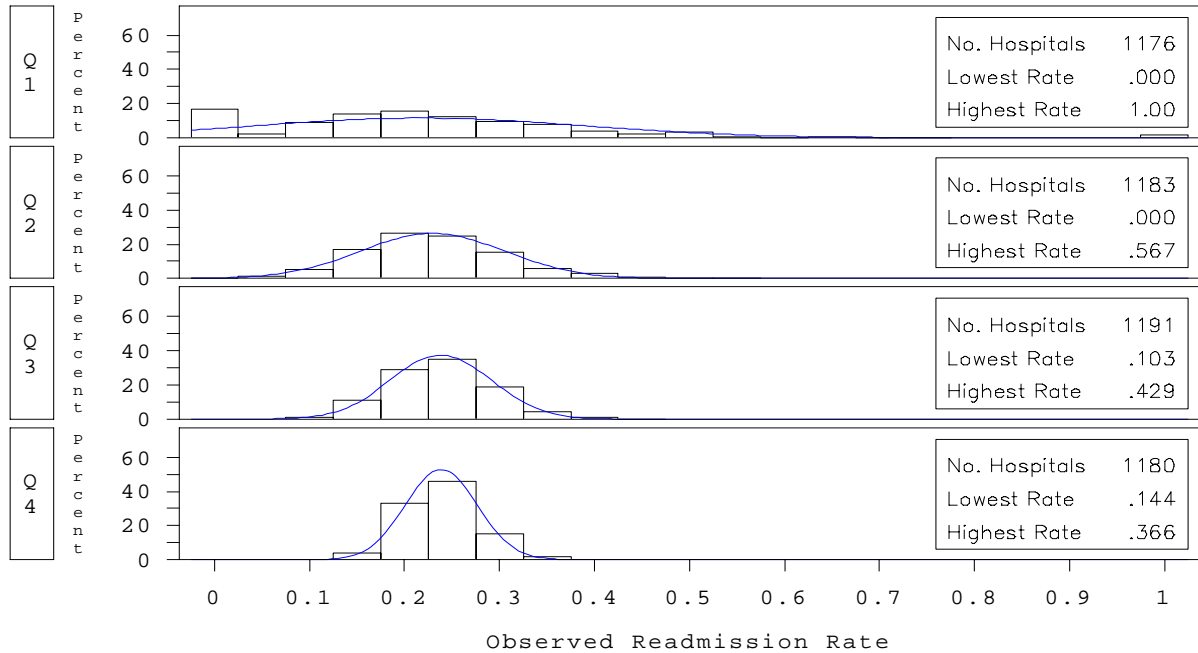


Figure 4 – Distribution of Hospital-level Unadjusted 30-Day HF Readmission Rates, by Hospital Volume Quartile (Full 2004 Sample)



Note: Hospital Volume Index Admissions--Q1: 1 - 26, Q2: 27 - 71, Q3: 72 - 168, Q4: 169 - 1642

Figure 5 – Distribution of Standardized Hospital-level 30-Day HF Readmission Rates (Full 2004 Sample) – HGLM

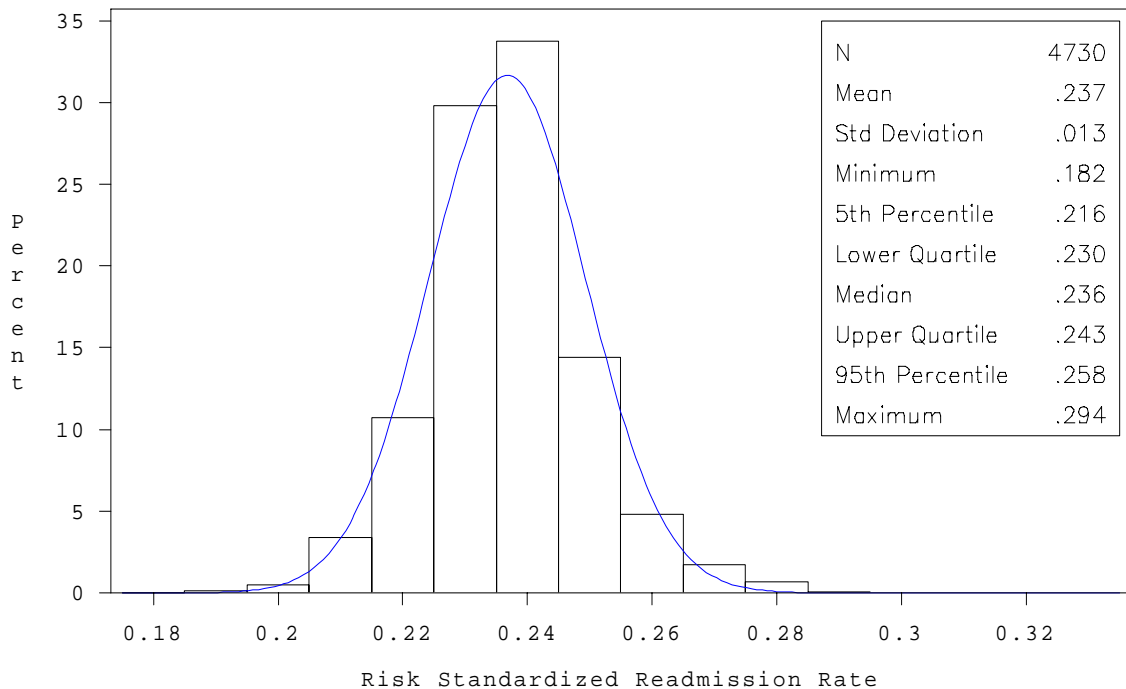
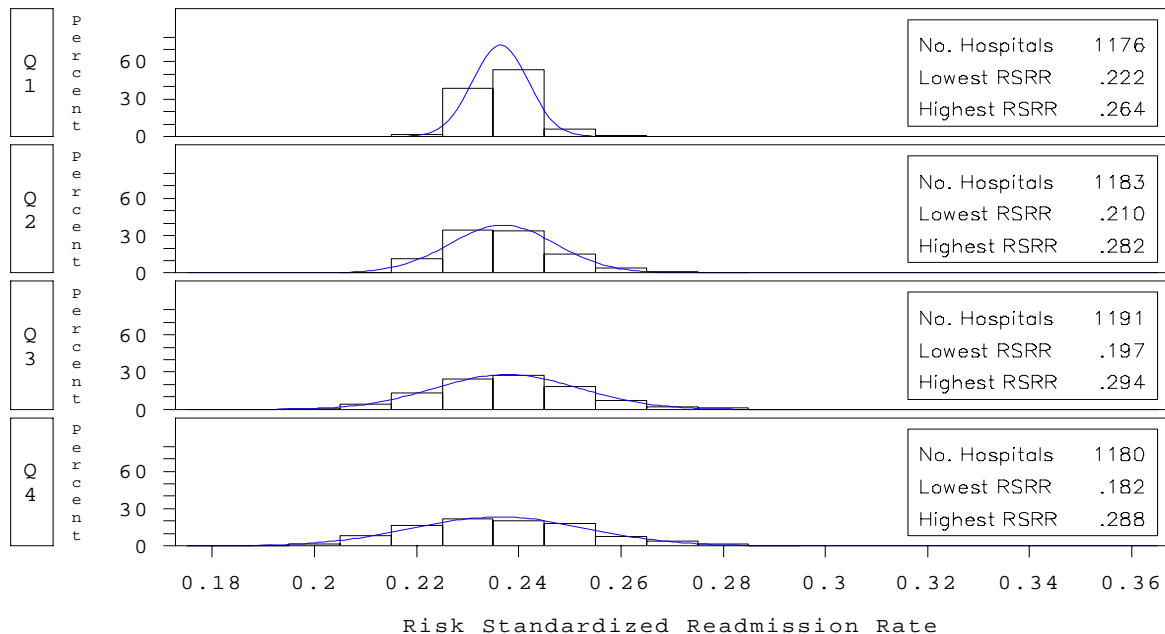


Figure 6 - Distribution of Standardized Hospital-level 30-Day HF Readmission Rates, By Hospital Volume Quartile (Full 2004 Sample) – HGLM



Note: Hospital Volume Index Admissions--Q1: 1 - 26, Q2: 27 - 71, Q3: 72 - 168, Q4: 169 - 1642

2.14 Administrative Model Validation Using the Medical Record Dataset

We sought to validate our administrative HF model against the gold standard model in the same cohort of patients for which hospital-level, HF chart data are available.

2.15 Derivation of Medical Record Model

2.15.1 Components

From the medical chart-abstracted HF cases described in section 2.5, we linked these files to the corresponding administrative data from the Medicare enrollment database. Because only patients aged 66 years and older were included some data were excluded based on linkage and other factors. The derivation sample contained 64,329 cases with an unadjusted 30-day readmission rate of 23.7%. The medical record model validation included clinician and hospital outpatient data.

2.15.2 Inclusion/Exclusion Criteria

The same coding and transfer rules described in the HF administrative dataset were used in defining the HF chart dataset.

2.15.3 Medical Record Model Building

The chart model was derived in the NHF dataset with the data elements described in section 2.5. We selected variables for this model using the same approach we used for the administrative model. We used a modified approach to stepwise logistic regression. We created 200 bootstrap samples and summarized the percent of times that each of the candidate variables was selected (as significant at $p < 0.05$) in logistic regressions using each of the 200 repeated samples. We also assessed the direction and magnitude of regression coefficients. The physician team reviewed these results and decided to retain most risk adjuster variables above a 75% cutoff based on their clinical relevance and strength of association with readmission. In addition, several other variables (e.g. dementia and metastatic cancer) were retained due to their clinical importance although their statistical association with readmission was weaker. This resulted in a final chart data risk-adjustment model including 30 variables. The variables in this model, along with the variable parameters, standardized estimates, and significance levels, are shown in Table 15 (for the GLM). The performance of this model is shown in Table 16. It was not substantively different in this validation sample ($R^2 = 0.02$ and ROC area = 0.58).

Table 15 – HF 30-Day Readmission Chart Model (Based on 1998-2001 NHF Dataset) – GLM

Variable	Percent	Estimate	Standard Error	Odds Ratio	95% CI	
Intercept		-1.70	0.03			
Male	41.73	-0.06	0.02	0.94	0.90	0.98
Age: 75-84	43.10	-0.05	0.02	0.95	0.91	0.99
Age: 85+	27.38	-0.14	0.03	0.87	0.83	0.92
Chronic obstructive pulmonary disease	33.99	0.13	0.02	1.14	1.09	1.18
Dementia/Alzheimer's disease	9.08	-0.06	0.03	0.95	0.89	1.01
Diabetes (any type)	40.00	0.06	0.02	1.07	1.02	1.11
Cerebrovascular accident	18.41	0.06	0.02	1.06	1.02	1.12
Congestive heart failure	70.49	0.24	0.02	1.27	1.22	1.33
History of PTCA	10.17	0.08	0.03	1.09	1.02	1.16
History of coronary artery disease	57.47	0.15	0.02	1.16	1.11	1.21
Systolic blood pressure < 125 mm Hg	25.18	0.16	0.02	1.17	1.12	1.22
Systolic blood pressure unknown (Y/N)	0.07	-0.53	0.45	0.59	0.24	1.43
Respiratory rate < 12	0.19	-0.05	0.22	0.95	0.62	1.46
Respiratory rate > 25	32.50	0.04	0.02	1.04	1.00	1.09
Heart rate <60 beats/min.	5.13	-0.02	0.04	0.98	0.90	1.06
Heart rate >100 beats/min.	26.93	0.08	0.02	1.08	1.03	1.13
Heart rate unknown	0.10	0.40	0.34	1.49	0.76	2.90
Cardiac arrest	0.51	0.06	0.13	1.06	0.83	1.36
LVEF < 40	29.20	0.05	0.02	1.05	1.00	1.11
LVEF unknown	36.00	0.14	0.02	1.15	1.10	1.20
Aortic stenosis	7.35	0.13	0.04	1.14	1.06	1.22
Sodium < 130 mg/dL	4.83	0.02	0.04	1.02	0.94	1.11
Sodium > 145 mg/dL	4.11	-0.06	0.05	0.95	0.86	1.04
Sodium unknown	1.98	-0.05	0.11	0.95	0.78	1.17
BUN > 40 or creatinine > 2.5 mg/dL	20.69	0.34	0.02	1.40	1.34	1.47
BUN and creatinine unknown (Y/N)	1.71	0.20	0.12	1.22	0.98	1.54
Glucose > 200	17.98	0.06	0.03	1.07	1.01	1.12
Glucose unknown	3.57	0.01	0.07	1.01	0.89	1.15
Hematocrit < 30	11.23	0.20	0.03	1.22	1.16	1.30
Hematocrit unknown	4.28	0.04	0.05	1.04	0.94	1.15

- Between-state variance estimate using hierarchical model is 0.02 (SE=.005).

Table 16 – HF Gold Standard Model Performance – GLM

Model	Calibration		Discrimination		Residuals Lack of Fit (Pearson Residual Fall %)				Model χ^2 [Number of Covariates] [‡]
	(γ_0, γ_1)	Adjusted R^2 [*]	Predictive Ability [†] (lowest decile, highest decile)	ROC	<-2	[-2, 0)	[0, 2)	[2+	
Gold standard model derivation sample (NHF)									
1998- 2001 N=64,329 Number of 30-day readmission = 15,223	(0,1)	0.02	0.16-0.34	0.58	0	76.34	18.98	4.68	981 (30)
Linked administrative model validation sample									
1998- 2001 N=64,329 Number of 30-day readmission = 15,223	(0,1)	0.04	0.15-0.38	0.61	0	76.34	17.46	6.21	1,697 (37)

* Max-rescaled r-squared

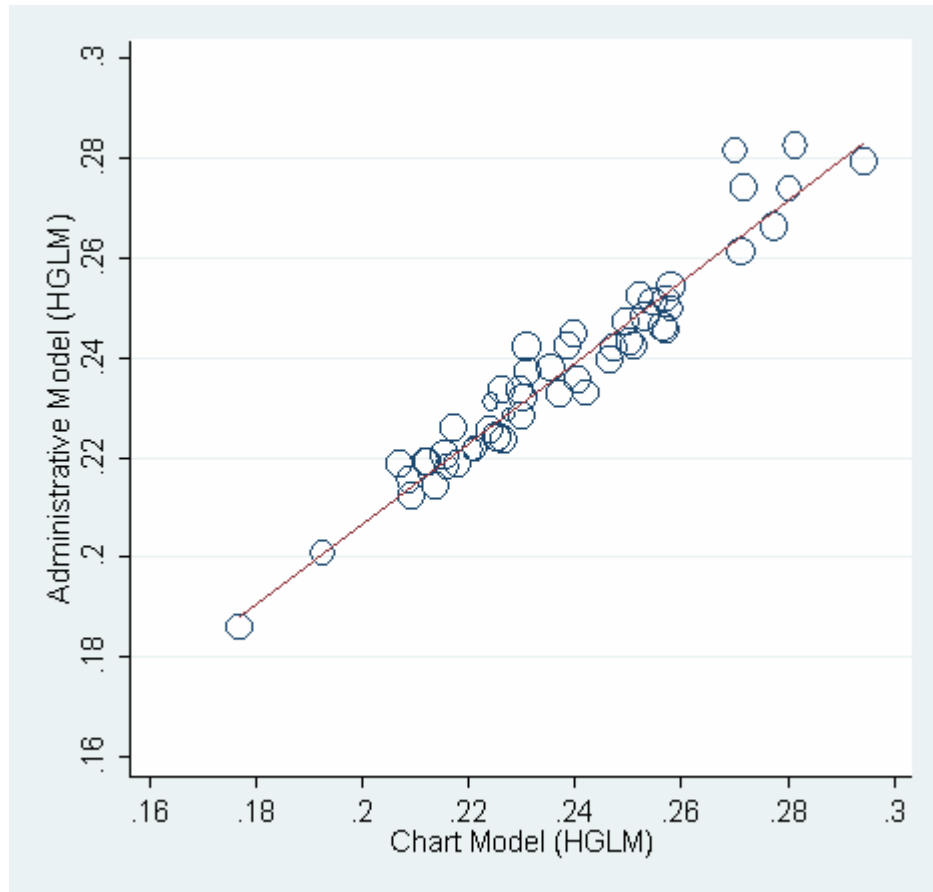
Wald chi-squared

† Measure by observed rates

2.15.4 Comparison of Administrative Model with Medical Record Model

Because the medical chart dataset included only a limited number of cases from each state, plus the District of Columbia and Puerto Rico, we did not have available a sufficient number of cases from each hospital to compare the administrative and chart models at the hospital level. As a result, our comparison was performed at the state level. Based on the 64,329 cases with linked administrative and chart data, we estimated state-specific risk-adjusted 30-day readmission rates. The median difference between the models in the state-specific risk-standardized readmission rates was 0.06 percentage points (25th percentile = -0.5; 75th percentile = 0.5; 10th percentile = -0.9; 90th percentile = 0.8 percentage points). We also estimated the linear relationship between the two sets of estimates using regression techniques and weighting by the total number of cases in each hospital. The correlation coefficient of the standardized rates from the administrative and chart models is 0.97 (Figure 7). While these correlation estimates do not account for the standard errors associated with each point estimate, they do indicate a strong relationship between the two models for each outcome.

Figure 7 – Administrative versus Medical Record Model (HGLM) – State-Specific Standardized 30-Day HF Readmission Rates



$R^2 = 0.95$; Correlation = 0.973

3. MAIN FINDINGS/SUMMARY

We present a hierarchical logistic regression model for 30-day readmission after HF hospitalization that is based on administrative data and is suitable for public reporting. The model is a strong surrogate for a similar “gold standard” model based on chart data. The approach employs a grouper of 15,000 ICD-9 codes that is in the public domain yielding clinically coherent variables. There is a standardized period of follow-up. The model does not adjust for variables that may represent complications, rather than comorbidities. The study sample is appropriately defined. The statistical approach takes into account the clustering of patients within hospitals and differences in sample size across hospitals.

The patient-level discrimination and the explained variation of the model are consistent with the few published models of readmission after HF that report predictive ability (Philbin and DiSalvo, 1999; Yamokoski et al, 2007). The model performs as expected given that the risk of readmission is likely much more dependent on the quality of care and system characteristics than on patient severity and comorbidity characteristics. The readiness for discharge, the proper medications, and the proper transition to the outpatient setting may be even more important for readmission than for mortality. Results of intervention studies underscore this potential (MedPAC, 2007). In addition, research suggests that some HF admissions may be discretionary, with higher rates in geographic areas with a greater supply of hospital beds than areas with fewer beds (Fisher, Wennberg et al., 1994).

Our approach to risk adjustment is tailored to and appropriate for a publicly reported outcome measure. Adjusting for patient characteristics improved model performance. The ROC of 0.603 is higher than that of a model with just age and gender, 0.516, and very similar to a model with all candidate variables, with ROC of 0.604. We excluded covariates, however, that we would not want to adjust for in a quality measure, such as potential complications, certain patient demographics (e.g., race, socioeconomic status), and patients’ admission path and discharge disposition (e.g. admit from, or discharge to, a skilled nursing facility). These characteristics may be associated with readmission and thus could increase the model performance to predict patient readmissions. However, these variables may be related to quality or supply factors that should not be included in an adjustment that seeks to control for patient clinical characteristics while illuminating important quality differences. For example, if hospitals with a higher share of a certain ethnic group have higher readmission rates, then including ethnic group in the model will attenuate this difference and obscure differences that are important to identify.

In summary, we present a claims-based HF 30-day readmission measure that is suitable for public reporting. It is consistent with the consensus standards for publicly reported outcomes measures, and can be implemented using available data.

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5. APPENDIX

189 Conditional Categories with Potential Complications of Index Admissions

CC #	Description	Potential Complication in Index Admission
1	HIV/AIDS	
2	Septicemia/Shock	✓
3	Central Nervous System Infection	
4	Tuberculosis	
5	Opportunistic Infections	
6	Other Infectious Diseases	✓
7	Metastatic Cancer and Acute Leukemia	
8	Lung, Upper Digestive Tract, and Other Severe Cancers	
9	Lymphatic, Head and Neck, Brain, and Other Major Cancers	
10	Breast, Prostate, Colorectal and Other Cancers and Tumors	
11	Other Respiratory and Heart Neoplasms	
12	Other Digestive and Urinary Neoplasms	
13	Other Neoplasms	
14	Benign Neoplasms of Skin, Breast, Eye	
15	Diabetes with Renal Manifestation	
16	Diabetes with Neurologic or Peripheral Circulatory Manifestation	
17	Diabetes with Acute Complications	✓
18	Diabetes with Ophthalmologic Manifestation	
19	Diabetes with No or Unspecified Complications	
20	Type I Diabetes Mellitus	
21	Protein-Calorie Malnutrition	
22	Other Significant Endocrine and Metabolic Disorders	
23	Disorders of Fluid/Electrolyte/Acid-Base	✓
24	Other Endocrine/Metabolic/Nutritional Disorders	
25	End-Stage Liver Disease	
26	Cirrhosis of Liver	
27	Chronic Hepatitis	
28	Acute Liver Failure/Disease	✓
29	Other Hepatitis and Liver Disease	
30	Gallbladder and Biliary Tract Disorders	
31	Intestinal Obstruction/Perforation	✓
32	Pancreatic Disease	
33	Inflammatory Bowel Disease	
34	Peptic Ulcer, Hemorrhage, Other Specified Gastrointestinal Disorders	✓
35	Appendicitis	
36	Other Gastrointestinal Disorders	
37	Bone/Joint/Muscle Infections/Necrosis	
38	Rheumatoid Arthritis and Inflammatory Connective Tissue Disease	

CC #	Description	Potential Complication in Index Admission
39	Disorders of the Vertebrae and Spinal Discs	
40	Osteoarthritis of Hip or Knee	
41	Osteoporosis and Other Bone/Cartilage Disorders	
42	Congenital/Developmental Skeletal and Connective Tissue Disorders	
43	Other Musculoskeletal and Connective Tissue Disorders	
44	Severe Hematological Disorders	
45	Disorders of Immunity	
46	Coagulation Defects and Other Specified Hematological Disorders	✓
47	Iron Deficiency and Other/Unspecified Anemias and Blood Disease	
48	Delirium and Encephalopathy	✓
49	Dementia	
50	Senility, Nonpsychotic Organic Brain Syndromes/Conditions	
51	Drug/Alcohol Psychosis	
52	Drug/Alcohol Dependence	
53	Drug/Alcohol Abuse, Without Dependence	
54	Schizophrenia	
55	Major Depressive, Bipolar, and Paranoid Disorders	
56	Reactive and Unspecified Psychosis	
57	Personality Disorders	
58	Depression	
59	Anxiety Disorders	
60	Other Psychiatric Disorders	
61	Profound Mental Retardation/Developmental Disability	
62	Severe Mental Retardation/Developmental Disability	
63	Moderate Mental Retardation/Developmental Disability	
64	Mild/Unspecified Mental Retardation/Developmental Disability	
65	Other Developmental Disability	
66	Attention Deficit Disorder	
67	Quadriplegia, Other Extensive Paralysis	
68	Paraplegia	
69	Spinal Cord Disorders/Injuries	
70	Muscular Dystrophy	
71	Polyneuropathy	
72	Multiple Sclerosis	
73	Parkinson's and Huntington's Diseases	
74	Seizure Disorders and Convulsions	
75	Coma, Brain Compression/Anoxic Damage	✓
76	Mononeuropathy, Other Neurological Conditions/Injuries	
77	Respirator Dependence/Tracheostomy Status	✓
78	Respiratory Arrest	✓
79	Cardio-Respiratory Failure and Shock	✓
80	Congestive Heart Failure	✓
81	Acute Myocardial Infarction	✓

CC #	Description	Potential Complication in Index Admission
82	Unstable Angina and Other Acute Ischemic Heart Disease	✓
83	Angina Pectoris/Old Myocardial Infarction	
84	Coronary Atherosclerosis/Other Chronic Ischemic Heart Disease	
85	Heart Infection/Inflammation, Except Rheumatic	
86	Valvular and Rheumatic Heart Disease	
87	Major Congenital Cardiac/Circulatory Defect	
88	Other Congenital Heart/Circulatory Disease	
89	Hypertensive Heart and Renal Disease or Encephalopathy	
90	Hypertensive Heart Disease	
91	Hypertension	
92	Specified Heart Arrhythmias	✓
93	Other Heart Rhythm and Conduction Disorders	✓
94	Other and Unspecified Heart Disease	
95	Cerebral Hemorrhage	✓
96	Ischemic or Unspecified Stroke	✓
97	Precerebral Arterial Occlusion and Transient Cerebral Ischemia	✓
98	Cerebral Atherosclerosis and Aneurysm	
99	Cerebrovascular Disease, Unspecified	
100	Hemiplegia/Hemiparesis	✓
101	Diplegia (Upper), Monoplegia, and Other Paralytic Syndromes	✓
102	Speech, Language, Cognitive, Perceptual	✓
103	Cerebrovascular Disease Late Effects, Unspecified	
104	Vascular Disease with Complications	✓
105	Vascular Disease	✓
106	Other Circulatory Disease	✓
107	Cystic Fibrosis	
108	Chronic Obstructive Pulmonary Disease	
109	Fibrosis of Lung and Other Chronic Lung Disorders	
110	Asthma	
111	Aspiration and Specified Bacterial Pneumonias	✓
112	Pneumococcal Pneumonia, Emphysema, Lung Abscess	✓
113	Viral and Unspecified Pneumonia, Pleurisy	
114	Pleural Effusion/Pneumothorax	✓
115	Other Lung Disorders	
116	Legally Blind	
117	Major Eye Infections/Inflammations	
118	Retinal Detachment	
119	Proliferative Diabetic Retinopathy and Vitreous Hemorrhage	
120	Diabetic and Other Vascular Retinopathies	
121	Retinal Disorders, Except Detachment and Vascular Retinopathies	
122	Glaucoma	
123	Cataract	
124	Other Eye Disorders	

CC #	Description	Potential Complication in Index Admission
125	Significant Ear, Nose, and Throat Disorders	
126	Hearing Loss	
127	Other Ear, Nose, Throat, and Mouth Disorders	
128	Kidney Transplant Status	
129	End Stage Renal Disease	✓
130	Dialysis Status	✓
131	Renal Failure	✓
132	Nephritis	✓
133	Urinary Obstruction and Retention	✓
134	Incontinence	
135	Urinary Tract Infection	✓
136	Other Urinary Tract Disorders	
137	Female Infertility	
138	Pelvic Inflammatory Disease and Other Specified Female Genital Disorders	
139	Other Female Genital Disorders	
140	Male Genital Disorders	
141	Ectopic Pregnancy	
142	Miscarriage/Abortion	
143	Completed Pregnancy With Major Complications	
144	Completed Pregnancy With Complications	
145	Completed Pregnancy Without Complication	
146	Uncompleted Pregnancy With Complications	
147	Uncompleted Pregnancy With No or Minor Complications	
148	Decubitus Ulcer of Skin	✓
149	Chronic Ulcer of Skin, Except Decubitus	
150	Extensive Third-Degree Burns	
151	Other Third-Degree and Extensive Burns	
152	Cellulitis, Local Skin Infection	✓
153	Other Dermatological Disorders	
154	Severe Head Injury	✓
155	Major Head Injury	✓
156	Concussion or Unspecified Head Injury	✓
157	Vertebral Fractures	
158	Hip Fracture/Dislocation	✓
159	Major Fracture, Except of Skull, Vertebrae, or Hip	✓
160	Internal Injuries	
161	Traumatic Amputation	
162	Other Injuries	
163	Poisonings and Allergic Reactions	✓
164	Major Complications of Medical Care and Trauma	✓
165	Other Complications of Medical Care	✓
166	Major Symptoms, Abnormalities	
167	Minor Symptoms, Signs, Findings	

CC #	Description	Potential Complication in Index Admission
168	Extremely Low Birthweight Neonates	
169	Very Low Birthweight Neonates	
170	Serious Perinatal Problem Affecting Newborn	
171	Other Perinatal Problems Affecting Newborn	
172	Normal, Single Birth	
173	Major Organ Transplant	
174	Major Organ Transplant Status	✓
175	Other Organ Transplant/Replacement	✓
176	Artificial Openings for Feeding or Elimination	✓
177	Amputation Status, Lower Limb/Amputation	✓
178	Amputation Status, Upper Limb	✓
179	Post-Surgical States/Aftercare/Elective	✓
180	Radiation Therapy	
181	Chemotherapy	
182	Rehabilitation	
183	Screening/Observation/Special Exams	
184	History of Disease	
185	Oxygen	
186	CPAP/IPPB/Nebulizers	
187	Patient Lifts, Power Operated Vehicles, Beds	
188	Wheelchairs, Commodes	
189	Walkers	