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Chronic Obstructive Pulmonary Disease and Thirty-day Rehospitalizations: An Analysis of the Nationwide Readmissions Database

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Chronic Obstructive Pulmonary Disease and Thirty-day Rehospitalizations: An Analysis of the Nationwide Readmissions Database

A dissertation submitted in partial satisfaction of the

requirements for the degree of Doctor of Philosophy

in Health Policy and Management

by

Russell Glen Buhr

2019

ABSTRACT OF THE DISSERTATION

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Doctor of Philosophy in Health Policy and Management

University of California, Los Angeles, 2019

Professor Carol M. Mangione, Co-Chair

Professor Michael K. Ong, Co-Chair

Hospital readmissions following acute exacerbations of chronic obstructive pulmonary disease (COPD) are frequent occurrences, resulting following one in five discharges. Readmissions are costly and also put patients at risk for adverse outcomes stemming from ongoing hospitalizations. Under the Hospital Readmissions Reduction Program, the Centers for Medicare and Medicaid Services have imposed penalties on excess readmissions for COPD, among other conditions. In this dissertation, we explore the effect of comorbidity, operationalized by the Charlson and Elixhauser indices, on readmission odds using multilevel logistic regression modelling and employing information criteria in order to determine which provides better fit in estimating

readmissions. The Elixhauser index having prevailed, we estimated the readmission odds for returns related to an ongoing COPD diagnosis, versus for all other causes. We found that only 45% of returns were for ongoing COPD, and that those who returned for other reasons had substantially higher burdens of comorbidity. Finally, we evaluated the effect of the implementation of the Hospital Readmissions Reduction Policy on readmission rates for COPD, controlling for secular trends. We found that the addition of COPD to the list of penalized conditions did not significantly affect the already down-trending rates of readmissions when compared to non-penalized conditions or compared to the other penalized conditions of congestive heart failure, myocardial infarction, or pneumonia. Readmissions for COPD remain an ongoing problem for healthcare burden and cost, but overall readmissions do seem to be lessening. Understanding the effect of comorbidity on readmissions will help health systems better plan their efforts to improve care, and for policies like the Hospital Readmissions Reduction Program to adjust their expected readmission rates more fairly when applying penalties.

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2019

Dedication

For my grandparents Walt and Dot, for instilling the value of a good education, for my parents Ron and Ann, for instilling the value of hard work and persistence, for my sister Andrea, for instilling the value of overcoming life's adversities, for my dear friend Jolene for being one of my biggest cheerleaders, and for my husband, Will, for pushing me every day to become the best version of myself.

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Research was made possible by publicly available data from the Agency for Healthcare Research and Quality's Healthcare Cost and Utilization Project (HCUP) Nationwide Readmission Database. A full list of partner organizations furnishing data for the project is available at https://www.hcup-us.ahrq.gov/db/hcupdatapartners.jsp.

I would like to acknowledge the time and guidance of his dissertation committee. Recognizing how hard each of you work and the tireless effort you put into helping foster the development of trainees and junior faculty is truly an inspiration. I can only hope that with time and hard work I will become half the scientist and physician that you are. My most sincere thanks for the hours you've spent with me, indulging silly questions and bad ideas, perusing over my work with a fine-toothed comb to find ways to make it better, encouraging, motivating, and helping me get through this, all the while being some of the kindest and most giving people I have ever worked with. I also thank Drs. Igor Barjaktarevic and Christopher Cooper for being exceptional colleagues and mentors in the COPD research sphere. I also am eternally grateful to Dr. Nicholas Jackson for his hard work on our statistical analyses. You are gracious, patient, and

brilliant, and I am fortunate to have you as a colleague. I truly could not have done this without all you.

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Chapter 1: Background

Burden of COPD Readmissions

Chronic obstructive pulmonary disease (COPD) results in significant morbidity and mortality and is the third leading cause of death in the United States [1]. A major source of morbidity is hospitalization due to acute exacerbations of COPD, leading to impaired quality of life, as well as social and economic burden [2]. Of those hospitalized for acute exacerbations of COPD, one in five are readmitted within 30 days of discharge despite aggressive attempts to reduce readmissions [3].

These index COPD hospitalizations and subsequent readmissions both represent a significant economic burden on the U.S. healthcare system [4,5]. More importantly, readmitted patients and their families bear substantial stress and are exposed to risk of healthcare-associated injury and infection. Despite improvements in care and dedicated prevention efforts, the epidemiology of readmissions following COPD exacerbations, including associated causes and risk factors remains poorly understood [6]. Gaining this understanding is instrumental for the success of readmission reduction programs.

State of Knowledge of COPD Healthcare Utilization Drivers

Management of COPD involves use of respiratory inhaled medications, risk reduction vis-à-vis smoking cessation, and early recognition of exacerbations. Exacerbations of COPD are a frequent occurrence, and happen at all stages of the disease, though as health status worsens, these exacerbations more frequently result in hospitalization [7]. These exacerbations are a key driver of hospital and healthcare utilization and are associated with worsened quality of life.

Sociodemographic Factors

Adjustment for patient-level factors should be included due to previously described variability in readmission rates by these types of factors [8]. COPD disproportionately affects those with lower socioeconomic status, and readmissions have been demonstrably variable in hospitals serving these communities [9-13].

Ecologic Factors

Seasonal variability in readmission rates have been described in heart failure and pneumonia in other studies [14,15]. This temporal variability is demonstrated in COPD exacerbations resulting in hospitalization in previous studies, as well [16-18]. Geographic disparities in COPD hospitalization have also been described [19].

Health Literacy & Behaviors

Ongoing tobacco smoking is associated with higher symptom burden, and reduction in tobacco smoking have been correlated with reduced healthcare utilization [20,21]. Use of patient self-management programs and the Chronic Care Model have been shown to improve health status and decrease frequency of exacerbations and healthcare utilization for emergency visits [22,23]. Poorer health literacy is associated with higher rates of hospitalization in COPD patients [24]

Comorbidity

Patients with COPD frequently have multiple comorbid illnesses, and these correlate with exacerbation frequency, especially in the case of other comorbid respiratory diseases like asthma, obstructive sleep apnea, or pulmonary hypertension [25-28]. Anxiety and depression have previously been demonstrated as independent risk factors for hospitalization in COPD [29-32]. Cardiovascular comorbidity, including

congestive heart failure, were also associated with significantly higher rates of hospital readmissions following COPD exacerbations [33]. Anemia correlates with higher readmission risk in one study [34]. Presence of multiple comorbidities is associated with higher symptom burden and hospital utilization [35]. Comorbidity is also associated with higher rates of near-term mortality and hospital utilization [36,37].

Health System and Hospitalization Factors

Prior studies have associated index hospital length of stay with short term outcomes including ED usage and readmission rates [38,39]. Other factors associated with COPD healthcare utilization include inactivity [40], non-adherence [41], and polypharmacy [42]). Community-dwelling elderly comprise a large proportion of patients hospitalized for COPD. Informal caregivers, often family, neighbors, or friends, provide a significant amount of support to COPD patients [43]. Prior studies evaluated informal caregivers as an influence in COPD medication adherence [44], or as a potential intervention point for improving self-management[45], while others focus on the caregiver's perspectives and burdens [46]. Post discharge acute care utilization has been reported as higher in teaching hospitals in other conditions [47-49]. Prior study of all-diagnosis hospital readmissions has shown difference in readmission reasons based on time to readmission [50].

Overall, the milieu of factors associated with COPD hospitalization and readmissions is quite complex, and a number of potential intervention points are identifiable [51]. It is also worth noting that the causes of readmissions (e.g., readmission diagnoses) have been variably described in recent literature. Readmission penalties, further described below, are assigned for readmissions even when not clinically related to the cause of the index hospitalization. In one study, though, there was not a

substantial difference in the ways readmission penalties were estimated whether the readmission diagnosis was related to the index diagnosis [52] One prior study of Medicare patients also showed a minority of patients readmitted for COPD diagnosis [53]. A more recent study, using a subset of the same data that this study will use, found that a plurality of readmissions were for recurrent COPD, albeit this did not represent a majority of the cases [54].

Prior Readmission Reduction Efforts

Readmission reduction techniques have been studied with variable success. Many of these programs have focused on improving COPD care by improving medication adherence or focusing on disease control. A study of a patient self-management program did show reduction in healthcare utilization, while a meta-analysis of these programs showed significant heterogeneity in the types of programs with no clear signal toward which types reduced readmission rates [55,56]. Transitional care programs did reduce readmission rates in COPD [57,58]. Telehealth programs have been shown to have the ability to predict COPD exacerbations with some success [59]. However, telehealth monitoring interventions targeted at patients with history of COPD exacerbations did not have a significant effect on health related quality of life or reduction of hospitalization [60].

Early referral to pulmonary rehabilitation, which has been shown to increase quality of life and symptom management, also was not associated with decreased healthcare utilization [61]. Dispensing respiratory medications at the time of discharge was associated with higher rates of prescription fills and lower rates of 30- and 60-day hospital readmissions in another study [62]. Short-term oxygen therapy in the period after hospitalization, on the other hand, did not have a significant effect on health-related quality of life or acute care utilization [63]

Medicare's Hospital Readmission Reduction Program

As part of the Patient Protection and Affordable Care Act of 2010 (ACA), the Centers for Medicare and Medicaid Services (CMS) proposed and implemented the Hospital Readmission Reduction Program (HRRP), which penalizes excessive readmissions following hospitalization for certain conditions [64,65]. The program aims to reduce healthcare utilization while simultaneously improving care coordination and quality by penalizing excess readmissions financially.

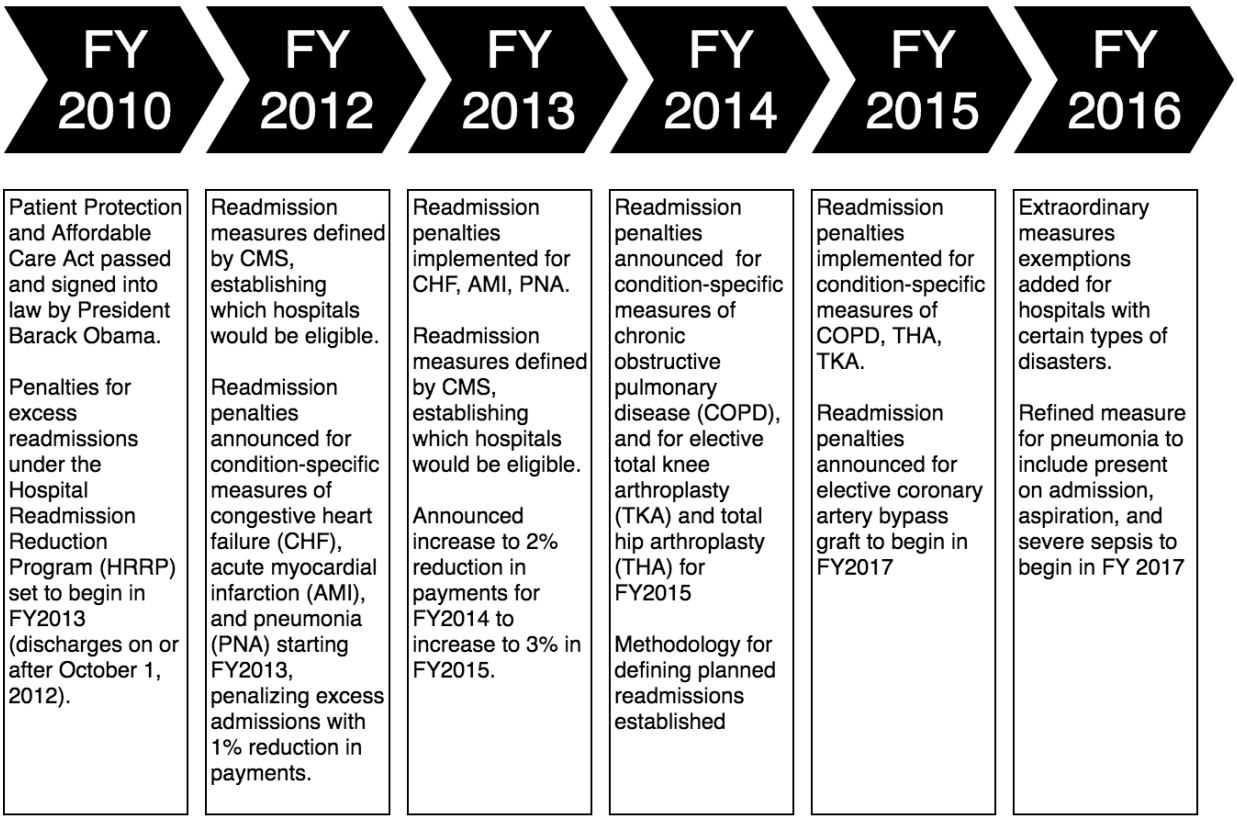

Figure 1: Timeline of announcement and implementation of the various phases of the Center for Medicare and Medicaid Services Hospital Readmission Reduction Program.

Fiscal years for Medicare run October 1 of the year prior until September 30 of the year indicated by the "FY20xx" label. Adapted from CMS HRRP documentation [64].

Key medical conditions of interest in the HRRP include congestive heart failure (CHF), pneumonia (PNA), acute myocardial infarction (AMI), which were announced in

May 2011, finalized in August 2011, and implemented effective October 1, 2012 [66,67]. It was also established that starting in Fiscal Year 2015 (October 1, 2014) additional conditions could be added for penalties, though they were not delineated at the time of the original passage of the ACA and were left open to public comment. In May 2013 COPD was announced as a possible additional condition of interest in a proposed rule, which was finalized in August 2013, and implemented starting for discharges on October 1, 2014 [68,69]. In addition, elective total knee arthroplasty and coronary artery bypass grafting are included as surgical conditions of interest, not pertinent to the proposed dissertation study. Timeline of implementation of the HRRP follows above in Figure 1.

Readmission penalties are not without controversy, and their continued analysis has shown that penalties may not be accomplishing their intended goals uniformly. In one study, hospitals that received the maximum HRRP penalties for excess readmissions were located in counties with higher rates of poverty and lower rates of education, raising the concern that hospitals in underserved communities may be bearing an unfair portion of penalties [70-74]. In another estimate, safety net hospitals were estimated to have nearly twice the HRRP penalties compared to non-safety net hospitals, although the penalties in this 2014 study were relatively small overall [75]. It has been suggested based on other research that adding socioeconomic data to readmission calculations may provide a more useful estimate for calculation of penalties, as well [76,77]. This being said, in the key conditions of AMI, PNA, and CHF, even safety net hospitals showed a decrease in readmission rates with the implementation of the HRRP [78].

Overall readmission rates do appear to have trended down since the inception and implementation of the HRRP [79].A study of COPD readmission rates from 2007-2012 in a sample from 8 states showed a modest decrement in readmission rates, though this was even before the implementation of the COPD penalties [80]. Another study found reduction of readmission in key HRRP conditions in Florida patients went down between 1-2% from 2008 to 2014, with Medicare fee-for-service, Medicare Advantage, and privately insured patients all having changes in readmission rates [81]. There do appear to be some spillover effects in other state-level analyses of the HRRP showing reductions in readmission rates in HRRP conditions even in non-Medicare patients [82]. However, the effect size in readmission reductions has been smaller in non-penalized hospitals than those with Medicare fee-for-service patients, and lower in non-target conditions than in HRRP target conditions in the non-penalized hospitals [83].

Chapter 2: Conceptual Model

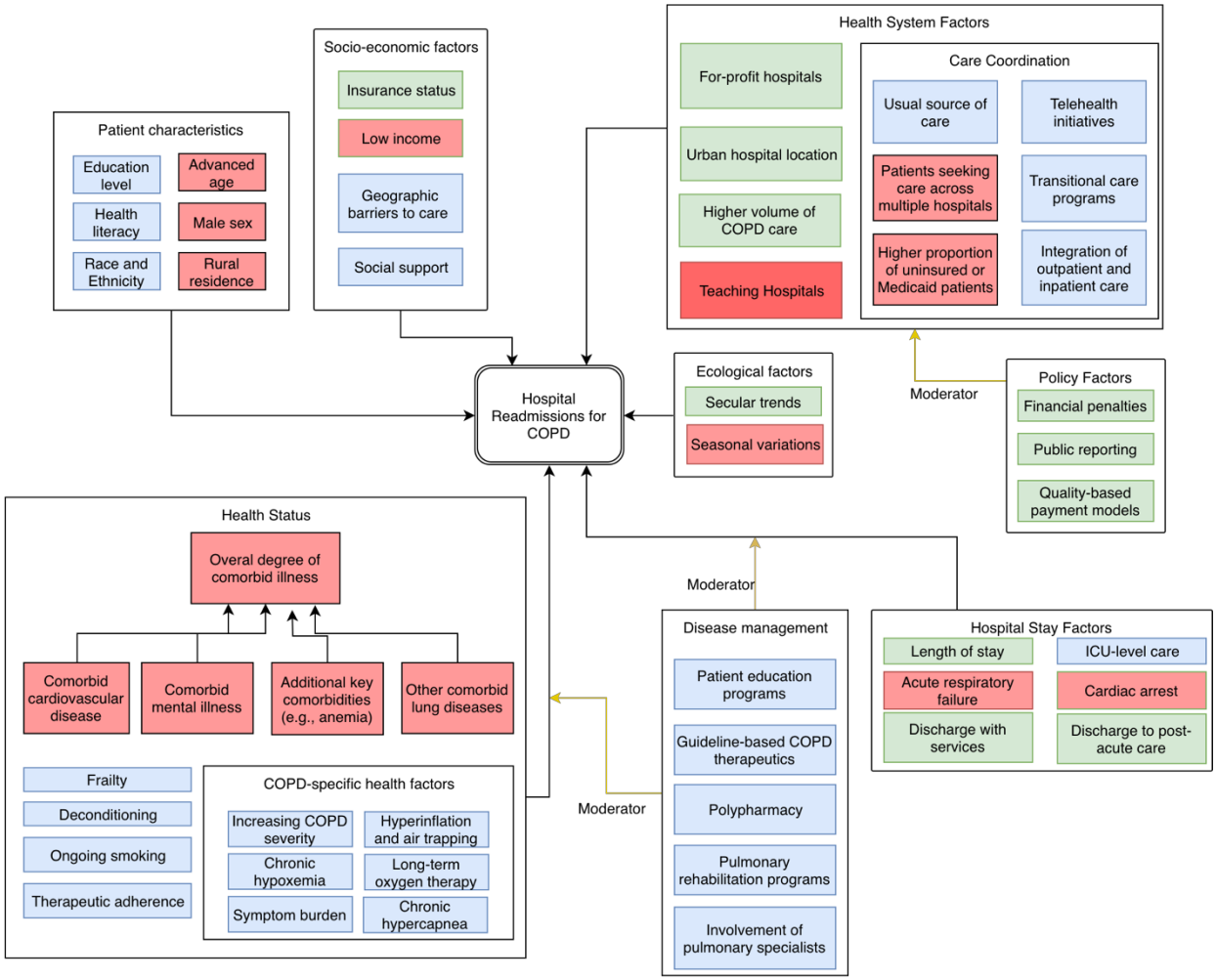

Figure 2: Conceptual model of readmissions

Boxes in green denote expected positive effect (reduction) in readmission rates, while boxes in red denote negative effect (increase) in readmission rates. Boxes in blue are expected to influence readmission but are unable to be measured from the available data in this study.

The conceptual model above summarizes our knowledge from the aforementioned published literature and explain the potential relationships of these factors to one another. The red boxes represent factors suggested in the literature that could increase COPD readmission rates, while the green boxes represent factors that

could decrease them. The blue boxes represent factors that we think would influence readmission rates but are unable to be operationalized into measurements with the available data for this study. The individual factors are binned into larger domains that we expect will influence healthcare utilization in COPD patients, vis-à-vis readmission rates. As described in the preceding introductory section, we know that intrinsic patient sociodemographic factors play a role in readmission risk and are largely immutable. Health system coordination activities are expected to reduce hospital readmissions. We cannot measure these directly but do know from previously published literature that certain hospital characteristics tend to be associated with lower utilization. We expect that policy factors, in this case, the Hospital Readmission Reduction Program, will have a significant influence on health system behaviors that will work to reduce hospital readmissions in an effort to protect their revenue. The limitations of this dataset do not provide the ability to analyze characteristics of care provision other than certain characteristics of an individual hospital stay (such as use of mechanical ventilation), but unfortunately do not provide information about referrals or treatment. Lastly, we expect that patient health status, driven largely by comorbidity, will heavily influence utilization patterns, and for the interest of this project, readmissions.

Our first analysis focuses on health status (lower left quadrant), operationalized by comorbidity indices. Our second analysis focuses more on factors that influence readmission for recurrent COPD versus other causes. Our third analysis focuses on the effect of policy levers, i.e., the HRRP, on readmission rates (top right quadrant). With the limitations of the data, we will not be able to model all of the variability contributing

to COPD readmission rates, but we will attempt to cover as much of these factors as can be readily modeled using the available administrative data.

Chapter 3: Data Source, Overarching Methods, Aims, and Hypotheses

The Nationwide Readmissions Database (NRD) consists of yearly cross-sectional samples abstracted from the State Inpatient Databases. This database fills a gap in currently available knowledge about rehospitalizations, as there has not previously been an all-payer, nationally representative sample from which to estimate hospital readmissions. The Agency for Healthcare Research and Quality (AHRQ) maintains this database, which is compiled from discharge data from the State Inpatient Databases of multiple states [84]. For the purposes of this analysis, the databases from 2010-2016 are being included, which represent all currently available data at the time of this dissertation. The information contained in this section is applicable to all of the subsequent sections and provides an overview of the methodology for handling the data for the overall dissertation project.

Database Construction

The NRD is aggregated from State Inpatient Databases, maintained by the AHRQ. Summary of the states included in each year and the raw and weighted counts for the NRD are found in Table 1. Individual observations in the dataset represent hospital discharge records, summarizing key administrative characteristics from an individual hospitalization. Within an observation, three identification numbers are coded: one for the hospitalization, one for the patient, and one for the hospital in which the admission took place. The patient linkage number is used to follow patients across

multiple hospitalizations within the database year, but are not unique across multiple years, which precludes following an individual patient across multiple years.

Table 1: Summary of included states and raw counts by year in the NRD

Year	States Included	Number of States	Number of Hospitals	Number of Discharges (unweighted)	Number of Discharges (weighted)
2010	AK, AR, CA, FL, GA, HI, LA, MA, MO, MS, NE, NM, NY, SC, TN, UT, VA, WA	18	1,809	13,907,610	37,184,093
2011	AK, AR, CA, FL, GA, HI, LA, MA, MO, MS, NE, NM, NY, SC, TN, UT, VA, WA	18	1,804	13,915,176	36,909,160
2012	AK, AR, CA, FL, GA, HI, LA, MA, MO, NE, NM, NY, SC, TN, UT, VA, VT, WA	18	1,715	13,459,216	36,465,049
2013	AR, CA, FL, GA, HI, IA, LA, MA, MO, NE, NM, NV, NY, SC, SD, TN, UT, VA, VT, WA, WI	21	2,006	14,325,172	35,580,348
2014	AR, CA, FL, GA, HI, IA, LA, MA, MD, MO, NE, NM, NV, NY, SC, SD, TN, UT, VA, VT, WA, WI	22	2,048	14,894,613	35,306,427
2015	AK, AR, CA, FL, GA, HI, IA, LA, MA, MD, MO, MS, NE, NM, NV, NY, OR, PA, SC, SD, TN, UT, VA, VT, WA, WI, WY	27	2,367	17,198,125	35,673,252
2016	AK, AR, CA, FL, GA, HI, IA, LA, MD, MA, MI, MS, MO, NE, NV, NM, NY, OR, PA, SC, SD, TN, UT, VT, WA, WI, WY	27	2,355	17,197,683	35,660,906
Included in all years:	AR, CA, FL, GA, HI, LA, MA, MO, NE, NM, NY, SC, TN, UT, VA, WA	16	**TOTAL**	**104,897,595**	**252,779,235**

Adapted from NRD documentation [85]

Measurements and Variable Definitions

Each year contains datasets that include patient demographic data, including age (with all subjects aged > 90 aggregated as "90"), sex, payer, and information about patient's city of residency, but do not include race or ethnicity. Variables included in the NRD and additional variables constructed for the analyses are identified in Table 2. Income is provided in quartiles, based on ZIP code of primary residence, rather than individual actual income. Regarding insurance status, only primary payer is reported, and it should be noted that dual-eligible patients (*i.e.,* Medicaid + Medicare) will be categorized as Medicare patients [86].

Administrative data about each given hospitalization includes date of admission (serialized, rather than in calendar dates), length of stay, year, month and quarter of admission, and discharge disposition, and whether patient was a resident of the same state as the hospital where she or he received care. Resident status is included, as linkage markers are only reliably valid within the same state, potentially underestimating readmissions that occur in multiple states, possible in particular in hospitals that are near state borders. Observations where transfers to other acute care hospitals occurred are collapsed with the discharging hospital's information reported. Discharge diagnoses and procedures are provided using ICD-9 codes for 2010 through 3rd quarter of 2015, and ICD-10 for 4th quarter of 2015 and all of 2016 [86].

Hospital characteristics include hospital ownership, number of beds, annual discharges, teaching status, and size of municipality where hospital is located. Notably, all those in the sample are short-term, acute care, community hospitals. Costs are provided with total filed charges and the hospitals' cost to charge ratio for estimates.

Sampling weights for each record are provided, which are calculated based on the patient and hospital characteristics relative to the overall sample in order to provide national estimates [86]. The separate, annual datasets were merged, with the indicator variable for year of study retained to allow for stratification analyses by individual year. Subjects are not identifiable across individual years, though they may be present in more than one year of the study in some cases.

In Table 2, we show an accounting of the measurements either provided by AHRQ in the database or constructed for the analyses in this dissertation study. Included are the description of the variable, its specifications, and the level of analysis that it represents. For continuous variables, transformations were explored using graphical laddering technique, where the distribution is plotted as a histogram and compared against a normal distribution curve, then transformed by various operations to visually determine which transformation provides the closest approximation of normality. In addition, categorical cut points into various quantiles of continuous variables were explored, with break points described in the variable explanation. In addition, we provide mapping of which specific aims are to be modeled with which individual variables. For all analyses, we are using variables as specified in the index discharge, as we are looking primarily at factors that predict various readmission outcomes. References for methodology for development of constructed variables, where appropriate, are included in footnotes to the table.

Table 2: Global list of measurements and variable construction to be used across each analysis

Variable	Specification	Type	Level	Description	Specific Aim
Observation identifier	Patient-stay ID	Observation level ID	Patient-stay	Within a given year, each individual hospitalization has a unique identifier	All
Patient identifier	Subject ID	Patient ID	Patient	Within a given year, an individual patient has a unique identifier allowing linkage between visits for readmission estimates and measures of utilization	All
Hospital identifier	Cluster ID	Clustering ID	Hospital cluster	ID variable for hospital. Since ID numbers are not traceable across years, the same hospital may be present in more than one year of the analysis but labeled as a new cluster.	All
Charlson Comorbidity Index Score	Primary Predictor	Continuous	Patient-stay	Summary score of Charlson Comorbidity Index at time of hospital discharge, tested as continuous and categorial (by quartile) score levels	1, 2
Elixhauser Comorbidity Index Score	Primary Predictor	Continuous	Patient stay	Summary score of Elixhauser Comorbidity Index at time of hospital discharge, tested as continuous and categorial (by quartile) score levels	1, 2
Individual comorbid conditions	Covariate	Indicator	Patient stay	Individual comorbidity flags from Elixhauser and Charlson scores retained for sub-analyses	1
Use of non-invasive ventilation	Covariate	Indicator	Patient stay	Use of non-invasive ventilation (CPAP or BPAP) during index hospitalization	1, 2
Use of mechanical ventilation	Covariate	Indicator	Patient stay	Intubation and/or use of mechanical ventilation during index hospitalization	1, 2

Variable	Specification	Type	Level	Description	Specific Aim
Placement or presence of tracheostomy	Covariate	Indicator	Patient stay	Placement of tracheostomy or presence of long-term tracheostomy during index hospitalization	1, 2
Occurrence of cardiac arrest	Covariate	Indicator	Patient stay	Occurrence of cardiac arrest during index hospitalization.	1, 2
Performance of resuscitation	Covariate	Indicator	Patient stay	Performance of cardiopulmonary resuscitation during index hospitalization	1, 2
Use of extra-corporeal life support	Covariate	Indicator	Patient stay	Use of extra-corporeal membrane oxygenation (ECMO) during index hospital stay	1, 2
Age	Covariate	Continuous	Patient stay	Age in years at the time of hospital discharge	All
Sex	Covariate	Categorical	Patient	Sex of patient	All
Patient residence location	Covariate	Categorical	Patient stay	Designation of patient residence at the county level by National Center for Health Statistics criteria, emphasizing urban distinctions and further dividing between central and fringe counties in major metropolitan areas, with smaller metropolitan areas divided by population size, and non-metropolitan areas divided into micropolitan and non-core (rural) categories	All

Variable	Specification	Type	Level	Description	Specific Aim
Patient income	Covariate	Categorical	Patient stay	Classification of the estimated median household income of residents in the patient's ZIP code, provided in quartile form by AHRQ in the database. This data is derived from demographic data from the Claritas database. Notably, values are coded as missing in this field if not available, or in instances with ZIP codes having populations below a minimum threshold, or if only one ZIP code within a quartile was present in a given state to protect confidentiality[1]	1, 2
Year	Fixed effect	Categorical	Patient stay	Calendar year of discharge from index hospitalization	All
Discharge Quarter	Fixed effect	Categorical	Patient stay	Quarter of discharge from index hospitalization	All
Discharge Month	Fixed effect	Categorical	Patient stay	Month of discharge from index hospitalization	All
Length of stay	Covariate	Continuous	Patient stay	Length of stay in whole days of index hospitalization	1, 2
Primary payer	Covariate	Categorical	Patient stay	Expected primary payer at time of discharge. Includes Medicare (includes managed and fee-for-service), Medicaid (includes managed and fee-for-service), private (includes HMO and PPO, commercial carriers), self-pay, no charge, and other categories (includes worker's compensation and other government programs)	All
Utilization estimate	Covariate	Continuous	Patient	Estimate of utilization status, defined as number of overall hospital stays for any cause over the course of a given year for a single patient	1, 2

Variable	Specification	Type	Level	Description	Specific Aim
Scatter of care	Covariate	Continuous	Patient	Estimate of care fragmentation, defined as number of hospitals in which patient sought care in the given year	1, 2
Discharge disposition	Covariate	Categorical	Patient stay	Disposition at time of discharge from index hospitalization. Includes routine discharges home without services, transfers to other short-term hospitals for further inpatient care, transfers to other health facilities (including skilled nursing, intermediate care, hospice, psychiatric hospitals, and long-term acute care hospitals), discharges home with home health services (including home hospice), transfer to law enforcement, or discharged alive but destination unknown. For this analysis, patients who left against medical advice or died during index hospitalization are excluded, in line with CMS HRRP policy. Will be broken down further into dummy variables for (a) home without services, (b) home with home health, (c) transfer for post-acute care services	All
Hospital ownership	Covariate	Categorical	Hospital cluster	Ownership or control of hospital, includes government/nonfederal (county or municipal, non-Veterans Affairs facilities), private/non-profit, or private/for-profit designations	All
Hospital bed size	Covariate	Categorical	Hospital cluster	Size of hospital by beds grouped into small/medium/large., The cutoffs for each category of which vary by region.[1]	All

Variable	Specification	Type	Level	Description	Specific Aim
Hospital teaching status	Covariate	Categorical	Hospital cluster	Teaching status of hospital, divided into metropolitan/non-teaching, metropolitan/non-teaching, or non-metropolitan (which are considered non-teaching in this database due to the very low frequency of rural teaching hospitals)	All
Hospital urban/rural designation	Covariate	Categorical	Hospital cluster	Designation of hospital location at the county level as provided by American Hospital Association files. Includes large metropolitan (≥1 million residents), small metropolitan (<1 million residents), micropolitan, and non-urban categories.	All
Hospital COPD discharge volume	Covariate	Continuous	Hospital cluster	Number of qualifying COPD index discharges in the analysis year	All
Proportion of Medicaid patient-days estimate	Covariate	Continuous	Hospital cluster	Proxy for safety net hospital status, defined as proportion of patient days in hospital with expected payer of Medicaid	All

[1] Per AHRQ NRD Database Documentation [84]

Index Hospitalization Inclusion and Exclusion Criteria

Eligible admissions include those where the patient was discharged alive and not against medical advice. In order to qualify as an index admission, there must not have been another admission for any cause in the prior thirty days (that is, a thirty-day washout period), consistent with CMS HRRP guidelines [64]. Because of inability to track readmissions beyond the end of a calendar year, December hospitalizations will not be counted as index admissions. Because of the inability to determine if January hospitalizations were actually readmissions from the prior December, and to ensure that the thirty-day washout period occurred, they will also be excluded as index admissions. It should be noted that a single patient may have multiple hospitalizations over the course of the year, and as long as thirty days has elapsed since the last discharge, a new stay may be regarded as a qualifying index admission pursuant to the CMS HRRP guidelines [64].

Because of a known issue in the database, there are small fraction (<1%) of observations with overlapping stays due to miscoding of transfers [86], and as such, transfers were excluded from the analysis. As noted above, since linkages are not traceable across states, those who were not a resident of the same state as the hospital where they were admitted may have been lost to follow up when returning to their home state and were excluded. This may have resulted in under-sampling of subjects who were residents of metropolitan areas on borders or who sought care in regional referral centers. In an AHRQ analysis using the 2011 Medicare Standard Analytic File to approximate the effect of limiting to within-state admission-readmission pairs did result in a 0.41 percentage point decrease in the rates for COPD [86].

Inclusion discharge diagnosis codes for COPD are found in Table 44-Table 45. In addition, diagnostic codes for the other CMS HRRP eligible conditions (pneumonia, Table 46-Table 47, myocardial infarction, Table 48-Table 49, and congestive heart failure, Table 50-Table 51) are also found in Appendix B [87,88]. Indicator variables for HRPP-eligible stays were added to each observation as part of the data cleaning and coding process. Counts were tabulated at the hospital level for these diagnoses of interest, and any hospital with fewer than 25 annual eligible condition-specific cases will be excluded from the analysis, keeping in line with the HRRP methodology [87,88]. A summary of the overall inclusion and exclusion schema follows in Table 3, which are adapted from the CMS HRRP program documentation and the Yale New Haven HRRP Methodology Reports [64,87,88].

Table 3: Criteria for inclusion and exclusion as an index COPD hospitalization

Inclusion Criteria	Rationale
Discharge from hospital for acute exacerbation of COPD as principal discharge diagnosis	Coding algorithm designed as specified in Published HRRP methodology[1] (see Appendix B, Table 44 & Table 45 for diagnostic codes)
Discharge from hospital for acute respiratory failure as principal discharge diagnosis with COPD as secondary diagnosis	Coding algorithm designed as specified in Published HRRP methodology[1] (see Appendix B, Table 44 & Table 45 for diagnostic codes)

Exclusion Criteria	Rationale
Discharges in January	Unable to determine if stay is a readmission from previous December due to multiple cross-sectional rather than longitudinal database[2]
Discharges in December	Unable to follow for readmission into following January across calendar years due to multiple cross-sectional rather than longitudinal database[2]
Discharge within 30 days of a previous admission for any cause	Published HRRP methodology[1] includes a wash out period of 30 days before another hospitalization qualifies as an index stay
Discharges against medical advice	Published HRRP methodology[1] excludes these cases as care coordination limited by patient leaving
Death in index hospital stay	Unable to be readmitted if died during first admission[1]
Discharge from hospital with fewer than 25 COPD index admissions in a given year	Published HRRP methodology[1] excludes these cases for lack of volume of condition of interest
Discharge from hospital in state other than that of patient residency	Construction of database limits ability to follow patient across state lines due to non-unique identifiers[2]
Transfer to other facility same day as admission	Inconsistencies of coding transfers[2] complicated the analysis, with small number, judgment call made to drop these stays to simplify coding

[1] HRRP methodology reports [87,88]
[2] AHRQ NRD Database Documentation [86]

Readmission Specifications

Thirty-day readmissions were coded by determining the elapsed time from the index hospital discharge (determined by adding length of stay to date of admission). All cause readmissions within 30 days of the index discharge will be counted, except as for reasons excluded in the CMS HRRP policy measure documentation, with exceptions made for returns to hospital for specified diagnosis and procedure codes [87,88]. For subjects admitted for a procedure or diagnostic reason considered a planned admission, the readmission does not qualify for this analysis and was not counted. If the subject is admitted for a procedure or diagnostic reason that is considered potentially planned, and the principal diagnosis at discharge is not an acute condition or complication of prior care, the readmission does not qualify for this analysis and was not counted. A schematic of the previously published CMS HRRP methodology for excluding planned readmissions follows below in Figure 3.

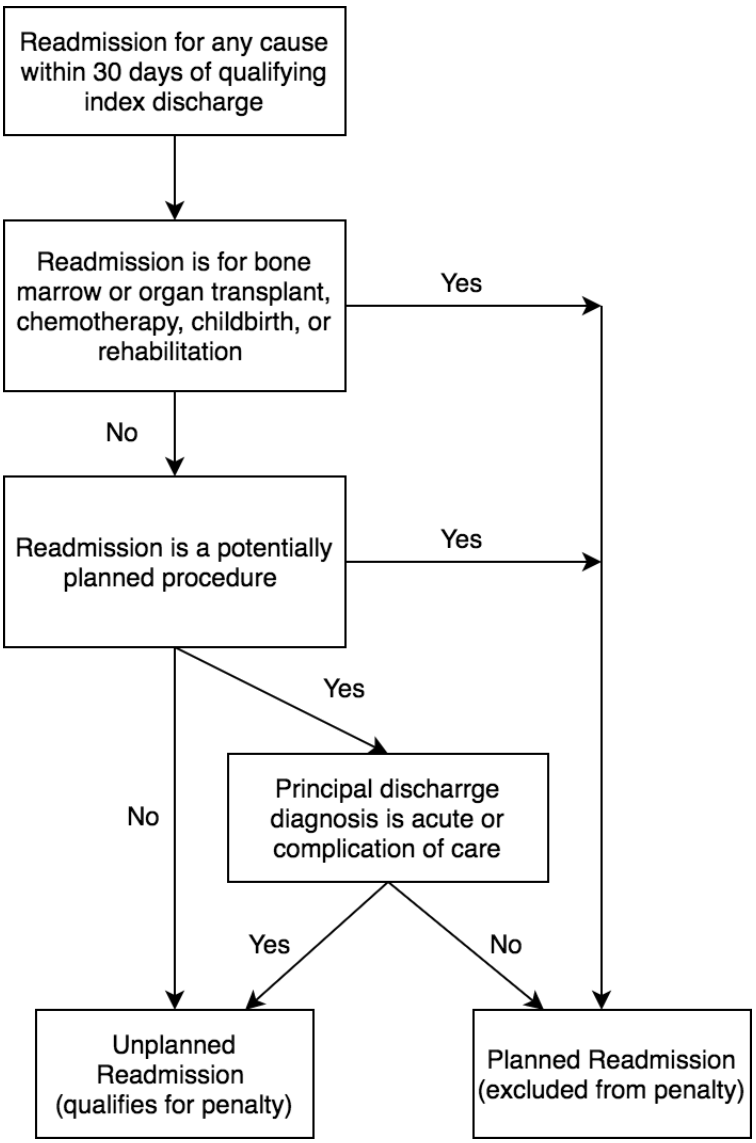

Figure 3: Published HRRP schema for excluding planned readmissions from the analysis

The AHRQ Clinical Classification System (CCS), ICD-9, and ICD-10 codes for these criteria are found in Appendix B. Criteria for stays coded as "always planned" are found in Table 52. Criteria for stays coded as "potentially planned" are found in Table 53, Table 54, Table 55, and Table 56. Acute conditions or complications of care that negate the exclusion of a "potentially planned" stay are found in Table 57, Table 58, Table 59, and Table 60. Figure adapted from HRRP Methodology Reports [87,88].

Summary of Study Population

Table 4 shows the raw counts of the data for analysis in this study, as tabulated for this study from the inclusion and exclusion criteria described above. The data is described by year and summarized in the final column. The first block displays all the hospitalizations in the given year. The next section shows the number of unique hospitals found in that given year. Because hospital identification numbers are not unique across the dataset, *i.e.,* they cannot be used to follow the same hospital across multiple years, it is not possible to estimate the total number of unique hospitals in the sample, as certain hospitals may be included in multiple years with more than one identification number. Below this are the number of hospitals that had a volume of at least 25 qualifying index stays and following that are the total number of qualifying index stays that occurred in hospitals with at least 25 qualifying index stays (all cause, then the HRRP conditions of interest). For the primary analyses in Chapters 4 and 5, only the COPD cases are pertinent, but the values for the other conditions and all-cause admissions are included, as they are going to be used in Chapter 6 for trend analyses. Finally, the last section of the table demonstrates the number of readmissions and readmission rates for the same conditions.

Table 4: Unweighted summary counts of NRD data by HRRP inclusion criteria

	2010	2011	2012	2013	2014	2015	2016	Total
Total Admissions in Dataset								
	13,907,610	13,915,176	13,459,216	14,325,172	14,894,613	17,198,125	17,197,683	104,897,595
Total Hospitals in Dataset								
	1,809	1,803	1,715	2,004	2,048	2,367	2,355	§
Hospitals with ≥ 25 eligible discharges, N (%)								
All	1,790 (98.9%)	1,783 (98.8%)	1,694 (98.8%)	1,981 (98.9%)	2,015 (98.4%)	2,324 (98.1%)	2,318 (98.4%)	§
COPD	1,412 (78.1%)	1,398 (77.5%)	1,320 (77.0%)	1,433 (71.5%)	1,470 (71.8%)	1,732 (72.5)	1,699 (72.1%)	§
PNA	1,583 (87.5%)	1,562 (86.6%)	1,474 (85.9%)	1,645 (82.1%)	1,678 (82.0%)	1,954 (82.6%)	1,875 (79.6%)	§
AMI	831 (45.9%)	819 (45.4%)	824 (48.0%)	903 (45.1%)	933 (45.6%)	1,076 (45.5%)	1,085 (46.1%)	§
CHF	1,339 (74.0%)	1,299 (72.0%)	1,236 (72.1%)	1,359 (67.8%)	1,391 (68.0%)	1,626 (69.0%)	1,608 (68.2%)	§
Eligible Index Admits, N (% of index)								
All	9,035,186	9,033,704	8,773,832	9,339,602	9,676,906	11,122,887	11,151,268	68,133,385
COPD	226,123 (2.58%)	229,323 (2.62%)	218,973 (2.57%)	231,045 (2.57%)	230,294 (2.47%)	277,343 (2.58%)	270,549 (2.51%)	1,683,650 (2.56%)
PNA	313,616 (3.5%)	322,928 (3.61%)	306,302 (3.53%)	333,020 (3.61%)	335,856 (3.51%)	392,299 (3.57%)	299,225 (2.72%)	2,303,246 (3.42%)
AMI	129,321 (1.71%)	129,678 (1.71%)	132,222 (1.77%)	145,467 (1.84%)	151,799 (1.84%)	185,269 (1.95%)	193,595 (2.01%)	1,067,351 (1.84%)
CHF	225,567 (2.58%)	218,430 (2.51%)	208,347 (2.46%)	229,504 (2.55%)	245,808 (2.64%)	301,408 (2.81%)	305,681 (2.84%)	1,734,745 (2.64%)
Readmissions, N (Rate %)								
All	878,770 (9.73%)	881,452 (9.76%)	846,465 (9.65%)	879,051 (9.41%)	911,884 (9.42%)	1,043,020 (9.38%)	1,058,707 (9.49%)	6,499,349 (9.54%)
COPD	40,071 (17.72%)	40,756 (17.77%)	38,256 (17.47%)	39,486 (17.09%)	39,158 (17.00%)	46,750 (16.86%)	45,942 (16.98%)	290,914 (17.24%)
PNA	44,060 (14.05%)	45,111 (13.97%)	42,615 (13.91%)	45,042 (13.53%)	45,607 (13.58%)	51,608 (13.16%)	39,781 (13.29%)	313,824 (13.63%)
AMI	16,745 (12.95%)	16,610 (12.81%)	16,270 (12.31%)	17,261 (11.87%)	17,471 (11.51%)	21,542 (11.63%)	21,712 (11.22%)	127,611 (11.96%)
CHF	45,822 (20.31%)	44,038 (20.16%)	40,980 (19.67%)	43,953 (19.15%)	46,678 (18.99%)	56,800 (18.84%)	57,701 (18.88%)	335,972 (19.37%)

§ Hospital identifiers are not consistent across each year, therefore unable to estimate overall sample total

Human Subjects and Data Protection

The study protocol was reviewed by the institutional review board of the University of California, Los Angeles and an exemption granted (UCLA IRB #18-001208). Data are supplied already de-identified by the Agency for Healthcare Research and Quality with no linkage to protected health information.

Specific Aims and Hypotheses

The dissertation is broken down into three main research questions, which represent the following three chapters. The primary purpose of Chapter 4 is to relate patient- and hospital-related factors to readmission odds, with the primary factor of interest being comorbid illness.

Aim 1.1 Model readmission risk using comorbidity indices as a primary predictor, adjusted for patient and hospital factors

Elixhauser and Charlson indices have not been incorporated into readmission prediction tools for COPD. We will fit two separate models, one for each index, and compare the goodness of fit and performance characteristics of the two models.

Hypothesis 1.1: Patients with higher degrees of comorbidity, as defined by increase in composite Charlson or Elixhauser Comorbidity indices, will have higher readmission odds, adjusted for patient and hospital level covariates

Hypothesis 1.2: Seasonal variability in COPD admissions will be present, and readmission rates will be higher during those periods of the year, as well.

Hypothesis 1.3: Urban teaching hospitals are expected to have higher readmission rates than non-teaching hospitals.

Hypothesis 1.4: Readmissions rates will be lower in for-profit hospitals than non-profit or government-run hospitals.

Hypothesis 1.5: Patients without insurance will have higher readmission rates than those with any insurance.

Hypothesis 1.6: Patients with Medicaid insurance will have higher readmission rates than those with Medicare or private insurance.

Hypothesis 1.7: Patients who reside in communities with lower incomes will have higher readmission rates.

The primary purpose of Chapter 5 is to describe the diagnoses at the time of readmissions to determine the specific influence that particular comorbid conditions may have on influencing readmission odds, both for a recurrent COPD diagnosis and for other causes.

Aim 2.1: Determine the diagnoses for which patients are readmitted after index COPD readmission

Hypothesis 2.1: The principal attributable cause at the time of readmission following COPD exacerbations are not for recurrent COPD exacerbations, as defined by the HRRP criteria outlined in the introduction.

Hypothesis 2.2: Differences in comorbidity, both in aggregate and by individual categorical measurements will be observed between those readmitted for non-COPD-related and COPD-related causes.

Aim 2.2: Determine the factors that influence the diagnoses for which patients return

Hypothesis 2.2: A difference in time from index discharge to readmission will be observed between non-COPD-related and COPD-related causes

Hypothesis 2.3: Shorter index lengths of stay will portend higher likelihood of readmission for the same diagnosis.

The final analysis in Chapter 6 will evaluate the trend of readmissions since implementation of the penalties, in particular for COPD, using the conditions of congestive heart failure, pneumonia, and acute myocardial infarction to establish secular trends.

Aim 3.1: Describe the effect of announcement and implementation of the penalty for COPD readmission on readmission rates for COPD.

Hypothesis 3.1: COPD readmission rates will drop following the announcement and subsequent implementation of COPD as an HRRP condition.

Hypothesis 3.2: Patients admitted to hospitals with higher proportions of Medicare patients will have larger drop in readmission rates than those with lower proportions of Medicare patients

Hypothesis 3.3: Patients admitted to for-profit hospitals will have a larger drop in readmission rates than non-profit or government-run hospitals

Hypothesis 3.4: Patients admitted to teaching hospitals, which more often have exemptions from the Acute Inpatient Prospective Payment scheme under which the HRRP falls, will have smaller drops in readmission rates compared to non-teaching hospitals.

Together, the first two analyses seek to improve the current state of knowledge surrounding the factors that may influence utilization of healthcare resources via hospital readmissions in COPD patients. The third analysis seeks to further our understanding of the effect the policy change of adding COPD as a condition penalized under the HRRP, both on the target population of Medicare beneficiaries, and the spillover effect to other insured populations. These will inform policymakers on ways to fine tune the HRRP to accomplish its stated objectives to improve quality and reduce cost of care and inform health systems on strategies for readmission reduction efforts.

Chapter 4: Comorbidity and thirty-day hospital readmission odds in chronic obstructive pulmonary disease: a comparison of the Charlson and Elixhauser Comorbidity Indices

Abstract

Background

Readmissions following exacerbations of chronic obstructive pulmonary disease (COPD) are prevalent and costly. Multimorbidity is common in COPD and understanding how comorbidity influences readmission risk will enable health systems to manage these complex patients.

Objectives

We compared two commonly used comorbidity indices, published by Charlson and Elixhauser, regarding their ability to estimate readmission odds in COPD to determine which one provided a superior model.

Data Source

We analyzed discharge records for COPD from the Nationwide Readmissions Database spanning 2010 to 2016. Inclusion and readmission criteria from the Hospital Readmissions Reduction Program were utilized.

Methods

Elixhauser and Charlson Comorbidity Index scores were calculated from published methodology. A multilevel logistic regression model with random intercepts for hospital clusters was fit for each comorbidity index, including year, patient-level, and hospital-level covariates to estimate odds of thirty-day readmissions. Sensitivity analyses included testing age inclusion thresholds and model stability across time.

Results

In analysis of 1.6 million COPD discharges, readmission odds increased by 9% for each half standard deviation (~1.5 points) increase of Charlson Index scores and 13% per half standard deviation (~7.5 points) increase of Elixhauser Index scores. Model fit was slightly better for the Elixhauser Index using information criteria. Model parameters were stable in our sensitivity analyses.

Conclusions.

Both comorbidity indices provide meaningful information in predicting readmission odds for COPD with slightly better model fit in the Elixhauser model. Incorporation of comorbidity information into risk prediction models and hospital discharge planning may be informative to mitigate readmissions.

Introduction

The global burden of chronic obstructive pulmonary disease (COPD) continues to rise [89,90], and in the United States, COPD remains the 4th leading cause of death as of 2017 [91]. Exacerbations are common, and economic burden from related hospitalization and are substantial [2,5]. In October 2014, the Centers for Medicare and Medicaid Services (CMS) Hospital Readmissions Reduction Program (HRRP) began assessing financial penalties to hospitals with excessive 30-day hospital readmissions of Medicare patients following hospitalizations for exacerbations of COPD [64]. Readmission risk reduction programs have shown variable success in decreasing unplanned rehospitalizations [5,92]. Efforts to understand readmission risk and how to reduce it are ongoing and are of high importance to health systems.

COPD patients have a high burden of various comorbid conditions [29,35,93-96]. Presence of multiple comorbidities is associated with higher symptom burden, mortality, and hospital utilization [36,37,97,98]. COPD patients often meet the threshold of the "multimorbid" patient, having at least 2 chronic conditions that may affect the way they experience their disease process and drive up their utilization of healthcare [99]. Risk adjustment methods are undertaken in the HRRP, accounting for advancing age and key comorbid conditions, but not socioeconomic or demographic factors [87,88]. The performance of risk adjustment measures in the HRRP remain debated [100], in particular whether risk adjustments adequately control for factors outside the control of a treating hospital. However, among Medicare patients, accounting for socioeconomic status is not consistently associated with readmission risk [76,101]. Race and ethnicity are implicated for risk [102], though this appears to be mediated by clinical severity [103].

Accurate quantification of the impact of comorbidity is critically important for any program that uses a financial penalty to reduce readmissions at the hospital level. Two aggregate comorbidity indices are frequently used in research methodology and could potentially adjust for between-hospital differences in burden of chronic illness. The Charlson Comorbidity Index (CCI) was originally developed to predict mortality in hospitalized patients [104-106]. Higher CCI scores correlated with mortality, risk of readmission, and lower likelihood to receive appropriate COPD treatments [107]. The Elixhauser Comorbidity Index (ECI) was designed as an inventory of comorbidities [108], and was later updated with condition weights to predict in-hospital mortality [109,110], and readmission [111]. Both indices have been updated for use with ICD-10 in administrative data [112,113]. The two indices have some overlap in their domains, though the coding schema for the domains differ.

Previous study has shown these two indices to have differential ability to discriminate between important outcomes within the COPD population [114]. Gaining a better understanding of milieu comorbidities in the COPD population will better inform methodology to appropriately adjust for readmission risks. Delineating comorbidity also will providers and delivery networks to better predict readmission risk and plan readmission reduction efforts. To this end, the goal of this analysis is to compare these two indices with respect to their ability to identify comorbidities and how their composite scores contribute to the risk of readmission outcomes among COPD patients.

Methods

Data Source

We analyzed discharge records from January 2010 to December 2016 in a pooled, multiple cross-sectional analysis the Nationwide Readmissions Database (NRD) [84]. The NRD contains a nationally representative sample of all-payer discharges from acute care hospitals across multiple states and regions. The NRD does not allow for an individual patient to be linked across years, and as such, qualifying index discharges were restricted to stays occurring in February through November, as we could not have identified whether January stays were actually readmissions from the prior December, and could not follow December index stays into the next January. We restricted to patients who were residents of the same state in which they were admitted to reduce the risk of loss to follow up when crossing state lines [86]. Sample weights provided with the dataset were applied to calculate national estimates in order to compensate for under-sampled patient and hospital characteristics [86]. In the analyses that follow, raw numbers indicate the actual observations, while reported percentages and models utilize the sample weights to provide a population estimate.

Variable Construction

An index hospitalization is defined by discharge alive from an acute care hospital, excluding discharges against medical advice, occurring at least 30 days since another hospitalization. A COPD exacerbation is defined by principal diagnosis of COPD exacerbation or principal diagnosis of respiratory failure and secondary diagnosis of COPD [87,88], excluding cases involving lung transplants. We included index discharges from the NRD from 2010 through 2016 for patients aged ≥40 years with a qualifying

COPD diagnosis admitted to a hospital with at least 25 such discharges over the 10 months of each year included in our analysis. A readmission is return to any hospital for any diagnosis within 30 days of discharge, with the exception of certain key conditions granted exemption from penalization. These definitions were constructed to be aligned with the published HRRP methodology [87,88].

Most variables of interest were included in the original dataset; however, we derived several important to the analysis. The Charlson and Elixhauser comorbidity index scores were calculated using ICD codes and Diagnosis Related Groups, using adaptations of published macros[115,116] to recode the diagnoses into each respective index's categories and calculate weighted scores [111,112,117]. We used the discharge diagnoses reported at the time of the index discharge without a look-back period to prior admissions due to the limitations of the dataset to identify patients only within each individual year.

Patient level variables included sociodemographics, payer, geographic location, and discharge disposition. Income estimates provided with the NRD were constructed by taking the median income at ZIP code center for the patient's address [86]. We constructed indicators for key in-hospital events (*e.g.,* use of mechanical ventilation) using ICD codes. Hospital level variables included location, ownership, teaching status, and size. We estimated the proportion of within-hospital Medicaid patient-days by taking the number of patient-days paid by Medicaid divided by total patient-days each year. We tabulated the number of hospitals visited and number of total admissions per patient within a given year to estimate overall utilization. Hospital volume for all-cause and COPD-specific discharges were also tabulated for each year. Additional details on

database structure variable definitions organization can be found in the supplementary methods (Chapter 3).

Statistical Analysis

Summary statistics were calculated at the patient level, comparing readmitted and non-readmitted COPD patients. Continuous variables were compared between groups using Welch's t-test (*i.e.*, unequal variance), while categorical variables were compared using Chi-squared tests. Overall readmission rates were aggregated for population estimates by year, month, and quarter. Readmission rates for sub-strata of interest for hospital characteristics were calculated, with differences in these rates across categories estimated by Chi-squared tests. Adjusted readmission odds were estimated using a two-level, mixed-effects logistic regression model with random intercepts assigned at the hospital cluster level using complete case analysis.

Separate models were fitted using the Charlson or the Elixhauser indices as primary predictor, with fixed effects for year, patient- and hospital-level covariates consistent across both models. The models were first fitted with only the comorbidity index (candidate Model 1), then patient (Model 2) and hospital (Model 3) covariates were added, with the process repeated for each index. Comparison of the two models was made using Akaike and Bayesian information criteria, where lower values of the information criterion signify better fit [118,119]. A threshold of 10% missingness for variables of interest was set *a priori* to determine the necessity for use of imputation techniques, which was not reached for any variable included in this analysis.

Sensitivity Analysis

We tested the stability of our estimates over time by refitting the model for individual years and comparing to the pooled cohort. We also compared the effect expanding our age criteria to adults aged ≥ 18 years, having initially favored an older age cutoff given the paucity of COPD in younger patients and concern that these observations may have represented miscoding. We also attempted to fit a three-level model with discharges nested in patients nested in years, to account for repeated measures of the same patient within a year. All analyses were performed in Stata Version 15.1 (StataCorp, College Station, TX) with weighted estimates reported using patient level survey weights for national representativeness. The study was reviewed and determined to be exempt from oversight based on its use of deidentified, publicly-available data by the University of California, Los Angeles Institutional Review Board (IRB# 18-001208).

Results

A total of 1,622,983 index admissions (weighted effective population N = 3,743,164) for COPD occurred during the seven-year study period, 17.2% of which were readmitted within 30 days of discharge. Patient characteristics are found in Table 5. There were more women (58.9%) than men in the population, with proportionally fewer readmissions among women than men. Readmitted patients were older (68.7 vs 67.9 years). Those living in ZIP codes with the lowest and highest income quartiles had proportionally more readmissions than the middle quartiles. Medicare and Medicaid patients had higher proportions of readmissions than private insurance or self-pay status. Readmitted patients were less often discharged to home routinely, with higher

proportions of discharge to post-acute care or with home health services. The readmitted patients also had longer lengths of stay (4.16 vs 3.67 days) with more intense care patterns, including non-invasive and mechanical ventilation, need for tracheostomy placement, cardiac arrest, and resuscitation efforts.

Hospital characteristics and aggregated sub-cohort readmission rates by hospital type are found in Table 6. In keeping with previously described findings [120], teaching hospitals had higher aggregate readmission rates (17.7%) across this study than non-teaching hospitals. For-profit hospitals had a higher aggregate readmission rate (17.5%) when compared to governmental (16.8%) and non-profit (17.3%) facilities. Hospital all-cause discharge volume correlated with higher readmission rates, and hospitals with the highest volume quartile of qualifying COPD stays had the highest readmission rates (18.0%). Hospitals with higher proportions of Medicaid patients also had higher raw readmission rates. In the highest quartile, where at least 23.9% of patient-days were paid by Medicaid, the readmission rate was 17.7%. There was significant temporal variation in readmission rates both within individual years and across the entire study period, as shown in Figure 4. Aggregated within-year trends showed higher readmission rates in the first and third quarters (panel A) and an uptick was observed in July and August (panel B). Across the entire study period, quite a bit of variability was observed across time, with an overall trend toward decreasing readmission rates over the seven years of data (panels C and D).

Distribution of comorbid conditions are shown in Table 7 (CCI) and Table 8 (ECI). Readmitted patients had significantly higher mean CCI (2.41 vs. 2.10) and ECI (20.5 vs. 16.3) scores. The distribution of the composite Charlson and Elixhauser scores are

shown in Figure 5. In the Charlson, the readmitted patients show a higher proportion of Charlson scores 3 or greater compared to the non-readmitted. Similarly, the Elixhauser is distributed such that the readmitted show a greater proportion of scores greater than 22 compared to the non-readmitted group. Comorbid conditions were significantly higher in readmitted patients across all observed Charlson domains, with the exception of connective tissue diseases, though these differences were often slight (i.e. within 1-2%). The most pronounced differences were for congestive heart failure (34.8% of readmitted versus 26.1% of non-readmitted) and advanced diabetes (18.1% vs. 13.1%). In the Elixhauser conditions, readmitted patients had a higher proportion of all comorbid conditions with the exception of hypertension. Using the Elixhauser methodology, there was a much higher proportion of congestive heart failure (34% in readmitted versus 25.4% in non-readmitted patients), renal failure (17.2% vs. 12.3%), and iron deficiency anemias (19.9% vs. 14.4%), with significant but smaller differences among those with diabetes and cardiovascular diseases. Average comorbidity scores within hospitals were plotted over time, with the mean scores for both indices increasing over the study period (Figure 6).

Multi-level logistic regression models were fitted separately for the Charlson Index and the Elixhauser Index and compared Table 9. In order to standardize comparisons between the two models as much as possible, the comorbidity indices were re-scaled by their distributions, such that an odds ratio was calculated for a change of one-half standard deviation instead of individual units. Using this scaling in the fully adjusted models, a 1/2 SD change in the Charlson score (~1.5 points) was associated with a 9% increase in readmission odds while a 1/2 SD change in the

Elixhauser score (~7.5 points) portended a 13% increase in readmission odds. The unadjusted (Model 1), patient-adjusted (Model 2), and patient- and hospital-adjusted (Model 3) estimates in their original scaling are found in Table 12 (CCI) and Table 13 (ECI).

A temporal trend was observed, with readmission odds decreasing for each year of the study in the adjusted models. Women had lower odds than men and readmission odds decreased with increases in age when adjusted for other factors. In both models, Medicaid patients had higher readmission odds and the privately insured had lower odds compared to Medicare. Compared to routine discharges home, those with transfers to post-acute care and home with home health services had significantly higher readmission odds. Each day increase in length of stay portended slightly higher readmission odds. Smaller but significant effects were observed for hospital location, while hospital teaching status, volume of discharges, and proportion of Medicaid patient-days were not significant.

The effect sizes for covariates were similar for both comorbidity models. To compare the fit of the two models, we employed the Akaike (AIC) and Bayesian (BIC) information criteria, which deal with the balance between goodness-of-fit and parsimony of any given model. In our analysis, the Elixhauser model had a lower AIC (3,355,795 vs. 3,366,918) and BIC (3,356,300 vs, 3,367,434) than the Charlson, demonstrating slightly better fit.

In the sensitivity analyses, we found that the odds ratios for the comorbidity indices, our primary variables of interest, did not vary significantly across time, with stable estimates in the naïve, patient-adjusted, and fully-adjusted models (Table 10 and

Figure 7). The three-level model to estimate an additional random intercept for repeated patient visits within a year did not converge and was not used. When we evaluated whether our original age restriction to patients ≥ 40 years old had any significant influence on the models, we found that there was no substantial change in our estimates when using a more liberal age cutoff of ≥ 18 years old (Table 15 for CCI and Table 16 for ECI).

We also evaluated whether the presence of the comorbidity index substantially changed the estimates of the covariates by fitting an additional set of models without the respective comorbidity indices (Table 14). This showed small changes in the effect size, but there were no sign changes and the confidence intervals overlapped in the reduced and original models, with a substantial improvement in log likelihood with the addition of the comorbidity indices (Table 11). Of notable difference, the effects of discharge disposition and care intensity diminished, likely demonstrating some collinearity between these factors and degree of comorbidity.

Discussion

In this large, all-payer, population study of 30-day rehospitalizations following admission or a COPD exacerbation, we examined the relative contributions of comorbidity and key patient and hospital factors to the risk for rehospitalization. In this population, escalating degrees of comorbidity was associated with significantly higher odds of 30-day readmission even after controlling for other key patient and hospital factors in both the Charlson and Elixhauser models. This is in line with previously published work in the Veterans Affairs population showing that higher Charlson scores were associated with higher risk of readmissions [107], and a new finding for use of the

Elixhauser model in COPD. While the comparison of comorbidity indices has been previously published with regard to predicting COPD exacerbations and hospitalizations [114], our findings showing the comparison of two widely-used candidate comorbidity indices to predict readmissions is also a new approach. In this comparison, the Elixhauser Comorbidity Index performed slightly better, with the inclusion of more parameters providing a better model fit. We speculate that one of the primary reasons why this occurs is directly related to the ability of the indices to capture heterogeneity among the patients. Specifically, the Charlson index is comprised of 17 commodities while the Elixhauser is comprised of 29. With a greater number of possible values for the index to take, the Elixhauser would naturally show better discrimination and explain greater variability in the odds of readmission compared to the Charlson.

While previous studies of Medicare patients for other HRRP conditions have not shown socioeconomic status to be consistently correlated with readmission outcomes [76,101], our study did show that patients who lived in higher income neighborhoods had progressively lower adjusted readmission odds. Furthermore, while other studies in these populations have raised concern about higher readmission burdens in hospitals serving lower-income patients [13,70,121,122], our study did not show a significant correlation between adjusted readmission odds and proportion of Medicaid days. Our methodology did not allow for exact approximation of Disproportionate Share Hospital estimates due to lack of information on supplemental security income [123], and using Medicaid as a proxy may underrepresent the burdens on safety-net hospitals. These findings may be at odds with the arguments for additional adjustments for socioeconomic factors, but

given the proxies used to measure income status in this study, it is difficult to draw a definitive conclusion from these data.

In sensitivity analyses, we found that including comorbidity scores improved upon models compared to ones simply using patient demographic and hospital characteristics. This is unsurprising, given the rich detail that comorbidity information adds. The fact that comorbidity scores increased with time may reflect coding practice changes, as health systems may attempt to use the inclusion of additional comorbid conditions in their discharge diagnoses to increase the severity reflected in coding schema for Diagnosis Related Grouping [124], or to mitigate readmission penalties by shoring up risk categorization. Regardless, our estimates for readmission odds were stable across time despite the decreases in readmission rates and the increases in coded comorbidity.

Limitations

Inconsistent coding of comorbid conditions at the time of hospital discharge may hinder our ability to truly model the breadth of comorbidity in our study. Additionally, lack of granular, clinical data limits our ability to understand practice patterns and the true severity of disease. However, most granular clinical datasets are limited to an isolated payer or integrated delivery system, and generalizability outside of the population whose data was used becomes more challenging. We were also limited by the structure of the database, using pooled cross-sectional data instead of a true longitudinal sample, further limited by the database's inability to identify the same patient or hospital across years. As such, there were likely some cases where a patient was measured more than once but not identified as such. While some degree of auto-correlation is possible from

our approach, the large sample size was felt to adequately compensate for this. The same is true of repeated visits from the same patient within a year introducing additional correlation between readmissions resulting in potentially overly narrow confidence intervals. While we considered random sampling of individual patients within a year to account for this, we felt that an iterative re-sampling approach would not have provided additional clarity.

Within these limitations, however, our approach fills in important gaps in the currently published literature. By including an all-payer sample, we are able to better understand the patient milieu beyond the Medicare population, where most previous studies have been done. The sample is nationally representative and covers all community hospital discharges within the study period across a range of 18 to 27 states (depending on the year) with 16 states included in all years of the database (Table 1) [86]. Use of such a broad patient population enables insights not previously afforded by individual health system or payer populations.

Conclusion

In a large, national, all-payer sample of COPD hospitalizations, comorbidities are frequent and play a substantial role in the 30-day readmission risk. Between two available comorbidity scoring systems, the Elixhauser Comorbidity Index provides slightly better model fitting when compared to the Charlson Comorbidity Index and could be favored for future analyses of this type. Using comorbidity in risk adjustment tools may give policy makers additional insight into how best to adjust for multiple comorbid conditions when assessing penalties. In addition, health systems seeking to improve their delivery methods can use such a scoring system to better understand their own

distribution of comorbidities in order to develop programs tailored to their individual patient populations.

Tables and Figures:

Table 5: Baseline patient-level characteristics of the aggregated cohort, comparing readmitted to non-readmitted patients in index stays

	Overall N=1,662,983	**Not Readmitted** N=1,375,099	**Readmitted** N=287,884	***P***
Sex, *%*				
Male	41.1%	40.8%	42.8%	<.001
Female	58.9%	59.2%	57.2%	
Age, *Mean ± SD*	68.0 ± 11.9	67.9 ± 11.9	68.7 ± 11.7	<.001
Median household income by ZIP code, *%*				
1st Quartile	37.1%	37.0%	37.5%	<.001
2nd Quartile	26.7%	26.8%	26.4%	
3rd Quartile	20.9%	20.9%	20.8%	
4th Quartile	13.9%	13.9%	14.1%	
Missing	1.4%	1.4%	1.4%	
[1]**Patient geographic location**, *%*				
Central county metro area ≥1M	22.3%	22.0%	23.5%	<.001
Fringe county metro area ≥1M	24.6%	24.4%	25.5%	
County metro area 250,000-999,999k	20.8%	20.9%	20.4%	
County metro area 50,000-249,999k	10.3%	10.4%	10.1%	
Micropolitan area	13.0%	13.1%	12.2%	
Non-metro/non-micropolitan (rural)	9.0%	9.1%	8.3%	
[2]**Primary Payer**, *%*				
Medicare (includes dual-eligible)	70.4%	69.6%	74.3%	<.001
Medicaid	12.0%	11.8%	13.0%	
Private insurance	11.6%	12.3%	8.3%	
Self-pay	3.1%	3.4%	1.9%	
Other, including no-charge	2.9%	3.0%	2.4%	
Number of admissions each patient had over a year, *Mean ± SD*	2.50 ± 1.96	2.13 ± 1.60	4.31 ± 2.50	<.001
Number hospitals where each patient received care over a year, *Mean ± SD*	1.33 ± 0.67	1.31 ± 0.64	1.44 ± 0.75	<.001
Discharge disposition, *%*				
Routine to home	67.5%	69.1%	60.1%	<.001
Transfer to post-acute care	13.1%	12.4%	16.3%	
Home with home health services	18.7%	17.8%	22.8%	
Other	0.7%	0.7%	0.8%	
[§]**Length of Stay**, *Mean ± SD*	3.75 ± 2.04	3.67 ± 1.96	4.16 ± 2.38	<.001
Care intensity and complications, *%*				
Use of non-invasive ventilation	8.0%	7.7%	9.7%	<.001
Use of mechanical ventilation	4.7%	4.5%	5.7%	<.001
Placement or presence of tracheostomy	0.8%	0.8%	1.2%	<.001
Cardiac arrest	0.2%	0.2%	0.3%	<.001
Performance of CPR	0.1%	0.1%	0.2%	<.001

Note: Unweighted N's displayed. Frequencies derived using weighted analysis. [§]Geometric Mean and SD for log transformed variable presented [1]N's 1,373,301 & 287,296; [2]N's 1,372,214 & 287,362

Table 6: Baseline characteristics of hospitals included in pooled cohort

	Cohort Proportion	Readmission Rate	*P*
Hospital ownership/control, *%*			
Government, non-federal	16.1%	16.8%	<.001
Private, non-profit	62.9%	17.2%	
Private, for-profit	21.0%	17.4%	
Hospital teaching status, *%*			
Metro, non-teaching	44.2%	17.3%	<.001
Metro, teaching	30.0%	17.6%	
Non-metro, non-teaching	25.8%	15.9%	
Hospital geographic location, *%*			
Large metro area ≥1M	43.7%	17.9%	
Small metro area <1M	30.5%	16.8%	<.001
Micropolitan area	15.3%	16.0%	
Non-metro/non-micropolitan (rural)	10.5%	15.5%	
Hospital bed size[a], *%*			
Small	26.6%	16.5%	<.001
Medium	32.3%	17.1%	
Large	41.1%	17.4%	
Hospital total all-cause annual discharges, *Mean ± SD*	6,296 ± 6,425		
Quartiles of Hospital total all-cause annual discharges, *(N) %*			
1st Quartile (≤ 8,971)	59.1%	16.4%	<.001
2nd Quartile (8,972 – 15,406)	20.9%	17.5%	
3rd Quartile (15,407 – 24,534)	12.9%	17.7%	
4th Quartile (≥24,535)	7.1%	18.0%	
COPD Discharges, *Mean ± SD*	161 ± 133		
COPD Discharge Quartiles			
1st Quartile (≤ 122)	48.5%	15.8%	
2nd Quartile (123 – 205)	24.1%	17.0%	<.001
3rd Quartile (206 – 322)	17.0%	17.6%	
4th Quartile (≥ 323)	10.4%	18.0%	
Proportion of Medicaid patient days, *Mean ± SD*	17.1% ± 11.2%		
Medicaid Proportion Quartiles, *%*			
1st Quartile (≤ 10.6%)	31.5%	16.9%	
2nd Quartile (10.6% - 16.1%)	25.1%	17.2%	<.001
3rd Quartile (16.1% - 23.9%)	22.9%	17.3%	
4th Quartile (≥ 23.9%)	20.5%	17.6%	

Note: Unweighted frequencies displayed for cohort proportions. Weighted frequencies for Sub-Strata readmission rates presented. P values are for between hospital characteristic differences in readmission rates.
[a] Bed size distinction varies by region [86]

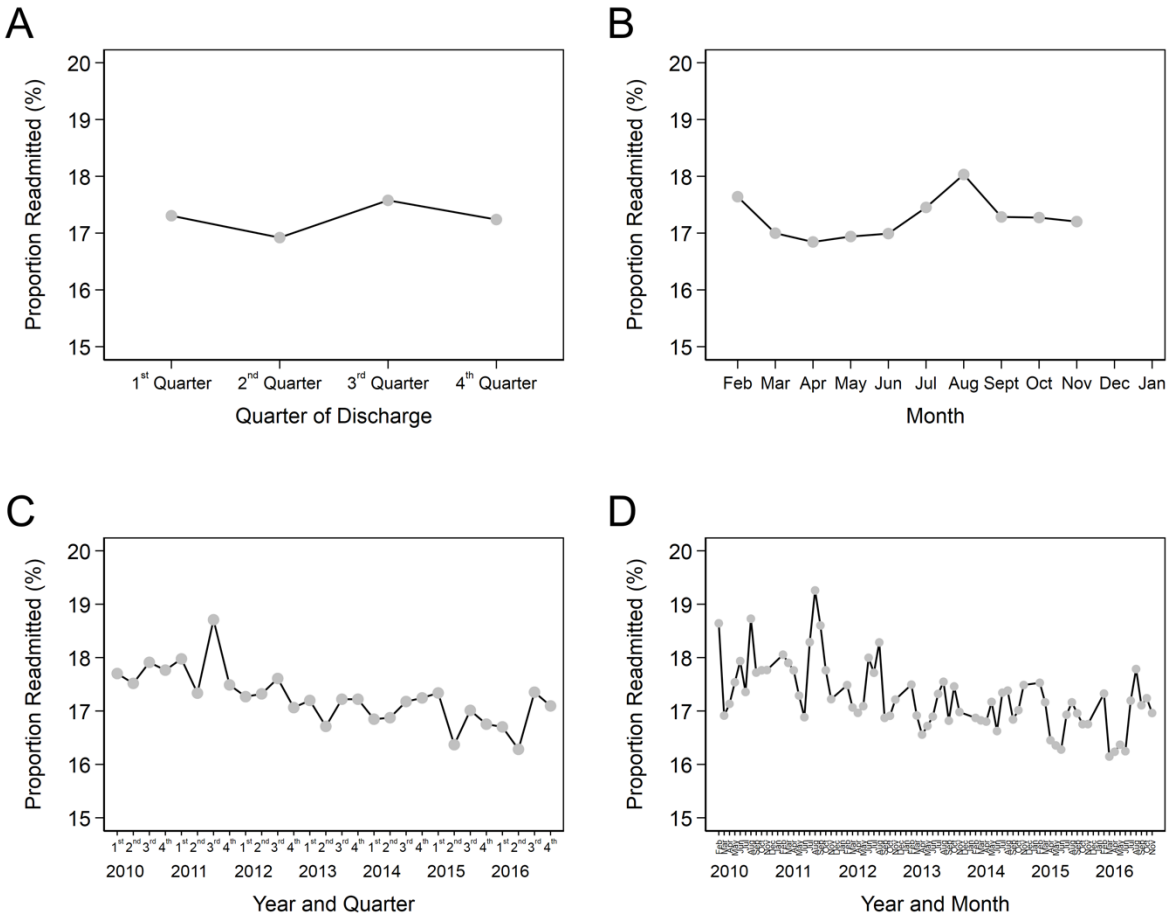

Figure 4: Readmission rates by quarter (panel A), month (panel B), year and quarter (panel C), and year and month (panel D)

Table 7: Baseline comorbidity characteristics of the aggregated cohort, comparing readmitted to non-readmitted patients in index stays for the Charlson Index

	Overall (1,622,983)	**Not Readmitted** (1,375,099)	**Readmitted** (287,884)	***P***
Charlson Index Composite	2.16 ± 1.43	2.10 ± 1.39	2.41 ± 1.57	<.001
Charlson Index Grouping				
Index Score = 1	42.7%	44.2%	35.5%	<.001
Index Score = 2	27.6%	27.5%	27.8%	
Index Score ≥ 3	29.7%	28.3%	36.8%	
Charlson Component Comorbidities				
Neurologic/Psychiatric				
Cerebrovascular disease	3.1%	3.0%	3.5%	<.001
Dementia	1.8%	1.8%	1.9%	0.041
Hemiplegia/paraplegia	0.3%	0.3%	0.3%	<.001
Cardiovascular				
Congestive heart failure	27.6%	26.1%	34.8%	<.001
Peripheral vascular disease	5.6%	5.4%	6.2%	<.001
Myocardial infarction	7.8%	7.6%	8.9%	<.001
Respiratory				
Chronic pulmonary disease	100.0%	100.0%	100.0%	---
Gastrointestinal				
Peptic ulcer disease	0.8%	0.8%	0.9%	<.001
Mild liver disease	2.2%	2.1%	2.4%	<.001
Moderate or severe liver disease	0.2%	0.1%	0.2%	<.001
Renal/Electrolyte Disorders				
Moderate or severe renal disease	14.0%	13.1%	18.1%	<.001
Infectious Disease				
HIV/AIDS	0.2%	0.2%	0.3%	<.001
Hematologic/Oncology				
Malignancy (any type)	3.4%	3.2%	4.4%	<.001
Metastatic solid tumor	1.1%	1.0%	1.7%	<.001
Rheumatologic and Musculoskeletal				
Connective tissue disease	2.2%	2.2%	2.2%	0.131
Endocrine				
Diabetes mellitus	16.5%	16.4%	17.0%	<.001
Diabetes mellitus w/ end-organ damage	2.1%	2.0%	2.6%	<.001

Note: Unweighted N's displayed. Frequencies derived using weighted analysis.

Table 8: Baseline comorbidity characteristics of the aggregated cohort, comparing readmitted to non-readmitted patients in index stays for the Elixhauser Index.

	Overall (1,622,983)	**Not Readmitted** (1,375,099)	**Readmitted** (287,884)	***P***
Elixhauser Index Composite	17.0 ± 15.0	16.3 ± 14.7	20.5 ± 16.0	<.001
Elixhauser Comorbidity Domain Count	3.99 ± 1.84	3.92 ± 1.81	4.37 ± 1.91	<.001
Elixhauser Component Comorbidities				
Neurologic/Psychiatric				
Paralysis	1.3%	1.2%	1.5%	<.001
Other neurologic disorders	8.6%	8.3%	9.8%	<.001
Alcohol abuse	4.5%	4.5%	4.7%	<.001
Drug abuse	3.6%	3.5%	4.2%	<.001
Psychoses	6.3%	6.1%	7.6%	<.001
Depression	16.9%	16.7%	17.8%	<.001
Cardiovascular				
Congestive heart failure	26.9%	25.4%	34.0%	<.001
Peripheral vascular disease	7.9%	7.7%	9.2%	<.001
Valvular Heart Disease	6.5%	6.2%	7.5%	<.001
Hypertension	54.1%	54.5%	52.2%	<.001
Respiratory				
Chronic pulmonary disease	100.0%	100.0%	100.0%	---
Pulmonary circulation disorders	7.9%	7.6%	9.8%	<.001
Gastrointestinal				
Peptic ulcer disease	0.1%	0.1%	0.2%	<.001
Liver disease	2.4%	2.3%	2.8%	<.001
Renal/Electrolyte Disorders				
Renal Failure	13.1%	12.3%	17.2%	<.001
Fluid and electrolyte disorders	28.0%	27.4%	30.9%	<.001
Infectious Disease				
HIV/AIDS	0.2%	0.2%	0.3%	<.001
Hematologic/Oncology				
Solid tumor without metastasis	3.4%	3.1%	4.6%	<.001
Metastatic cancer	1.1%	1.0%	1.7%	<.001
Lymphoma	0.5%	0.5%	0.6%	<.001
Coagulopathy	3.2%	3.1%	3.8%	<.001
Blood loss anemia	0.4%	0.3%	0.5%	<.001
Deficiency anemia	15.4%	14.4%	19.9%	<.001
Rheumatologic and Musculoskeletal				
Rheumatoid arthritis and collagen vascular disorders	3.3%	3.3%	3.5%	<.001
Endocrine				
Diabetes mellitus (uncomplicated)	26.3%	25.8%	28.4%	<.001
Diabetes mellitus (complicated)	6.0%	5.7%	7.3%	<.001
Hypothyroidism	13.7%	13.6%	14.0%	<.001
Obesity	19.1%	19.0%	19.6%	<.001
Weight loss	4.6%	4.5%	5.4%	<.001

Note: Unweighted N's displayed. Frequencies derived using weighted analysis.

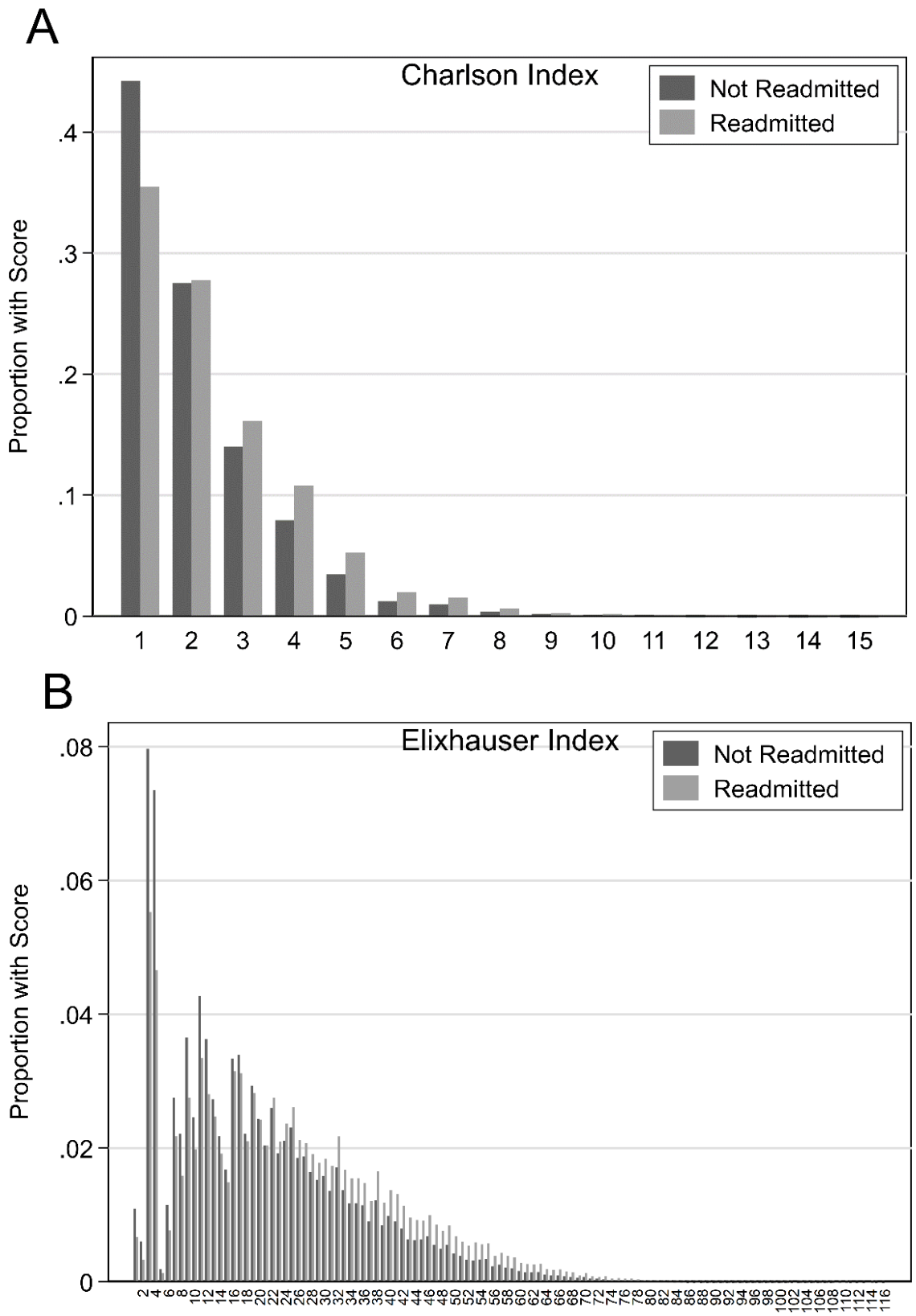

Figure 5: Charlson (Panel A) and Elixhauser (Panel B) distributions between readmitted and not readmitted patient stays

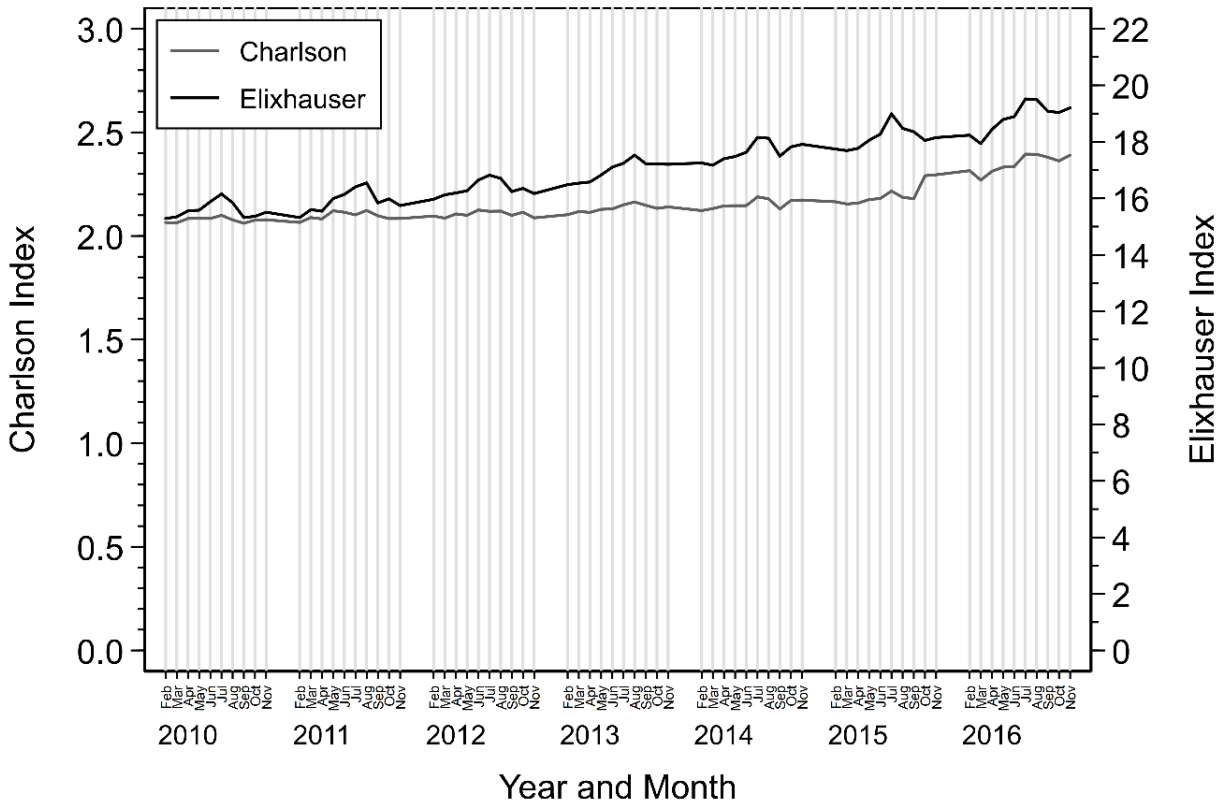

Figure 6: Charlson and Elixhauser Index Scores by year and month

Table 9: Multilevel logistic regression model for Charlson (left) and Elixhauser (right) Indices, adjusted for patient and hospital factors with random intercepts for hospital clusters

Model Info	**Charlson Comorbidity Index**		**Elixhauser Comorbidity Index**	
N	1,658,372		1,658,372	
LL	-1,683,418.10		-1,677,856.30	
df	41		41	
AIC	3,366,918.30		3,355,794.50	
BIC	3,367,423.50		3,356,299.80	
Predictors	**OR (95% CI)**	***P***	**OR (95% CI)**	***P***
Comorbidity Index *(per ½ SD change)*	1.09 (1.09, 1.09)	<.001	1.13 (1.12, 1.13)	<.001
Year *(ref=2010)*				
2011	1.00 (0.97, 1.02)	0.673	0.99 (0.97, 1.01)	0.484
2012	0.96 (0.94, 0.98)	<.001	0.95 (0.93, 0.97)	<.001
2013	0.93 (0.91, 0.95)	<.001	0.91 (0.89, 0.93)	<.001
2014	0.92 (0.90, 0.94)	<.001	0.89 (0.87, 0.91)	<.001
2015	0.88 (0.86, 0.90)	<.001	0.86 (0.84, 0.88)	<.001
2016	0.87 (0.85, 0.89)	<.001	0.85 (0.83, 0.87)	<.001
Quarter *(ref=1st)*				
2nd Quarter	0.97 (0.96, 0.98)	<.001	0.97 (0.95, 0.98)	<.001
3rd Quarter	1.01 (1.00, 1.02)	0.167	1.00 (0.99, 1.02)	0.778
4th Quarter	0.99 (0.98, 1.01)	0.277	0.99 (0.97, 1.00)	0.086
Sex *(ref=male)*				
Female	0.92 (0.91, 0.93)	<.001	0.92 (0.91, 0.92)	<.001
Age *(per 10 year)*	0.97 (0.97, 0.98)	<.001	0.98 (0.98, 0.99)	<.001
Income Quartile *(ref=1st)*				
2nd Quartile	0.98 (0.97, 0.99)	0.003	0.98 (0.97, 1.00)	0.009
3rd Quartile	0.97 (0.95, 0.98)	<.001	0.97 (0.96, 0.99)	<.001
4th Quartile	0.94 (0.93, 0.96)	<.001	0.95 (0.93, 0.97)	<.001
Missing	0.97 (0.93, 1.00)	0.083	0.97 (0.93, 1.01)	0.136
Payer *(ref=Medicare)*				
Medicaid	1.08 (1.06, 1.10)	<.001	1.08 (1.06, 1.09)	<.001
Private	0.69 (0.68, 0.71)	<.001	0.71 (0.70, 0.73)	<.001
Self-Pay	0.62 (0.60, 0.64)	<.001	0.63 (0.61, 0.65)	<.001
Other/No Charge	0.79 (0.77, 0.82)	<.001	0.80 (0.77, 0.82)	<.001
Disposition *(ref=Routine to home)*				
Post-acute care	1.30 (1.28, 1.32)	<.001	1.21 (1.19, 1.23)	<.001
Home Health	1.35 (1.33, 1.37)	<.001	1.30 (1.28, 1.32)	<.001
Other	1.13 (1.06, 1.20)	<.001	1.07 (1.00, 1.14)	0.038
LOS *(per day)*	1.02 (1.02, 1.02)	<.001	1.01 (1.01, 1.01)	<.001
Care intensity *(ref=No)*				
Non-invasive ventilation	1.16 (1.14, 1.18)	<.001	1.08 (1.06, 1.10)	<.001
Mechanical ventilation	0.95 (0.92, 0.97)	<.001	0.82 (0.79, 0.84)	<.001
Presence or placement of tracheostomy	1.02 (0.97, 1.09)	0.425	1.04 (0.99, 1.11)	0.133
Cardiac arrest	0.82 (0.74, 0.91)	<.001	0.81 (0.74, 0.90)	<.001
Performance of CPR	1.08 (0.95, 1.24)	0.242	1.09 (0.95, 1.24)	0.21
Hospital ownership *(ref=government)*				
Private, non-profit	0.99 (0.98, 1.01)	0.437	0.98 (0.96, 1.00)	0.022
Private, for-profit	1.04 (1.01, 1.06)	<.001	1.03 (1.01, 1.06)	0.002
Hospital teaching status *(ref=Non-teaching)*				
Teaching Hospital	1.01 (0.99, 1.02)	0.423	1.00 (0.98, 1.01)	0.902
Hospital location *(ref=Large metro area)*				
Small metro area	0.94 (0.92, 0.95)	<.001	0.93 (0.92, 0.95)	<.001

Model Info	Charlson Comorbidity Index		Elixhauser Comorbidity Index	
N	1,658,372		1,658,372	
LL	-1,683,418.10		-1,677,856.30	
df	41		41	
AIC	3,366,918.30		3,355,794.50	
BIC	3,367,423.50		3,356,299.80	
Predictors	**OR (95% CI)**	***P***	**OR (95% CI)**	***P***
Micropolitan area	0.89 (0.87, 0.91)	<.001	0.90 (0.88, 0.92)	<.001
Rural	0.87 (0.84, 0.90)	<.001	0.89 (0.86, 0.92)	<.001
Hospital Bed Size *(ref=Small)*				
Medium	1.01 (0.99, 1.03)	0.174	1.01 (0.99, 1.03)	0.389
Large	1.02 (1.00, 1.04)	0.04	1.01 (0.99, 1.03)	0.407
Annual Discharge (per 10k)	1.01 (1.00, 1.02)	0.13	1.01 (1.00, 1.02)	0.012
Proportion of Medicaid patient days per 10%	1.00 (1.00, 1.01)	0.531	1.00 (0.99, 1.01)	0.872

Table 10: Charlson and Elixhauser Indices (with 95% CI) over time per ½ standard deviation increase.

	2010	2011	2012	2013	2014	2015	2016
Charlson							
Model 1	1.11 (1.11, 1.12)	1.11 (1.10, 1.12)	1.11 (1.10, 1.12)	1.11 (1.10, 1.12)	1.11 (1.10, 1.12)	1.11 (1.11, 1.12)	1.11 (1.10, 1.11)
Model 2	1.10 (1.09, 1.11)	1.10 (1.09, 1.11)	1.10 (1.09, 1.11)	1.10 (1.09, 1.11)	1.10 (1.09, 1.11)	1.11 (1.10, 1.11)	1.10 (1.09, 1.10)
Model 3	1.09 (1.08, 1.10)	1.09 (1.08, 1.10)	1.09 (1.08, 1.09)	1.09 (1.08, 1.10)	1.09 (1.08, 1.10)	1.10 (1.09, 1.10)	1.09 (1.08, 1.09)
Elixhauser							
Model 1	1.16 (1.15, 1.17)	1.16 (1.15, 1.17)	1.15 (1.14, 1.15)	1.15 (1.14, 1.16)	1.15 (1.14, 1.16)	1.15 (1.14, 1.16)	1.15 (1.14, 1.16)
Model 2	1.14 (1.14, 1.15)	1.15 (1.14, 1.16)	1.14 (1.13, 1.14)	1.14 (1.13, 1.15)	1.14 (1.13, 1.15)	1.14 (1.14, 1.15)	1.14 (1.14, 1.15)
Model 3	1.13 (1.12, 1.14)	1.13 (1.12, 1.14)	1.12 (1.11, 1.13)	1.12 (1.12, 1.13)	1.12 (1.11, 1.13)	1.13 (1.12, 1.14)	1.12 (1.12, 1.13)

Model 2 adjusted for age, sex, income, time period (year and quarter), and insurer.

Model 3 adjusted for Model 2 covariates as well as discharge disposition, hospital length of stay, care intensity, and hospital characteristics (ownership type, teaching hospital status, location, size, annual number of discharges, and proportion Medicaid patients).

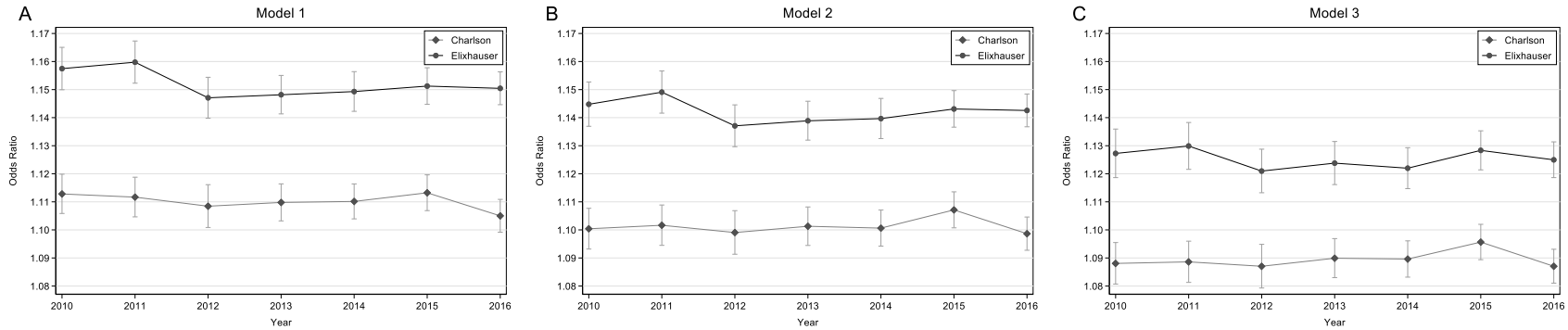

Figure 7: Changes in Charlson and Elixhauser Indices (with 95% CI) overtime per ½ standard deviation increase

Model 2 adjusted for age, sex, income, time period (year and quarter), and insurer.

Model 3 adjusted for Model 2 covariates as well as discharge disposition, hospital length of stay, care intensity, and hospital characteristics (ownership type, teaching hospital status, location, size, annual number of discharges, and proportion Medicaid patients).

Table 11: Comparisons between covariate-only and comorbidity index models

Index Type		Model 2 LL	Model 2 DF	Model 3 LL	Model 3 DF
Charlson Index	Covariate Only	-1,702,657.30	21	-1,690,687.40	40
	With Index	-1,693,222.5	22	-1,683,418.1	41
	-2LL Δ	18,869.6	1	14,538.6	1
Elixhauser Index	Covariate Only	-1,702,657.30	21	-1,690,687.40	40
	With Index	-1,683,905.4	22	-1,677,856.3	41
	-2LL Δ	37,503.8	1	25,662.2	1

Table 12: Multilevel Logistic Regression models of Readmission using Charlson Index using Hospital Level random intercept

Model Info	**Model 1**		**Model 2**		**Model 3**	
N	1,662,983		1,659,576		1,658,372	
LL	-1,702,361.6		-1,693,222.5		-1,683,418.1	
df	3		22		41	
AIC	3,404,729.3		3,386,489.0		3,366,918.3	
BIC	3,404,766.3		3,386,760.0		3,367,423.5	
Predictors	**OR (95% CI)**	***P***	**OR (95% CI)**	***P***	**OR (95% CI)**	***P***
Charlson Index *(per 1)*	1.15 (1.15, 1.15)	<.001	1.14 (1.13, 1.14)	<.001	1.12 (1.12, 1.12)	<.001
Year *(ref=2010)*						
2011			1.00 (0.97, 1.02)	0.709	1.00 (0.97, 1.02)	0.673
2012			0.96 (0.94, 0.98)	<.001	0.96 (0.94, 0.98)	<.001
2013			0.93 (0.91, 0.95)	<.001	0.93 (0.91, 0.95)	<.001
2014			0.92 (0.90, 0.94)	<.001	0.92 (0.90, 0.94)	<.001
2015			0.88 (0.87, 0.90)	<.001	0.88 (0.86, 0.90)	<.001
2016			0.88 (0.86, 0.90)	<.001	0.87 (0.85, 0.89)	<.001
Quarter *(ref=1st)*						
2nd Quarter			0.97 (0.95, 0.98)	<.001	0.97 (0.96, 0.98)	<.001
3rd Quarter			1.01 (0.99, 1.02)	0.411	1.01 (1.00, 1.02)	0.167
4th Quarter			0.99 (0.97, 1.00)	0.038	0.99 (0.98, 1.01)	0.277
Sex *(ref=male)*						
Female			0.94 (0.93, 0.95)	<.001	0.92 (0.91, 0.93)	<.001
Age *(per 10 year)*			1.00 (0.99, 1.00)	0.796	0.97 (0.97, 0.98)	<.001
Income Quartile *(ref=1st)*						
2nd Quartile			0.98 (0.97, 1.00)	0.019	0.98 (0.97, 0.99)	0.003
3rd Quartile			0.98 (0.97, 1.00)	0.015	0.97 (0.95, 0.98)	<.001
4th Quartile			0.97 (0.95, 0.99)	<.001	0.94 (0.93, 0.96)	<.001
Missing			0.96 (0.93, 1.00)	0.073	0.97 (0.93, 1.00)	0.083
Payer *(ref=Medicare)*						
Medicaid			1.07 (1.05, 1.09)	<.001	1.08 (1.06, 1.10)	<.001
Private			0.67 (0.66, 0.68)	<.001	0.69 (0.68, 0.71)	<.001
Self-Pay			0.59 (0.57, 0.61)	<.001	0.62 (0.60, 0.64)	<.001
Other/No Charge			0.77 (0.75, 0.80)	<.001	0.79 (0.77, 0.82)	<.001
Disposition *(ref=Routine to home)*						
Post-acute care					1.30 (1.28, 1.32)	<.001
Other					1.13 (1.06, 1.20)	<.001
Home Health					1.35 (1.33, 1.37)	<.001
LOS *(per day)*					1.02 (1.02, 1.02)	<.001
Care intensity *(ref=No)*						
Non-invasive ventilation					1.16 (1.14, 1.18)	<.001
Mechanical ventilation					0.95 (0.92, 0.97)	<.001
Presence or placement of tracheostomy					1.02 (0.97, 1.09)	0.425
Cardiac arrest					0.82 (0.74, 0.91)	<.001
Performance of CPR					1.08 (0.95, 1.24)	0.242
Hospital ownership *(ref=government)*						
Private, non-profit					0.99 (0.98, 1.01)	0.437
Private, for-profit					1.04 (1.01, 1.06)	<.001
Hospital teaching status *(ref=Non-teaching)*						
Teaching Hospital					1.01 (0.99, 1.02)	0.423
Hospital location *(ref=Large metro area)*						
Small metro area					0.94 (0.92, 0.95)	<.001

Micropolitan area	0.89 (0.87, 0.91)	<.001
Rural	0.87 (0.84, 0.90)	<.001
Hospital Bed Size *(ref=Small)*		
Medium	1.01 (0.99, 1.03)	0.174
Large	1.02 (1.00, 1.04)	0.040
Annual Discharge (per 10k)	1.01 (1.00, 1.02)	0.130
Proportion Medicaid per 10%	1.00 (1.00, 1.01)	0.531

Table 13: Multilevel Logistic Regression models of Readmission using Elixhauser Index using Hospital Level random intercept

Model Info	**Model 1**		**Model 2**		**Model 3**	
N	1,662,983		1,659,576		1,658,372	
LL	-1,692,216.5		-1,683,905.4		-1,677,856.3	
df	3		22		41	
AIC	3,384,439.0		3,367,854.8		3,355,794.5	
BIC	3,384,476.0		3,368,126.0		3,356,299.8	
Predictors	**OR (95% CI)**	***P***	**OR (95% CI)**	***P***	**OR (95% CI)**	***P***
Elixhauser Index *(per 3)*	1.06 (1.06, 1.06)	<.001	1.05 (1.05, 1.06)	<.001	1.05 (1.05, 1.05)	<.001
Year *(ref=2010)*						
2011			0.99 (0.97, 1.01)	0.515	0.99 (0.97, 1.01)	0.484
2012			0.95 (0.93, 0.97)	<.001	0.95 (0.93, 0.97)	<.001
2013			0.91 (0.89, 0.93)	<.001	0.91 (0.89, 0.93)	<.001
2014			0.89 (0.87, 0.91)	<.001	0.89 (0.87, 0.91)	<.001
2015			0.86 (0.84, 0.88)	<.001	0.86 (0.84, 0.88)	<.001
2016			0.86 (0.84, 0.88)	<.001	0.85 (0.83, 0.87)	<.001
Quarter *(ref=1st)*						
2nd Quarter			0.96 (0.95, 0.98)	<.001	0.97 (0.95, 0.98)	<.001
3rd Quarter			1.00 (0.98, 1.01)	0.739	1.00 (0.99, 1.02)	0.778
4th Quarter			0.98 (0.97, 1.00)	0.019	0.99 (0.97, 1.00)	0.086
Sex *(ref=male)*						
Female			0.93 (0.93, 0.94)	<.001	0.92 (0.91, 0.92)	<.001
Age *(per 10 year)*			1.00 (1.00, 1.01)	0.058	0.98 (0.98, 0.99)	<.001
Income Quartile *(ref=1st)*						
2nd Quartile			0.99 (0.97, 1.00)	0.035	0.98 (0.97, 1.00)	0.009
3rd Quartile			0.98 (0.97, 1.00)	0.018	0.97 (0.96, 0.99)	<.001
4th Quartile			0.97 (0.95, 0.99)	<.001	0.95 (0.93, 0.97)	<.001
Missing			0.97 (0.93, 1.01)	0.144	0.97 (0.93, 1.01)	0.136
Payer *(ref=Medicare)*						
Medicaid			1.07 (1.05, 1.09)	<.001	1.08 (1.06, 1.09)	<.001
Private			0.70 (0.68, 0.71)	<.001	0.71 (0.70, 0.73)	<.001
Self-Pay			0.61 (0.59, 0.63)	<.001	0.63 (0.61, 0.65)	<.001
Other/No Charge			0.78 (0.76, 0.81)	<.001	0.80 (0.77, 0.82)	<.001
Disposition *(ref=Routine to home)*						
Post-acute care					1.21 (1.19, 1.23)	<.001
Other					1.07 (1.00, 1.14)	0.038
Home Health					1.30 (1.28, 1.32)	<.001
LOS *(per day)*					1.01 (1.01, 1.01)	<.001
Care intensity *(ref=No)*						
Non-invasive ventilation					1.08 (1.06, 1.10)	<.001
Mechanical ventilation					0.82 (0.79, 0.84)	<.001
Presence or placement of tracheostomy					1.04 (0.99, 1.11)	0.133
Cardiac arrest					0.81 (0.74, 0.90)	<.001
Performance of CPR					1.09 (0.95, 1.24)	0.210
Hospital ownership *(ref=government)*						
Private, non-profit					0.98 (0.96, 1.00)	0.022
Private, for-profit					1.03 (1.01, 1.06)	0.002
Hospital teaching status *(ref=Non-teaching)*						
Teaching Hospital					1.00 (0.98, 1.01)	0.902
Hospital location *(ref=Large metro area)*						
Small metro area					0.93 (0.92, 0.95)	<.001

Micropolitan area	0.90 (0.88, 0.92)	<.001
Rural	0.89 (0.86, 0.92)	<.001
Hospital Bed Size *(ref=Small)*		
Medium	1.01 (0.99, 1.03)	0.389
Large	1.01 (0.99, 1.03)	0.407
Annual Discharge (per 10k)	1.01 (1.00, 1.02)	0.012
Proportion Medicaid per 10%	1.00 (0.99, 1.01)	0.872

Table 14: Only Covariates: Multilevel Logistic Regression models of Readmission using only the covariates as predictor with Hospital Level random intercept

Model Info	**Model 1**	**Model 2**		**Model 3**	
N		1,659,576		1,658,372	
LL		-761,221.6		-755,666.8	
df		20		39	
AIC		1,522,483.1		1,511,411.5	
BIC		1,522,729.5		1,511,892.1	
Predictors		**OR (95% CI)**	***P***	**OR (95% CI)**	***P***
Year *(ref=2010)*					
2011		1.00 (0.99, 1.02)	0.893	1.00 (0.99, 1.02)	0.933
2012		0.98 (0.96, 0.99)	0.002	0.97 (0.96, 0.99)	<.001
2013		0.95 (0.94, 0.97)	<.001	0.94 (0.93, 0.96)	<.001
2014		0.94 (0.92, 0.95)	<.001	0.95 (0.93, 0.96)	<.001
2015		0.93 (0.91, 0.94)	<.001	0.92 (0.90, 0.93)	<.001
2016		0.93 (0.92, 0.95)	<.001	0.92 (0.90, 0.93)	<.001
Quarter *(ref=1st)*					
2nd Quarter		0.98 (0.97, 0.99)	<.001	0.98 (0.97, 0.99)	<.001
3rd Quarter		1.03 (1.02, 1.04)	<.001	1.03 (1.02, 1.04)	<.001
4th Quarter		1.00 (0.99, 1.01)	0.847	1.01 (0.99, 1.02)	0.296
Sex *(ref=male)*					
Female		0.91 (0.91, 0.92)	<.001	0.89 (0.89, 0.90)	<.001
Age *(per 10 year)*		1.02 (1.02, 1.03)	<.001	0.99 (0.98, 0.99)	<.001
Income Quartile *(ref=1st)*					
2nd Quartile		0.98 (0.97, 0.99)	<.001	0.97 (0.96, 0.98)	<.001
3rd Quartile		0.98 (0.96, 0.99)	<.001	0.95 (0.94, 0.96)	<.001
4th Quartile		0.99 (0.98, 1.01)	0.28	0.94 (0.93, 0.95)	<.001
Missing		0.93 (0.90, 0.97)	<.001	0.94 (0.91, 0.97)	<.001
Payer *(ref=Medicare)*					
Medicaid		1.07 (1.06, 1.09)	<.001	1.07 (1.06, 1.09)	<.001
Private		0.65 (0.64, 0.66)	<.001	0.68 (0.67, 0.69)	<.001
Self-Pay		0.57 (0.55, 0.58)	<.001	0.60 (0.59, 0.62)	<.001
Other/No Charge		0.75 (0.73, 0.77)	<.001	0.78 (0.76, 0.80)	<.001
Disposition *(ref=Routine to home)*					
Post-acute care				1.32 (1.31, 1.34)	<.001
Other				1.18 (1.13, 1.24)	<.001
Home Health				1.37 (1.36, 1.38)	<.001
LOS *(per day)*				1.02 (1.02, 1.02)	<.001
Care intensity *(ref=No)*					
Non-invasive ventilation				1.17 (1.15, 1.19)	<.001
Mechanical ventilation				0.97 (0.95, 0.99)	<.001
Presence or placement of tracheostomy				1.00 (0.95, 1.04)	0.867
Cardiac arrest				0.84 (0.77, 0.92)	<.001
Performance of CPR				1.03 (0.93, 1.15)	0.581
Hospital ownership *(ref=government)*					
Private, non-profit				1.00 (0.99, 1.01)	0.784
Private, for-profit				1.03 (1.01, 1.04)	0.001
Hospital teaching status *(ref=Non-teaching)*					
Teaching Hospital				1.01 (1.00, 1.02)	0.192
Hospital location *(ref=Large metro area)*					
Small metro area				0.94 (0.93, 0.94)	<.001
Micropolitan area				0.90 (0.88, 0.91)	<.001

Rural	0.87 (0.85, 0.89)	<.001
Hospital Bed Size *(ref=Small)*		
Medium	1.01 (1.00, 1.03)	0.038
Large	1.02 (1.01, 1.04)	0.002
Annual Discharge (per 10k)	1.01 (1.00, 1.02)	<.001
Proportion of Medicaid per 10%	1.00 (1.00, 1.00)	0.861

Table 15: Multilevel Logistic Regression models of Readmission using Charlson Index using Hospital Level random intercept (age 18 and older)

Model Info	**Model 1**		**Model 2**		**Model 3**	
N	1,682,629		1,679,169		1,677,941	
LL	-1,720,155.5		-1,710,735.8		-1,700,884.0	
df	3		22		41	
AIC	3,440,317.0		3,421,515.5		3,401,850.0	
BIC	3,440,354.0		3,421,786.8		3,402,355.8	
Predictors	**OR (95% CI)**	***P***	**OR (95% CI)**	***P***	**OR (95% CI)**	***P***
Charlson Index *(per 1)*	1.15 (1.15, 1.15)	<.001	1.14 (1.13, 1.14)	<.001	1.12 (1.12, 1.12)	<.001
Year *(ref=2010)*						
2011			1.00 (0.97, 1.02)	0.658	0.99 (0.97, 1.02)	0.611
2012			0.96 (0.94, 0.98)	<.001	0.96 (0.94, 0.98)	<.001
2013			0.93 (0.91, 0.95)	<.001	0.93 (0.91, 0.95)	<.001
2014			0.92 (0.90, 0.94)	<.001	0.92 (0.90, 0.94)	<.001
2015			0.89 (0.87, 0.90)	<.001	0.88 (0.86, 0.90)	<.001
2016			0.88 (0.86, 0.90)	<.001	0.87 (0.85, 0.89)	<.001
Quarter *(ref=1st)*						
2nd Quarter			0.97 (0.95, 0.98)	<.001	0.97 (0.96, 0.98)	<.001
3rd Quarter			1.00 (0.99, 1.02)	0.523	1.01 (0.99, 1.02)	0.232
4th Quarter			0.98 (0.97, 1.00)	0.017	0.99 (0.98, 1.00)	0.162
Sex *(ref=male)*						
Female			0.94 (0.93, 0.95)	<.001	0.92 (0.91, 0.93)	<.001
Age *(per 10 year)*			1.00 (1.00, 1.01)	0.101	0.98 (0.97, 0.98)	<.001
Income Quartile *(ref=1st)*						
2nd Quartile			0.98 (0.97, 1.00)	0.017	0.98 (0.97, 0.99)	0.002
3rd Quartile			0.98 (0.97, 1.00)	0.010	0.97 (0.95, 0.98)	<.001
4th Quartile			0.97 (0.95, 0.98)	<.001	0.94 (0.93, 0.96)	<.001
Missing			0.97 (0.93, 1.01)	0.086	0.97 (0.93, 1.01)	0.098
Payer *(ref=Medicare)*						
Medicaid			1.07 (1.05, 1.09)	<.001	1.08 (1.06, 1.09)	<.001
Private			0.67 (0.66, 0.68)	<.001	0.69 (0.68, 0.70)	<.001
Self-Pay			0.59 (0.57, 0.61)	<.001	0.62 (0.60, 0.64)	<.001
Other/No Charge			0.77 (0.75, 0.80)	<.001	0.79 (0.77, 0.82)	<.001
Disposition *(ref=Routine to home)*						
Post-acute care					1.29 (1.27, 1.32)	<.001
Other					1.13 (1.06, 1.20)	<.001
Home Health					1.35 (1.33, 1.37)	<.001
LOS *(per day)*					1.02 (1.02, 1.02)	<.001
Care intensity *(ref=No)*						
Non-invasive ventilation					1.16 (1.14, 1.18)	<.001
Mechanical ventilation					0.95 (0.92, 0.97)	<.001
Presence or placement of tracheostomy					1.03 (0.97, 1.09)	0.387
Cardiac arrest					0.82 (0.74, 0.91)	<.001
Performance of CPR					1.08 (0.94, 1.23)	0.262
Hospital ownership *(ref=government)*						
Private, non-profit					0.99 (0.97, 1.01)	0.394
Private, for-profit					1.04 (1.02, 1.06)	<.001
Hospital teaching status *(ref=Non-teaching)*						
Teaching Hospital					1.01 (0.99, 1.02)	0.307
Hospital location *(ref=Large metro area)*						
Small metro area					0.94 (0.92, 0.95)	<.001

Micropolitan area	0.89 (0.87, 0.91)	<.001
Rural	0.87 (0.84, 0.90)	<.001
Hospital Bed Size *(ref=Small)*		
Medium	1.01 (0.99, 1.03)	0.207
Large	1.02 (1.00, 1.04)	0.049
Annual Discharge (per 10k)	1.01 (1.00, 1.02)	0.098
Proportion of Medicaid per 10%	1.00 (1.00, 1.01)	0.548

Table 16: Multilevel Logistic Regression models of Readmission using Elixhauser Index using Hospital Level random intercept (age 18 and older)

Model Info	**Model 1**		**Model 2**		**Model 3**	
N	1,682,629		1,679,169		1,677,941	
LL	-1,709,883.6		-1,701,310.5		-1,695,230.0	
df	3		22		41	
AIC	3,419,773.3		3,402,665.0		3,390,542.0	
BIC	3,419,810.3		3,402,936.3		3,391,047.8	
Predictors	**OR (95% CI)**	***P***	**OR (95% CI)**	***P***	**OR (95% CI)**	***P***
Elixhauser Index *(per 3)*	1.06 (1.06, 1.06)	<.001	1.05 (1.05, 1.06)	<.001	1.05 (1.05, 1.05)	<.001
Year *(ref=2010)*						
2011			0.99 (0.97, 1.01)	0.469	0.99 (0.97, 1.01)	0.432
2012			0.95 (0.93, 0.97)	<.001	0.95 (0.93, 0.97)	<.001
2013			0.91 (0.89, 0.93)	<.001	0.91 (0.89, 0.93)	<.001
2014			0.89 (0.87, 0.91)	<.001	0.89 (0.87, 0.90)	<.001
2015			0.86 (0.84, 0.88)	<.001	0.86 (0.84, 0.88)	<.001
2016			0.86 (0.84, 0.88)	<.001	0.85 (0.83, 0.87)	<.001
Quarter *(ref=1st)*						
2nd Quarter			0.96 (0.95, 0.98)	<.001	0.97 (0.95, 0.98)	<.001
3rd Quarter			1.00 (0.98, 1.01)	0.618	1.00 (0.99, 1.01)	0.912
4th Quarter			0.98 (0.97, 1.00)	0.008	0.99 (0.97, 1.00)	0.044
Sex *(ref=male)*						
Female			0.93 (0.93, 0.94)	<.001	0.92 (0.91, 0.92)	<.001
Age *(per 10 year)*			1.01 (1.00, 1.01)	<.001	0.99 (0.98, 0.99)	<.001
Income Quartile *(ref=1st)*						
2nd Quartile			0.98 (0.97, 1.00)	0.033	0.98 (0.97, 1.00)	0.008
3rd Quartile			0.98 (0.97, 1.00)	0.012	0.97 (0.95, 0.98)	<.001
4th Quartile			0.97 (0.95, 0.99)	<.001	0.95 (0.93, 0.97)	<.001
Missing			0.97 (0.93, 1.01)	0.164	0.97 (0.93, 1.01)	0.156
Payer *(ref=Medicare)*						
Medicaid			1.06 (1.05, 1.08)	<.001	1.07 (1.05, 1.09)	<.001
Private			0.70 (0.68, 0.71)	<.001	0.71 (0.70, 0.72)	<.001
Self-Pay			0.61 (0.59, 0.63)	<.001	0.63 (0.61, 0.65)	<.001
Other/No Charge			0.78 (0.76, 0.81)	<.001	0.80 (0.77, 0.82)	<.001
Disposition *(ref=Routine to home)*						
Post-acute care					1.20 (1.18, 1.22)	<.001
Other					1.07 (1.00, 1.14)	0.037
Home Health					1.30 (1.28, 1.32)	<.001
LOS *(per day)*					1.01 (1.01, 1.01)	<.001
Care intensity *(ref=No)*						
Non-invasive ventilation					1.09 (1.07, 1.11)	<.001
Mechanical ventilation					0.82 (0.79, 0.84)	<.001
Presence or placement of tracheostomy					1.05 (0.99, 1.11)	0.114
Cardiac arrest					0.82 (0.74, 0.90)	<.001
Performance of CPR					1.08 (0.95, 1.24)	0.233
Hospital ownership *(ref=government)*						
Private, non-profit					0.98 (0.96, 1.00)	0.017
Private, for-profit					1.03 (1.01, 1.06)	0.001
Hospital teaching status *(ref=Non-teaching)*						
Teaching Hospital					1.00 (0.99, 1.02)	0.937
Hospital location *(ref=Large metro area)*						
Small metro area					0.93 (0.92, 0.95)	<.001

Micropolitan area	0.90 (0.88, 0.92)	<.001
Rural	0.89 (0.86, 0.92)	<.001
Hospital Bed Size *(ref=Small)*		
Medium	1.01 (0.99, 1.03)	0.447
Large	1.01 (0.99, 1.03)	0.463
Annual Discharge (per 10k)	1.01 (1.00, 1.03)	0.008
Proportion of Medicaid per 10%	1.00 (0.99, 1.01)	0.840

Chapter 5: Factors associated with differential readmission diagnoses following acute exacerbations of COPD

Abstract

Rationale

Readmissions after exacerbations of chronic obstructive pulmonary disease (COPD) are penalized under the Hospital Readmissions Reduction Program (HRRP). Understanding attributable diagnoses at readmission would be useful for planning readmission reduction priorities.

Objectives

Determine the factors that portend readmission attributable to COPD versus non-COPD diagnoses among patients discharged following COPD exacerbations.

Methods

We analyzed COPD discharges in the Nationwide Readmissions Database from 2010 to 2016 mirroring inclusion and readmission definitions in HRRP. We evaluated readmission odds for COPD versus non-COPD returns using a multilevel, multinomial logistic regression model, adjusting for patient and hospital factors.

Measurements

Patient factors included age, sex, community characteristics, income, payer, discharge disposition, and Elixhauser comorbidity score. Hospital factors included hospital ownership, teaching status, volume of annual discharges, and proportion of Medicaid patients.

Main Results

Of 1,622,983 COPD index hospitalizations, 17.25% were readmitted within 30 days (7.69% for COPD and 9.46% for other diagnoses). Sepsis, heart failure, and respiratory infections were the most common non-COPD return diagnoses. Patients readmitted for COPD were younger, had less comorbid disease, and were more likely to have been discharged home. COPD returns were more common in the first 2 days after discharge, while non-COPD causes were more common in the remainder of follow up.

Conclusions

Readmissions following COPD exacerbations are common, and 55% of them are attributable to non-COPD diagnosis related groups at the time of return, with higher burden of comorbidity in the non-COPD return group. Readmission reduction efforts should focus intensively on factors beyond COPD disease management to meaningfully reduce readmissions.

Introduction

Readmissions of patients following hospitalization for acute exacerbations of chronic obstructive pulmonary disease (COPD) are common events with high economic burden [125]. The Patient Protection and Affordable Care Act of 2010 [65] outlined the Hospital Readmissions Reduction Program (HRRP). The HRRP aims to improve quality of care and reduce the cost of healthcare delivery to patients with the key conditions of pneumonia, myocardial infarction, congestive heart failure initially, and expanded to include COPD starting in October 2014 [64]. With the implementation of the HRRP, readmission reduction has become a key priority for health systems.

Multiple approaches to reduce readmissions are published and these programs have met variable degrees of success [92]. Many of these programs have focused on improving COPD care by improving medication adherence or focusing on disease control. Patient self-management programs have significant heterogeneity with inconsistent readmission reductions [55,56], while transitional care programs have shown some promise [57,58]. Though telehealth monitoring programs may predict COPD exacerbations [59], they have not have a consistent effect on health related quality of life or reduction of hospitalization [60]. Early referral to pulmonary rehabilitation has been shown to increase quality of life and symptom management but not decreased healthcare utilization [61]. Dispensing respiratory medications at hospital discharge showed higher rates of prescription fills and fewer readmissions [62]. Short-term, post-discharge oxygen therapy did not have a significant effect on health-related quality of life or acute care utilization [63].

The fact that these approaches have not been reliably successful begs the question of what factors are truly driving COPD readmissions. A previous study showed differences in

factors predicting timing of COPD readmissions and outlined that not all returns are related to persistent COPD exacerbations [54]. Comorbid conditions are frequently observed in the COPD patient population [93], and these likely play at least some role in the risk of undesirable outcomes like readmissions following an exacerbation [99,107].

Understanding the nature of readmissions at the time of return to hospital is key for planning and implementing effective readmission reduction programs. In this analysis, we will explore how key factors influence differing readmission risks between return for persistent or recurrent COPD exacerbations and those returning for some other diagnosis. While the HRRP is a Medicare-specific program, health systems are likely to use programs targeted at their entire payer mix when planning readmission reduction strategies. Previous analyses have largely been limited to either single-center studies of readmissions [126], Medicare claims [53], or private insured claims [127]. Using a sample that includes an all-payer mix and covers a large geographic area across the United States will allow for better estimates of factors influencing readmission risk and is the subject of this analysis.

Methods

Study Population

The Nationwide Readmissions Database (NRD) is an aggregated, national, all-payer sample of community acute care hospital discharges from multiple State Inpatient Databases [84]. The NRD was queried and discharge records pooled spanning January 2010 to December 2016. Records were excluded if the patient was not a resident of the state in which they were hospitalized to minimize loss to follow up. Sample weights were provided by the NRD to better approximate the dataset to known national

estimates across age, sex, and hospital types [86]. A more detailed explanation of the database construction and inclusion criteria can be found in the supplemental methods.

Measurements

For our main inclusion criteria and outcome measures, we mirrored the methodology used by the HRRP [87,88]. We defined an index stay as discharge of a patient at least 40 years of age for a qualifying COPD diagnosis, discharged alive, with at least 30 days having elapsed since a prior hospitalization. We excluded discharges if they involved a lung transplant, were against medical advice, or if they took place in a hospital with fewer than 25 COPD discharges in that calendar year. Since this is a pooled cross-sectional analysis and record identifiers were not reliably unique across years, we restricted observations to stays originating in February through November, as January stays may not have had the requisite washout period, and December stays could not be tracked into January. We defined readmissions as a subsequent hospitalization for any cause within 30 days of the index discharge date, with some exemptions as defined by the HRRP [87,88]. We further divided the readmission outcome into two parts: those readmitted with diagnoses that would have qualified as a COPD stay under the HRRP criteria, and those that were for any other cause.

Key covariates that were provided with the database included sociodemographic variables (*e.g.,* age, sex, community characteristics, payer, and median income at patient's ZIP code), discharge diagnoses, and hospital characteristics (*e.g.*, size, ownership, teaching status). We constructed additional covariates to account for key in-hospital events by aggregating across ICD diagnosis and procedure codes (*e.g.* mechanical ventilation), hospital discharge volume, and the Elixhauser Comorbidity

Index score [111], and calculated the proportion of annual within-hospital Medicaid patient days as a surrogate marker for safety-net hospitals.

Statistical Analysis

We tabulated patient-level descriptive statistics across the 3 groups of interest (*i.e.,* not readmitted, readmitted for a stay that would have qualified as COPD-related by HRRP criteria, and readmitted for any other diagnosis). Continuous variables were compared using Welch's t-tests (*i.e.* unequal variance) and categorical variables were compared using Chi squared tests. At the hospital level, we tabulated the proportions of hospitals within categories in key variables of interest and a sub-population readmission rate for that particular characteristic, which were tested for differences using Chi squared tests. We also tabulated the Diagnosis Related Group (DRG) coded for the readmission stay in order to capture attributable diagnoses at the time of readmission.

A multilevel, multinomial logistic regression was fit with random intercepts at the hospital cluster level, with the tripartite readmission outcome described above using the "not readmitted" patients as the reference group. We included fixed effects for year, patient-level, and hospital-level covariates as described above. We also fit a Cox proportional hazards model within the readmitted patient subgroup with Huber-White standard errors clustered at the hospital level to estimate the differential hazard of readmission for COPD versus non-COPD diagnoses across key covariates of interest. Time to readmission for each group was plotted to assess the time distribution for each outcome. In-hospital mortality during each readmission event was tabulated.

We designated a threshold of 10% missing data to necessitate imputation techniques, determined *a priori* for variables of interest, none of which met this level.

Complete case analyses were used for both models. We conducted sensitivity analyses to determine whether a lower age cutoff (≥18 years) affected modelling. We also tested the stability of our estimates across each individual year of the pooled analysis. Analyses were performed in Stata version 15.1 (StataCorp, College Station, TX) with weighted estimates reported using patient level survey weights for national representativeness. The study protocol was reviewed by the institutional review board at the University of California, Los Angeles, and deemed exempt from oversight due to the publicly available, deidentified nature of the data (IRB# 18-001208).

Results

A final sample of 1,622,983 qualifying COPD discharges were included in the pooled analysis, with a weighted effective population estimate of 3,743,164. The overall readmission rate was 17.25%, with 7.69% of patients readmitted for recurrent COPD and 9.46% readmitted for other diagnoses. Patient-level characteristics are found in Table 17. Those readmitted for recurrent COPD were significantly younger (66.9 vs. 70.1 years) with a lower proportion of Medicare (70.7% vs. 77.2%) and a higher proportion of Medicaid (15.4% vs. 11.1%) as primary payer compared to those readmitted for non-COPD causes. Those readmitted for recurrent COPD were more frequently discharged home without services (65.3% vs. 55.9%) and had shorter lengths of stay (4.62 vs. 4.06 days). Mechanical ventilation was more frequent among COPD-readmitted patients, while non-invasive ventilation and tracheostomy placement were less frequent. COPD-readmitted patients had lower mean Elixhauser Comorbidity Index scores (17.8 vs. 22.8), with markedly lower rates of congestive heart failure (28.3% vs.

38.6%) and renal failure (11.8% vs. 21.5%) compared to those readmitted for other causes (Table 18).

Hospital characteristics with differential readmission rates between types are shown in Table 19. The readmission rates were higher for non-COPD causes than for COPD causes across all hospital types. Generally parallel patterns of readmission rates were observed in the non-COPD and COPD cause groups, with two key exceptions. Across categories of hospital ownership, for-profit hospitals had the highest readmission rates for non-COPD causes, while rates were equal across all groups in the COPD cause group. In addition, while the rates were not significantly different in the non-COPD cause group across quartiles of proportions of Medicaid patient-days, within the COPD cause group, readmission rates increased across Medicaid quartiles.

An evaluation of temporal trends of readmission rates is plotted in Figure 8, where within-year (panels A and B) and across-study rates (panels C and D) are shown. We observed an overall downward trend in raw readmission rates for each group over the study period (Table 22). The coded DRGs for the non-COPD rehospitalizations are shown in Table 4. Sepsis, heart failure, and respiratory infections made up 7 of the top 10 ranked DRGs. In-hospital mortality during readmission stays was higher for non-COPD causes and stable throughout the study period (Table 23).

In the fully adjusted multinomial logistic regression model (Table 21), where the outcomes were not readmitted (reference category) versus readmitted for non-COPD diagnosis or for qualifying COPD diagnosis, the effect size of comorbidity, operationalized by change in the Elixhauser Comorbidity Index was larger for non-COPD group (OR 1.19 vs. 1.04 per ½ standard deviation, an approximately 7.5 unit

change in score). Increases in age were associated with higher non-COPD readmissions (OR 1.06 per 10 years), while actually protective against COPD causes (OR 0.89). Compared to Medicare, Medicaid patients had higher odds of COPD-related readmission (OR 1.10 vs. 1.03) while the converse was observed in the privately insured (OR 0.65 vs. 0.76). Transfers to post-acute care facilities, referenced against discharges home, had a larger association with readmissions for non-COPD causes (OR 1.35 vs. 1.00), while home-health had nearly equal adjusted readmission odds for each outcome (1.31 vs. 1.30). Increases in length of stay had 1% higher odds per day for readmission for non-COPD causes than COPD returns. Regarding in-hospital events, odds of COPD returns were higher for non-invasive ventilation (OR 1.37 vs. 0.89) and mechanical ventilation (OR 0.87 vs. 0.79).

To examine whether time to readmission influenced the reason for return, we included a Cox proportional hazards model, restricted to only the readmitted patients to determine possible predictors of differential time to readmission among the two readmission outcomes. There were not substantial differences using this approach compared to the multinomial model (Table 24). The proportion of patients readmitted on each day of follow up was plotted (Figure 9) to estimate the time to each of the two events, which showed that the median readmission time for non-COPD causes was 13 days compared to 14 days for COPD. Slightly more COPD readmissions occurred in the first 2 days after discharge however after approximately 2.4 days the proportion of non-COPD cases readmitted became consistently greater.

In sensitivity analyses, we evaluated the same model without the comorbidity adjustment (only covariates) and found minor adjustments to the effect sizes of the

covariates, particularly in the effect size of discharge disposition, however no sign changes for any of the odds ratios (Table 25). Readmission odds by Elixhauser score for each condition estimates across years (Figure 10), with overlapping confidence intervals at each year (Table 26). Regarding age differences, including 18-39 year-old patients in the cohort did not substantially change the readmission rates by condition, readmission diagnoses, or in-hospital death during readmission. Readmission odds for each condition of interest were not substantially different in the age-expanded model (Table 27).

Discussion

In this assessment of readmission odds following hospitalizations for COPD in a nationally representative all-payer sample, we evaluated factors that influenced whether a patient returned to hospital for recurrent COPD or for other causes. Consistent with a study of Medicare patients across seven states by Shah and colleagues, we also demonstrated that the majority of returns are for causes other than COPD [53]. Our findings are also consistent with those described by Jacobs and colleagues using the same source of data, though their analysis was limited to 2013-14 [54]. Our study offers an expanded analysis by including data from both before and after the HRRP penalties went into effect for COPD in October 2014 [64]. Our analysis also adds to the existing body of literature by assessing which factors are associated with readmissions related to ongoing COPD, versus those for other causes.

In a 2018 report, the American Thoracic Society highlighted the focus of programs on adherence to guidelines and reducing variability in COPD care as a potential pitfall in efforts to reduce COPD readmissions [128]. The majority (55%) of

patients who are readmitted return for causes other than COPD. This important finding further highlights the need to ensure that readmission reduction programs not only focus on COPD control, but on the overall management of the patient's often complex medical comorbidities. The HRRP penalties are assessed for readmission for any reason [87,88], and attention to the entire range of reasons people return to hospital, rather than only on factors influencing COPD management will be important in the effort to reduce readmission rates and costs. Use of strategies like multi-specialty clinics or integrated practice units may be useful in mitigating risk in the multimorbid COPD patient.

In our study, an increase in aggregated comorbidity by Elixhauser Index was associated with a significantly higher readmission odds, with nearly 5 times the effect size for non-COPD compared to COPD returns. While overall readmission rates did decline across the course of the study period, the effect of comorbidity on readmission odds for both groups remained significant. We also observed higher rates of nearly every individual Elixhauser component comorbidity in those readmitted for non-COPD causes. Taken together, these results underscore the need to account for comorbidities both at the individual and composite level when identifying those at highest risk for readmissions and necessitate a multi-disciplinary approach in order to reduce risk for the multimorbid patient.

Other significant factors that deserve further investigation include the use of post-acute care services including home health and skilled nursing facilities. Both of these were associated with higher likelihood of returning for non-COPD than for COPD-related causes, as well. This may be collinear to some degree with comorbidity, as more complex patients are probably less likely to be discharged home directly, but it is

interesting that those discharged to a post-acute care facility had such substantially higher odds of readmission for a non-COPD cause, with an adjusted odds ratio of 1.35. Use of transitional care programs, including short stays in nursing home have often been employed to mitigate the risk of adverse outcomes after discharge in sicker patients [129], which may be insufficient based on these data.

We elected to apply the HRRP criteria for coding a COPD-related admission to the readmission diagnoses, which is more stringent than using just a principal diagnosis or the Diagnosis Related Group. The rationale for doing so was to maintain the same standard for defining both the index and readmission event. We used Diagnosis Related Groups to further classify the readmission causes in order to use the same grouping logic that a payer would use when determining cause. When evaluating which DRGs patients returned for following a COPD exacerbation, pneumonia or other respiratory infections make up 13.8%, which may represent the evolution of respiratory infections that provoked the original exacerbation. Congestive heart failure (CHF) comprised 9.1% of the non-COPD causes, with about 1/3 of our COPD cohort having known comorbid CHF at the time of index admission, illustrating significant overlap between these two conditions. Both CHF and pneumonia are conditions of interest in the HRRP and would potentially garner their own penalties had sufficient time elapsed since a prior hospitalization. Among other causes in the top 20 return DRGs were esophagitis, gastritis, gastrointestinal bleeding, and psychoses, which may be potentially associated with the use of corticosteroids to treat a COPD exacerbation, as described in other population studies [130,131]. Lack of medication regimen data in our analysis precludes

further attribution of these causes, but the potential associations are interesting and warrant additional study.

Limitations

The structure of our data as pooled annual cross sections rather than a true longitudinal cohort limited us to use only 10 months (February to November) of index hospitalizations in order to stay aligned with HRRP policy inclusion criteria. As such, we may have missed some important observations during peak respiratory virus season. As in any administrative data analysis, we are beholden to the diagnostic and procedure codes in the discharge records, which may not necessarily reflect the true nature of a hospitalization. Despite these limitations, we were left with a robust and representative national cohort, making this an acceptable tradeoff.

Conclusion

Our study highlights the importance of understanding comorbidity as a major determinant of readmissions following COPD exacerbations, in particular in distinguishing which patients will return for COPD versus non-COPD related complaints. At the health system level, readmission programs should be designed with the multimorbid patient in mind. Engagement of care teams, facilitating communication, and shared decision making have all been identified as strategies to mitigate readmission risk in addition to COPD-focused disease management [128]. Our findings further highlight the need to move beyond COPD care alone. Development of systems to prospectively identify which patients are at risk for return for both COPD and non-COPD reasons may further elucidate readmission mitigation strategies and should be a subject of future study.

Tables and Figures

Table 17: Baseline patient-level characteristics of the aggregated cohort, comparing COPD and Non-COPD related readmissions to non-readmitted patients in index stays

	Not Readmitted N=1,375,099	**Non-COPD Readmitted** N=159,675	**COPD Readmitted** N=128,209	***P***
Sex, *%*				
Male	40.8%	43.0%	42.5%	<.001
Female	59.2%	57.0%	57.5%	
Age, *Mean ± SD*	67.9 ± 11.9	70.1 ± 11.9	66.9 ± 11.3	<.001
Median household income, *%*				
1st Quartile	37.0%	36.4%	38.8%	<.001
2nd Quartile	26.8%	26.4%	26.3%	
3rd Quartile	20.9%	21.1%	20.3%	
4th Quartile	13.9%	14.8%	13.2%	
Missing	1.4%	1.3%	1.4%	
[1]**Patient geographic location**, *%*				
Central county metro area ≥1M	22.0%	23.4%	23.6%	<.001
Fringe county metro area ≥1M	24.4%	25.9%	25.1%	
County metro area 250,000-999,999k	20.9%	20.2%	20.6%	
County metro area 50,000-249,999k	10.4%	10.0%	10.2%	
Micropolitan area	13.1%	12.2%	12.1%	
Non-metro/non-micropolitan (rural)	9.1%	8.2%	8.4%	
[2]**Primary Payer**, *%*				
Medicare (includes dual-eligible)	69.6%	77.2%	70.7%	<.001
Medicaid	11.8%	11.1%	15.4%	
Private insurance	12.3%	8.0%	8.7%	
Self-pay	3.4%	1.6%	2.4%	
Other, including no-charge	3.0%	2.2%	2.8%	
Number of admissions each patient had over a year, *Mean ± SD*	2.13 ± 1.60	4.06 ± 2.30	4.62 ± 2.69	<.001
Number hospitals where each patient each received care over a year, *Mean ± SD*	1.31 ± 0.64	1.29 ± 0.61	1.62 ± 0.86	<.001
Discharge disposition, *%*				
Routine to home	69.1%	55.9%	65.3%	<.001
Transfer to post-acute care	12.4%	19.6%	12.1%	
Home with home health services	17.8%	23.6%	21.9%	
Other	0.7%	0.9%	0.7%	
[§]**Length of Stay**, *Mean ± SD*	3.67 ± 1.96	4.39 ± 2.58	3.88 ± 2.11	<.001
Care intensity and complications, *%*				
Use of non-invasive ventilation	7.7%	8.6%	10.9%	<.001
Use of mechanical ventilation	4.5%	6.4%	4.8%	<.001
Placement or presence of tracheostomy	0.8%	1.4%	0.9%	<.001
Cardiac arrest	0.2%	0.3%	0.2%	<.001
Performance of cardiopulmonary resuscitation	0.1%	0.2%	0.1%	<.001

Note: Unweighted N's displayed. Frequencies derived using weighted analysis. [§]Geometric Mean and SD for log transformed variable presented [1]N's 1,373,301 & 159,378 & 127,918; [2]N's 1,372,214 & 159,407 & 127,955

Table 18: Baseline comorbidity characteristics of the aggregated cohort, comparing COPD and Non-COPD related readmissions to non-readmitted patients in index stays.

	Not Readmitted N=1,375,099	**Non-COPD Readmitted** N=159,675	**COPD Readmitted** N=128,209	***P***
Elixhauser Readmission Index, *Mean ± SD*	16.3 ± 14.7	22.8 ± 16.4	17.8 ± 14.9	<.001
Elixhauser Domain Count, *Mean ± SD*	3.92 ± 1.81	4.62 ± 1.93	4.05 ± 1.84	<.001
Elixhauser Component Comorbidities, *%*				
Congestive heart failure	25.4%	38.6%	28.3%	<.001
Valvular heart disease	6.2%	9.1%	5.6%	<.001
Pulmonary circulation disorders	7.6%	10.4%	9.0%	<.001
Peripheral vascular disease	7.7%	10.4%	7.6%	<.001
Hypertension (complicated + uncomplicated)	54.5%	50.0%	54.9%	<.001
Paralysis	1.2%	1.9%	1.1%	<.001
Other neurologic disorders	8.3%	10.5%	8.9%	<.001
Chronic pulmonary disease	100.0%	100.0%	100.0%	---
Diabetes mellitus (uncomplicated)	25.8%	29.2%	27.4%	<.001
Diabetes mellitus (complicated)	5.7%	8.4%	5.9%	<.001
Hypothyroidism	13.6%	15.3%	12.5%	<.001
Renal failure	12.3%	21.5%	11.8%	<.001
Liver disease	2.3%	3.2%	2.4%	<.001
Peptic ulcer disease	0.1%	0.2%	0.1%	0.062
HIV/AIDS	0.2%	0.3%	0.3%	<.001
Lymphoma	0.5%	0.8%	0.5%	<.001
Metastatic cancer	1.0%	2.2%	1.0%	<.001
Solid tumor without metastasis	3.1%	5.5%	3.6%	<.001
RA/collagen vascular disorders	3.3%	3.9%	3.0%	<.001
Coagulopathy	3.1%	4.5%	3.0%	<.001
Obesity	19.0%	19.9%	19.3%	<.001
Weight loss	4.5%	5.7%	4.9%	<.001
Fluid and electrolyte disorders	27.4%	33.2%	28.0%	<.001
Blood loss anemia	0.3%	0.6%	0.3%	<.001
Deficiency anemia	14.4%	22.3%	17.0%	<.001
Alcohol abuse	4.5%	4.7%	4.9%	<.001
Drug abuse	3.5%	3.9%	4.7%	<.001
Psychoses	6.1%	7.4%	7.8%	<.001
Depression	16.7%	17.0%	18.7%	<.001

Note: Unweighted N's displayed. Frequencies derived using weighted analysis.

Table 19: Baseline characteristics of hospitals included in pooled cohort

	Cohort Proportion	Non-COPD Rate	Non-COPD *P*	COPD Rate	COPD *P*
Hospital ownership/control, *%*					
Government, non-federal	16.1%	9.1%	<.001	7.7%	0.965
Private, non-profit	62.9%	9.6%		7.7%	
Private, for-profit	21.0%	9.8%		7.7%	
Hospital teaching status, *%*					
Metro, non-teaching	44.2%	9.8%	<.001	7.6%	<.001
Metro, teaching	30.0%	9.7%		7.9%	
Non-metro, non-teaching	25.8%	8.7%		7.3%	
Hospital geographic location, *%*					
Large metro area ≥1M	43.7%	10.1%	<.001	7.9%	<.001
Small metro area <1M	30.5%	9.3%		7.5%	
Micropolitan area	15.3%	8.8%		7.3%	
Non-metro/non-micropolitan (rural)	10.5%	8.3%		7.3%	
Hospital bed size, *%*					
Small	26.6%	9.1%	<.001	7.5%	<.001
Medium	32.3%	9.5%		7.7%	
Large	41.1%	9.7%		7.7%	
Hospital total all-cause annual discharges, *Mean ± SD*	6,296 ± 6,425				
Quartiles of Hospital total all-cause annual discharges, *%*					
1st Quartile (≤ 8,971)	59.2%	8.3%	<.001	7.2%	<.001
2nd Quartile (8,972 – 15,406)	20.8%	9.3%		7.5%	
3rd Quartile (15,407 – 24,534)	13.0%	9.7%		7.7%	
4th Quartile (≥24,535)	7.1%	9.9%		7.9%	
COPD Discharges, *Mean ± SD*	161 ± 133				
COPD Discharge Quartiles					
1st Quartile (≤ 122)	48.5%	8.8%	<.001	7.0%	<.001
2nd Quartile (123 – 205)	24.0%	9.5%		7.5%	
3rd Quartile (206 – 322)	17.1%	9.7%		7.9%	
4th Quartile (≥ 323)	10.3%	10.0%		8.1%	
Proportion Medicaid patient days, *Mean ± SD*	17.1% ± 11.2%				
Medicaid Proportion Quartiles, *%*					
1st Quartile (≤ 10.6%)	31.5%	9.6%	0.451	7.2%	<.001
2nd Quartile (10.6% - 16.1%)	25.4%	9.6%		7.7%	
3rd Quartile (16.1% - 23.9%)	22.8%	9.5%		7.8%	
4th Quartile (≥ 23.9%)	20.4%	9.5%		8.2%	

Note: Unweighted N's and Frequencies displayed for cohort proportions.
Weighted frequencies for Sub-Strata readmission rates presented.
P values are for between hospital characteristic differences in readmission rates.

Table 20: Top 20 Diagnosis Related Groups for Non-COPD related readmissions

Rank	DRG	%
1	871: Septicemia or severe sepsis without mechanical ventilation for > 96 hours with major complication or comorbidity	7.8%
2	291: Heart failure and shock with major complication or comorbidity	5.6%
3	193: Simple pneumonia and pleurisy with major complication or comorbidity	5.4%
4	194: Simple pneumonia and pleurisy with complication or comorbidity	4.2%
5	292: Heart failure and shock with complication or comorbidity	3.5%
6	177: Respiratory infections and inflammations with major complication or comorbidity	2.5%
7	392: Esophagitis, gastroenteritis, and miscellaneous digestive disorders without major comorbidity or complication	2.4%
8	178: Respiratory infections and inflammations with complication or comorbidity	1.7%
9	309: Cardiac arrhythmia and conduction disorders with complication or comorbidity	1.6%
10	885: Psychoses	1.5%
11	683: Renal failure with comorbidity or complication	1.5%
12	313: Chest pain	1.5%
13	378: Gastrointestinal hemorrhage with comorbidity or complication	1.4%
14	641: Miscellaneous disorders of nutrition, metabolism, or fluids/electrolytes without major comorbidity or complication	1.4%
15	603: Cellulitis without major comorbidity or complication	1.4%
16	189: Pulmonary edema and respiratory failure	1.2%
17	308: Cardiac arrhythmia and conduction disorders with major complication or comorbidity	1.2%
18	682: Renal failure with major comorbidity or complication	1.2%
19	312: Syncope and collapse	1.2%
20	All Others	51.5%

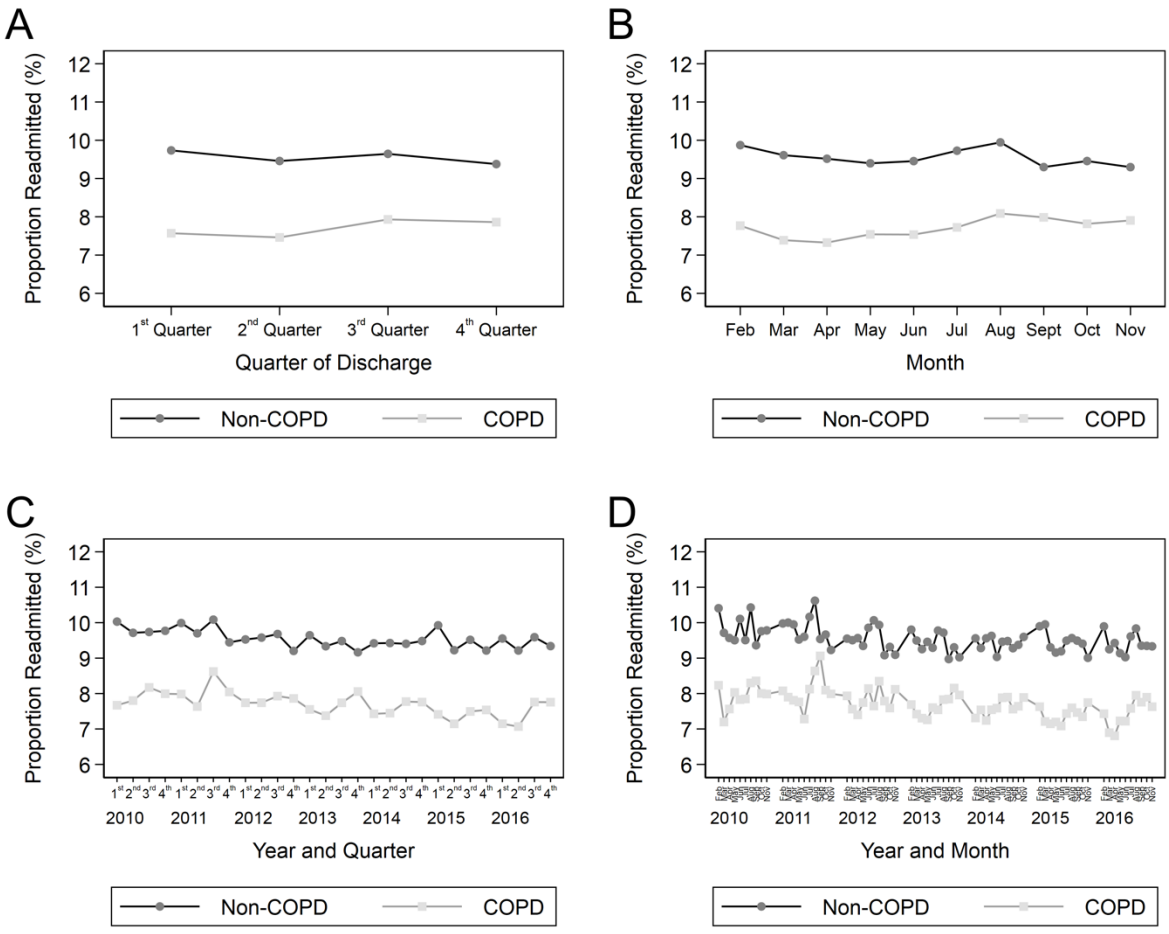

Figure 8: Readmission rates for COPD and Non-COPD by quarter (panel A), month (panel B),

Table 21: Multilevel Multinomial Logistic Regression models of Readmission using Elixhauser Index using Hospital Level random intercept.

Model Info	**Model 1**		**Model 2**		**Model 3**	
N	1,662,983		1,659,576		1,658,372	
LL	-2,128,251.5		-2,114,269.5		-2,105,502.3	
df	5		43		81	
AIC	4,256,513.0		4,228,625.0		4,211,166.5	
BIC	4,256,574.5		4,229,155.0		4,212,164.5	
Predictors	**Non-COPD** *ref=Not Readmitted*	**COPD** *ref=Not Readmitted*	**Non-COPD** *ref=Not Readmitted*	**COPD** *ref=Not Readmitted*	**Non-COPD** *ref=Not Readmitted*	**COPD** *ref=Not Readmitted*
Elixhauser *(per ½ SD)*	*1.22 (1.22, 1.23)	*1.06 (1.06, 1.06)	*1.21 (1.21, 1.21)	*1.06 (1.05, 1.06)	*1.19 (1.19, 1.19)	*1.04 (1.04, 1.05)
Year *(ref=2010)*						
2011			0.98 (0.96, 1.01)	1.01 (0.98, 1.04)	0.98 (0.96, 1.01)	1.00 (0.97, 1.03)
2012			*0.94 (0.91, 0.97)	*0.97 (0.94, 1.00)	*0.94 (0.92, 0.97)	*0.96 (0.93, 0.99)
2013			*0.90 (0.87, 0.92)	*0.93 (0.90, 0.96)	*0.90 (0.88, 0.93)	*0.92 (0.89, 0.95)
2014			*0.88 (0.85, 0.90)	*0.91 (0.88, 0.94)	*0.86 (0.84, 0.88)	*0.92 (0.89, 0.95)
2015			*0.85 (0.83, 0.87)	*0.87 (0.84, 0.89)	*0.86 (0.84, 0.89)	*0.85 (0.82, 0.87)
2016			*0.84 (0.82, 0.87)	*0.88 (0.85, 0.90)	*0.85 (0.82, 0.87)	*0.86 (0.83, 0.88)
Quarter *(ref=1st)*						
2nd Quarter			*0.95 (0.94, 0.97)	*0.97 (0.96, 0.99)	*0.96 (0.94, 0.98)	*0.97 (0.96, 0.99)
3rd Quarter			*0.97 (0.96, 0.99)	*1.03 (1.01, 1.05)	*0.98 (0.96, 1.00)	*1.03 (1.01, 1.05)
4th Quarter			*0.95 (0.93, 0.97)	*1.02 (1.00, 1.04)	*0.96 (0.94, 0.98)	*1.02 (1.00, 1.04)
Sex *(ref=male)*						
Female			*0.94 (0.93, 0.95)	*0.92 (0.91, 0.94)	*0.92 (0.91, 0.93)	*0.91 (0.90, 0.93)
Age *(per 10 years)*			*1.10 (1.09, 1.11)	*0.90 (0.90, 0.91)	*1.06 (1.05, 1.07)	*0.89 (0.89, 0.90)
Income Quartile *(ref=1st)*						
2nd Quartile			1.00 (0.98, 1.02)	*0.97 (0.95, 0.99)	0.99 (0.98, 1.01)	*0.97 (0.95, 0.98)
3rd Quartile			0.99 (0.98, 1.01)	*0.97 (0.95, 0.99)	0.99 (0.97, 1.00)	*0.95 (0.93, 0.97)
4th Quartile			1.00 (0.97, 1.02)	*0.94 (0.91, 0.96)	0.98 (0.96, 1.00)	*0.91 (0.89, 0.94)
Missing			0.95 (0.90, 1.00)	0.99 (0.94, 1.05)	*0.95 (0.90, 1.00)	0.99 (0.94, 1.05)
Payer *(ref=Medicare)*						
Medicaid			*1.02 (1.00, 1.05)	*1.10 (1.07, 1.12)	*1.03 (1.01, 1.06)	*1.10 (1.07, 1.12)
Private			*0.74 (0.72, 0.76)	*0.64 (0.63, 0.66)	*0.76 (0.74, 0.78)	*0.65 (0.63, 0.67)
Self-Pay			*0.60 (0.57, 0.63)	*0.60 (0.57, 0.63)	*0.62 (0.59, 0.65)	*0.62 (0.59, 0.65)
Other/No Charge			*0.76 (0.73, 0.79)	*0.80 (0.76, 0.83)	*0.77 (0.74, 0.80)	*0.81 (0.78, 0.85)
Disposition *(ref=Routine to home)*						
Post-acute care					*1.35 (1.33, 1.38)	1.00 (0.98, 1.03)

Other	*1.19 (1.11, 1.28)	0.92 (0.83, 1.01)
Home Health	*1.31 (1.29, 1.34)	*1.30 (1.27, 1.32)
LOS *(per day)*	*1.02 (1.01, 1.02)	*1.01 (1.00, 1.01)
Care intensity *(ref=No)*		
Non-invasive ventilation	*0.89 (0.87, 0.91)	*1.37 (1.34, 1.40)
Mechanical ventilation	*0.79 (0.76, 0.81)	*0.87 (0.84, 0.91)
Presence or placement of tracheostomy	1.07 (1.00, 1.14)	1.01 (0.92, 1.10)
Cardiac arrest	*0.87 (0.77, 0.98)	*0.68 (0.58, 0.81)
Performance of CPR	1.15 (0.98, 1.34)	0.98 (0.80, 1.21)
Hospital ownership *(ref=government)*		
Private, non-profit	*0.97 (0.95, 0.99)	0.99 (0.97, 1.01)
Private, for-profit	*1.05 (1.03, 1.08)	1.01 (0.98, 1.04)
Hospital teaching status *(ref=Non-teaching)*		
Teaching Hospital	0.98 (0.96, 1.00)	1.02 (1.00, 1.04)
Hospital location *(ref=Large metro area)*		
Small metro area	*0.94 (0.92, 0.95)	*0.93 (0.91, 0.95)
Micropolitan area	*0.91 (0.88, 0.93)	*0.89 (0.86, 0.92)
Rural	*0.88 (0.85, 0.92)	*0.89 (0.86, 0.93)
Hospital Bed Size *(ref=Small)*		
Medium	1.01 (0.98, 1.03)	1.01 (0.98, 1.03)
Large	1.01 (0.99, 1.04)	1.00 (0.98, 1.03)
Annual Discharge (per 10k)	*1.02 (1.01, 1.03)	1.00 (0.99, 1.02)
Proportion Medicaid per 10%	*0.99 (0.98, 1.00)	*1.01 (1.00, 1.02)

Note: Odds Ratios with 95% Confidence Intervals Presented. * denotes p <0.05

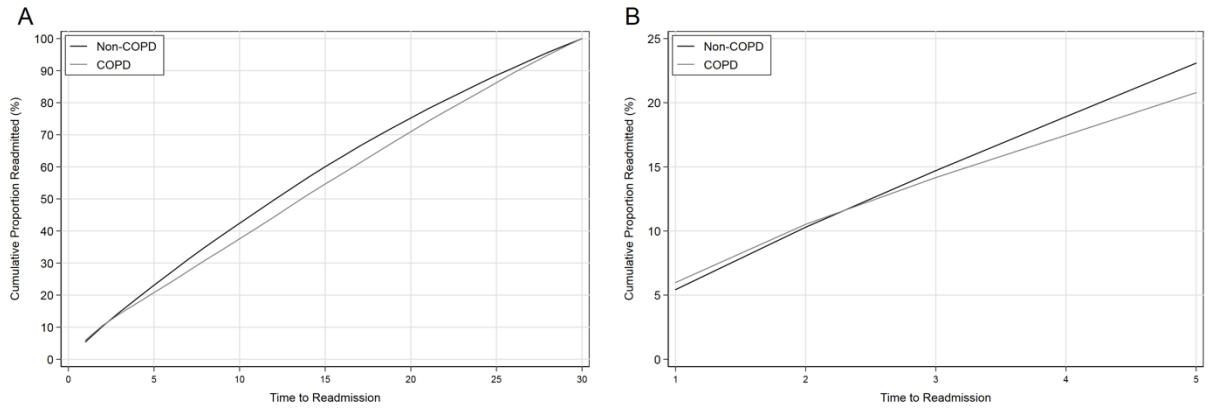

Figure 9: Proportional readmissions by readmission by cause showing overall distribution (A), and focused on point of crossing by linear interpolation (B)

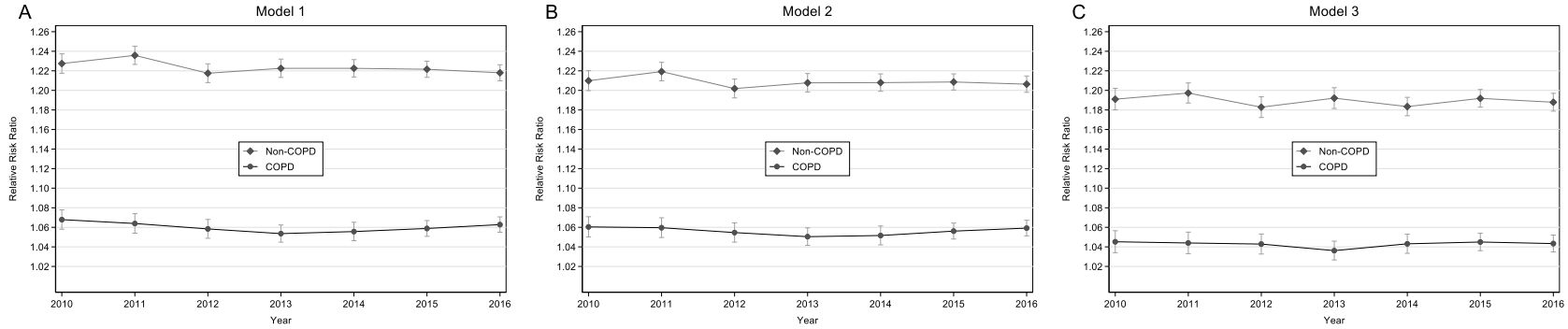

Figure 10: Estimates for the effect of the Elixhauser index over time on the risk of Non-COPD and COPD readmission. One-half standard deviation effect estimates presented

Table 22: Readmission rates by year

	Overall	2010	2011	2012	2013	2014	2015	2016
Non-COPD	9.56%	9.81%	9.82%	9.51%	9.42%	9.43%	9.47%	9.42%
COPD	7.69%	7.90%	8.04%	7.81%	7.64%	7.59%	7.37%	7.40%

Table 23: Among the readmitted, in-hospital death during following readmission by year

	Overall	2010	2011	2012	2013	2014	2015	2016
Non-COPD	6.05%	6.33%	6.34%	5.90%	6.08%	6.21%	5.65%	5.80%
COPD	3.49%	3.94%	3.50%	3.19%	3.53%	3.61%	3.14%	3.50%

Table 24: Cox Regression models of COPD Readmission using Elixhauser Index with Hospital Level clustering.

Model Info	**Model 1**		**Model 2**		**Model 3**	
N	287,884		287,362		287,186	
LL	-1,486,500.3		-3,555,481.8		-3,551,449.8	
df	1		20		39	
AIC	2,973,002.5		7,111,003.5		7,102,977.5	
BIC	2,973,013.3		7,111,214.5		7,103,390.0	
Predictors	**HR (95% CI)**	***P***	**HR (95% CI)**	***P***	**HR (95% CI)**	***P***
Elixhauser Index *(per 3)*	0.97 (0.97, 0.97)	<.001	0.97 (0.97, 0.97)	<.001	0.97 (0.97, 0.97)	<.001
Year *(ref=2010)*						
2011			1.01 (0.99, 1.04)	0.380	1.01 (0.98, 1.04)	0.487
2012			1.01 (0.98, 1.03)	0.617	1.00 (0.98, 1.03)	0.907
2013			1.00 (0.98, 1.03)	0.693	1.00 (0.97, 1.02)	0.763
2014			1.00 (0.97, 1.02)	0.901	1.02 (0.99, 1.04)	0.207
2015			0.99 (0.97, 1.02)	0.449	0.97 (0.95, 1.00)	0.045
2016			1.02 (1.00, 1.04)	0.109	1.01 (0.98, 1.03)	0.551
Quarter *(ref=1st)*						
2nd Quarter			0.99 (0.97, 1.00)	0.086	0.98 (0.97, 1.00)	0.033
3rd Quarter			0.98 (0.96, 0.99)	0.009	0.97 (0.96, 0.99)	0.002
4th Quarter			0.99 (0.97, 1.01)	0.405	0.99 (0.97, 1.01)	0.215
Sex *(ref=male)*						
Female			0.98 (0.96, 0.99)	<.001	0.98 (0.97, 1.00)	0.011
Age *(per 10 year)*			0.91 (0.90, 0.91)	<.001	0.92 (0.91, 0.93)	<.001
Income Quartile *(ref=1st)*						
2nd Quartile			1.00 (0.98, 1.01)	0.662	1.00 (0.98, 1.02)	0.951
3rd Quartile			0.99 (0.98, 1.01)	0.484	1.00 (0.98, 1.02)	0.831
4th Quartile			0.99 (0.97, 1.01)	0.227	0.99 (0.97, 1.01)	0.502
Missing			1.02 (0.97, 1.07)	0.398	1.03 (0.98, 1.08)	0.299
Payer *(ref=Medicare)*						
Medicaid			1.02 (1.00, 1.04)	0.083	1.01 (0.99, 1.03)	0.300
Private			0.95 (0.92, 0.97)	<.001	0.94 (0.92, 0.96)	<.001
Self-Pay			0.97 (0.93, 1.01)	0.160	0.97 (0.93, 1.01)	0.173
Other/No Charge			1.03 (0.99, 1.07)	0.140	1.03 (0.99, 1.07)	0.182
Disposition *(ref=Routine to home)*						
Post-acute care					0.82 (0.81, 0.84)	<.001
Other					1.03 (0.93, 1.14)	0.539
Home Health					1.02 (1.00, 1.04)	0.020
LOS *(per day)*					1.00 (0.99, 1.00)	<.001
Care intensity *(ref=No)*						
Non-invasive ventilation					1.23 (1.21, 1.26)	<.001
Mechanical ventilation					1.12 (1.08, 1.16)	<.001
Presence or placement of tracheostomy					0.87 (0.81, 0.94)	<.001
Cardiac arrest					0.97 (0.82, 1.14)	0.692
Performance of CPR					0.93 (0.75, 1.14)	0.459
Hospital ownership *(ref=government)*						
Private, non-profit					1.01 (0.99, 1.03)	0.337
Private, for-profit					1.00 (0.97, 1.02)	0.721
Hospital teaching status *(ref=Non-teaching)*						
Teaching Hospital					1.00 (0.98, 1.02)	0.840
Hospital location *(ref=Large metro area)*						
Small metro area					1.00 (0.98, 1.02)	0.966

Micropolitan area	1.01 (0.98, 1.03)	0.584
Rural	1.04 (1.00, 1.07)	0.060
Hospital Bed Size *(ref=Small)*		
Medium	0.98 (0.96, 1.01)	0.156
Large	0.97 (0.95, 0.99)	0.008
Annual Discharge (per 10k)	1.00 (1.00, 1.01)	0.375
Proportion Medicaid per 10%	1.01 (1.01, 1.02)	<.001

Note: Hazard Ratios with 95% Confidence Intervals Presented. * denotes p <0.05

Table 25: Covariates Only: Multilevel Multinomial Logistic Regression models of Readmission using only covariates with Hospital Level random intercept.

Model Info	**Model 2**		**Model 3**	
N	1,659,576		1,658,372	
LL	-2,139,461.8		-2,123,613.0	
df	41		79	
AIC	4,279,005.5		4,247,384.0	
BIC	4,279,510.5		4,248,357.0	
Predictors	**Non-COPD** *ref=Not Readmitted*	**COPD** *ref=Not Readmitted*	**Non-COPD** *ref=Not Readmitted*	**COPD** *ref=Not Readmitted*
Year *(ref=2010)*				
2011	0.990 (0.964, 1.017)	1.008 (0.978, 1.040)	0.992 (0.966, 1.018)	1.005 (0.975, 1.036)
2012	*0.962 (0.936, 0.989)	0.975 (0.946, 1.005)	*0.961 (0.936, 0.988)	*0.965 (0.936, 0.994)
2013	*0.937 (0.913, 0.962)	*0.943 (0.915, 0.972)	*0.934 (0.910, 0.959)	*0.929 (0.902, 0.957)
2014	*0.931 (0.907, 0.956)	*0.924 (0.897, 0.952)	*0.932 (0.908, 0.958)	*0.936 (0.909, 0.964)
2015	*0.915 (0.892, 0.940)	*0.881 (0.855, 0.908)	*0.916 (0.892, 0.940)	*0.858 (0.833, 0.884)
2016	*0.921 (0.897, 0.946)	*0.897 (0.871, 0.924)	*0.918 (0.895, 0.943)	*0.869 (0.845, 0.895)
Quarter *(ref=1st)*				
2nd Quarter	*0.963 (0.947, 0.979)	*0.976 (0.958, 0.994)	*0.969 (0.952, 0.985)	*0.976 (0.958, 0.994)
3rd Quarter	0.994 (0.977, 1.012)	*1.035 (1.016, 1.055)	1.000 (0.983, 1.018)	*1.034 (1.015, 1.054)
4th Quarter	*0.967 (0.949, 0.985)	*1.026 (1.006, 1.047)	*0.978 (0.960, 0.997)	*1.027 (1.007, 1.048)
Sex *(ref=male)*				
Female	*0.905 (0.894, 0.916)	*0.916 (0.903, 0.929)	*0.880 (0.869, 0.891)	*0.905 (0.893, 0.918)
Age *(per 10 years)*	*1.128 (1.121, 1.136)	*0.909 (0.902, 0.915)	*1.075 (1.067, 1.082)	*0.896 (0.890, 0.902)
Income Quartile *(ref=1st)*				
2nd Quartile	0.990 (0.973, 1.007)	*0.967 (0.949, 0.985)	0.984 (0.967, 1.001)	*0.964 (0.946, 0.983)
3rd Quartile	0.989 (0.971, 1.007)	*0.961 (0.941, 0.980)	*0.971 (0.953, 0.989)	*0.949 (0.929, 0.969)
4th Quartile	0.984 (0.964, 1.006)	*0.933 (0.910, 0.956)	*0.952 (0.930, 0.974)	*0.912 (0.889, 0.936)
Missing	*0.932 (0.885, 0.981)	0.991 (0.937, 1.047)	*0.932 (0.885, 0.981)	0.994 (0.940, 1.051)
Payer *(ref=Medicare)*				
Medicaid	1.019 (0.996, 1.043)	*1.092 (1.067, 1.117)	*1.032 (1.008, 1.056)	*1.096 (1.071, 1.122)
Private	*0.673 (0.656, 0.691)	*0.626 (0.608, 0.644)	*0.708 (0.690, 0.726)	*0.642 (0.624, 0.661)
Self-Pay	*0.516 (0.492, 0.542)	*0.575 (0.550, 0.601)	*0.560 (0.533, 0.588)	*0.603 (0.577, 0.630)
Other/No Charge	*0.716 (0.687, 0.747)	*0.784 (0.750, 0.819)	*0.739 (0.708, 0.771)	*0.804 (0.770, 0.840)

Disposition *(ref=Routine to home)*		
Post-acute care	*1.577 (1.546, 1.609)	*1.040 (1.015, 1.065)
Other	*1.361 (1.267, 1.462)	0.949 (0.862, 1.045)
Home Health	*1.454 (1.430, 1.479)	*1.328 (1.305, 1.352)
LOS *(per day)*	*1.026 (1.024, 1.029)	*1.010 (1.008, 1.012)
Care intensity *(ref=No)*		
Non-invasive ventilation	0.999 (0.976, 1.023)	*1.407 (1.375, 1.440)
Mechanical ventilation	1.022 (0.988, 1.057)	*0.920 (0.885, 0.956)
Presence or placement of tracheostomy	1.010 (0.941, 1.083)	0.997 (0.913, 1.089)
Cardiac arrest	0.908 (0.801, 1.029)	*0.691 (0.586, 0.814)
Performance of CPR	1.160 (0.990, 1.360)	0.986 (0.802, 1.212)
Hospital ownership *(ref=government)*		
Private, non-profit	1.002 (0.980, 1.025)	0.999 (0.974, 1.024)
Private, for-profit	*1.055 (1.028, 1.083)	1.007 (0.979, 1.035)
Hospital teaching status *(ref=Non-teaching)*		
Teaching Hospital	1.013 (0.995, 1.032)	*1.025 (1.004, 1.047)
Hospital location *(ref=Large metro area)*		
Small metro area	*0.929 (0.915, 0.944)	*0.930 (0.913, 0.948)
Micropolitan area	*0.876 (0.852, 0.900)	*0.883 (0.858, 0.910)
Rural	*0.828 (0.797, 0.860)	*0.881 (0.844, 0.919)
Hospital Bed Size *(ref=Small)*		
Medium	*1.025 (1.002, 1.048)	1.014 (0.989, 1.039)
Large	*1.055 (1.030, 1.080)	1.012 (0.986, 1.038)
Annual Discharge (per 10k)	1.010 (0.998, 1.022)	1.004 (0.993, 1.016)
Proportion Medicaid per 10%	*0.991 (0.983, 0.998)	*1.010 (1.001, 1.018)

Note: Odds Ratios with 95% Confidence Intervals Presented. * denotes p <0.05

Table 26: Multilevel Multinomial Elixhauser Coefficients (Odds Risk with 95% CI) over time

	2010	2011	2012	2013	2014	2015	2016
Non-COPD							
Model 1	1.23 (1.22, 1.24)	1.24 (1.23, 1.25)	1.22 (1.21, 1.23)	1.22 (1.21, 1.23)	1.22 (1.21, 1.23)	1.22 (1.21, 1.23)	1.22 (1.21, 1.23)
Model 2	1.21 (1.20, 1.22)	1.22 (1.21, 1.23)	1.20 (1.19, 1.21)	1.21 (1.20, 1.22)	1.21 (1.20, 1.22)	1.21 (1.20, 1.22)	1.21 (1.20, 1.21)
Model 3	1.19 (1.18, 1.20)	1.20 (1.19, 1.21)	1.18 (1.17, 1.19)	1.19 (1.18, 1.20)	1.18 (1.17, 1.19)	1.19 (1.18, 1.20)	1.19 (1.18, 1.20)
COPD							
Model 1	1.07 (1.06, 1.08)	1.06 (1.05, 1.07)	1.06 (1.05, 1.07)	1.05 (1.04, 1.06)	1.06 (1.05, 1.07)	1.06 (1.05, 1.07)	1.06 (1.05, 1.07)
Model 2	1.06 (1.05, 1.07)	1.06 (1.05, 1.07)	1.05 (1.04, 1.06)	1.05 (1.04, 1.06)	1.05 (1.04, 1.06)	1.06 (1.05, 1.06)	1.06 (1.05, 1.07)
Model 3	1.05 (1.03, 1.06)	1.04 (1.03, 1.06)	1.04 (1.03, 1.05)	1.04 (1.03, 1.05)	1.04 (1.03, 1.05)	1.04 (1.04, 1.05)	1.04 (1.03, 1.05)

Table 27: Multilevel Multinomial Logistic Regression models of Readmission (Aged ≥18 years) using Elixhauser Index using Hospital Level random intercept

Model Info	**Model 1**		**Model 2**		**Model 3**	
N	1,682,629		1,679,169		1,677,941	
LL	-2,149,924.5		-2,136,418.5		-2,127,514.0	
df	5		43		81	
AIC	4,299,859.0		4,272,923.0		4,255,190.0	
BIC	4,299,920.5		4,273,453.0		4,256,189.0	
Predictors	**Non-COPD** *ref=Not Readmitted*	**COPD** *ref=Not Readmitted*	**Non-COPD** *ref=Not Readmitted*	**COPD** *ref=Not Readmitted*	**Non-COPD** *ref=Not Readmitted*	**COPD** *ref=Not Readmitted*
Elixhauser Index *(per 3)*	*1.08 (1.08, 1.09)	*1.02 (1.02, 1.03)	*1.08 (1.08, 1.08)	*1.02 (1.02, 1.02)	*1.07 (1.07, 1.07)	*1.02 (1.02, 1.02)
Year *(ref=2010)*						
2011			0.98 (0.95, 1.01)	1.01 (0.98, 1.04)	0.98 (0.96, 1.01)	1.00 (0.97, 1.03)
2012			*0.94 (0.91, 0.97)	*0.97 (0.94, 1.00)	*0.94 (0.92, 0.97)	*0.96 (0.93, 0.99)
2013			*0.90 (0.87, 0.92)	*0.93 (0.90, 0.96)	*0.90 (0.88, 0.93)	*0.92 (0.90, 0.95)
2014			*0.88 (0.85, 0.90)	*0.91 (0.88, 0.93)	*0.86 (0.84, 0.88)	*0.92 (0.89, 0.95)
2015			*0.85 (0.83, 0.87)	*0.87 (0.84, 0.89)	*0.86 (0.84, 0.89)	*0.85 (0.82, 0.87)
2016			*0.84 (0.82, 0.87)	*0.88 (0.85, 0.90)	*0.85 (0.82, 0.87)	*0.86 (0.83, 0.88)
Quarter *(ref=1st)*						
2nd Quarter			*0.95 (0.94, 0.97)	*0.97 (0.96, 0.99)	*0.96 (0.94, 0.98)	*0.97 (0.96, 0.99)
3rd Quarter			*0.97 (0.95, 0.99)	*1.03 (1.01, 1.05)	*0.98 (0.96, 1.00)	*1.03 (1.01, 1.05)
4th Quarter			*0.95 (0.93, 0.97)	*1.02 (1.00, 1.04)	*0.96 (0.94, 0.97)	*1.02 (1.00, 1.04)
Sex *(ref=male)*						
Female			*0.94 (0.93, 0.95)	*0.92 (0.91, 0.94)	*0.92 (0.91, 0.93)	*0.91 (0.90, 0.93)
Age *(per 10 years)*			*1.09 (1.08, 1.10)	*0.92 (0.91, 0.93)	*1.05 (1.05, 1.06)	*0.91 (0.91, 0.92)
Income Quartile *(ref=1st)*						
2nd Quartile			1.00 (0.98, 1.02)	*0.97 (0.95, 0.99)	1.00 (0.98, 1.01)	*0.96 (0.95, 0.98)
3rd Quartile			1.00 (0.98, 1.01)	*0.96 (0.94, 0.98)	0.99 (0.97, 1.00)	*0.95 (0.93, 0.97)
4th Quartile			1.00 (0.98, 1.02)	*0.93 (0.91, 0.95)	0.98 (0.96, 1.00)	*0.91 (0.89, 0.93)
Missing			0.96 (0.91, 1.01)	0.99 (0.94, 1.05)	0.95 (0.90, 1.00)	0.99 (0.94, 1.05)
Payer *(ref=Medicare)*						
Medicaid			1.02 (0.99, 1.04)	*1.10 (1.08, 1.13)	*1.03 (1.00, 1.05)	*1.10 (1.08, 1.13)
Private			*0.74 (0.72, 0.75)	*0.65 (0.63, 0.67)	*0.75 (0.73, 0.77)	*0.66 (0.64, 0.68)
Self-Pay			*0.60 (0.57, 0.63)	*0.60 (0.58, 0.63)	*0.62 (0.59, 0.65)	*0.62 (0.59, 0.65)
Other/No Charge			*0.76 (0.72, 0.79)	*0.80 (0.77, 0.84)	*0.77 (0.74, 0.80)	*0.82 (0.78, 0.85)
Disposition *(ref=Routine to home)*						

Post-acute care	*1.36 (1.33, 1.38)	0.99 (0.97, 1.02)
Other	*1.20 (1.11, 1.28)	0.91 (0.83, 1.01)
Home Health	*1.31 (1.29, 1.34)	*1.29 (1.27, 1.31)
LOS *(per day)*	*1.02 (1.01, 1.02)	*1.01 (1.00, 1.01)
Care intensity *(ref=No)*		
Non-invasive ventilation	*0.89 (0.87, 0.91)	*1.38 (1.35, 1.41)
Mechanical ventilation	*0.78 (0.76, 0.81)	*0.87 (0.84, 0.91)
Presence or placement of tracheostomy	1.07 (1.00, 1.14)	1.01 (0.93, 1.11)
Cardiac arrest	*0.87 (0.77, 0.99)	*0.69 (0.58, 0.81)
Performance of CPR	1.14 (0.97, 1.33)	0.98 (0.80, 1.21)
Hospital ownership *(ref=government)*		
Private, non-profit	*0.97 (0.95, 0.99)	0.99 (0.96, 1.01)
Private, for-profit	*1.06 (1.03, 1.08)	1.01 (0.98, 1.04)
Hospital teaching status *(ref=Non-teaching)*		
Teaching Hospital	0.98 (0.97, 1.00)	1.02 (1.00, 1.04)
Hospital location *(ref=Large metro area)*		
Small metro area	*0.94 (0.92, 0.95)	*0.93 (0.91, 0.95)
Micropolitan area	*0.91 (0.88, 0.93)	*0.89 (0.87, 0.92)
Rural	*0.88 (0.85, 0.92)	*0.90 (0.86, 0.93)
Hospital Bed Size *(ref=Small)*		
Medium	1.01 (0.98, 1.03)	1.01 (0.98, 1.03)
Large	1.01 (0.99, 1.04)	1.00 (0.98, 1.03)
Annual Discharge (per 10k)	*1.02 (1.01, 1.04)	1.00 (0.99, 1.02)
Proportion Medicaid per 10%	*0.99 (0.98, 1.00)	*1.01 (1.00, 1.02)

Note: Odds Ratios with 95% Confidence Intervals Presented. * denotes p <0.05

Chapter 6: Effect of the Hospital Readmissions Reduction Program on 30-day readmissions for chronic obstructive pulmonary disease

Abstract

Importance:

Hospital readmissions rates for myocardial infarction (AMI), heart failure (CHF), and pneumonia demonstrably fell with implementation of the Hospital Readmissions Reduction Program (HRRP). It is not established whether readmissions rates for chronic obstructive pulmonary disease (COPD), an HRRP condition added in 2014, have changed.

Objective:

Determine whether addition of penalties under HRRP influenced COPD readmissions in Medicare and whether any spillover effect occurred in Medicaid or privately insured populations.

Design:

Retrospective cohort study across four periods of HRRP implementation. The pre-policy period was January 2010 until the proposed rule for CHF, AMI, and pneumonia (Phase 1) penalties (April 2011), ramp-up period from the proposed rule announcement until Phase 1 penalties activated (May 2011-September 2012), partial penalty (October 2012-September 2014), and full penalty with COPD (October 2014-December 2016). Medicare, Medicaid, and privately insured cohorts were compared.

Setting:

Discharges from the Nationwide Readmissions Database.

Participants:

Patients aged ≥40 years discharged alive from hospitalizations for COPD, AMI, CHF, and pneumonia defined by HRRP inclusion codes, and for all other conditions.

Exposures:

Announcement and implementation of HRRP penalties for CHF, AMI, and pneumonia (Phase 1), and COPD (Phase 2).

Main Outcomes:

Weighted thirty-day readmissions following discharges for AMI, CHF, COPD, pneumonia, and non-HRRP conditions. Comparisons of COPD readmission rate changes by period against non-HRRP rates and the HRRP Phase 1 rates.

Results:

1.2 million COPD hospitalizations were compared to 22 million non-HRRP and 3.4 million HRRP Phase 1 Medicare discharges. COPD readmissions fell from 18.9% to 17.7% between the pre-HRRP and full penalty periods. This was not significantly different than the change observed for HRRP Phase 1 (difference in change +0.64%) or non-HRRP conditions (difference in change -0.07%). Non-significant changes were observed in Medicaid (difference in change +0.64%, P-0.108 vs. HRRP Phase 1 and -0.07% vs. non-HRRP conditions) and private insurance (+0.32% and -0.54%). The slope of change in readmission was not significantly different across the transition from partial to full penalty in Medicare (-0.026% vs. HRRP Phase 1 and +0.004% vs. non-HRRP), Medicaid (-0.058% and -0.017%), or private insurance (+0.042% and +0.036%).

Conclusions and Relevance:

In the Medicare population, COPD readmission rates declined with implementation of HRRP, but the observed changes were not significantly different than the background change observed in the other HRRP and non-HRRP conditions. This may reflect an ecological effect from the HRRP rather than a failure of the penalty to achieve an effect.

Introduction

Rehospitalizations are a frequent and costly problem, particularly in the Medicare population, where nearly 20% returned within a month of discharge across all conditions [132]. In an effort to curtail these costs and promote quality, the Patient Protection and Affordable Care Act (ACA) of 2010 [65] set the groundwork for the Hospital Readmissions Reduction Program (HRRP), reducing Medicare reimbursements to hospitals with excess thirty-day readmissions following hospitalizations for key conditions of interest. The Centers for Medicare and Medicaid Services (CMS) enacted penalties for acute myocardial infarction (AMI), pneumonia (PNA), and congestive heart failure (CHF) in October 2012 [66,67]. Chronic obstructive pulmonary disease (COPD) was added as a condition of interest with penalties effective October 2014 [68,69]. Within COPD alone, estimates of readmission expense exceed $15 billion annually [86].

In the first phase of HRRP penalties (for CHF, AMI, and pneumonia), reduction in readmission rates was observed among the Medicare population [133], an effect even more robust in hospitals participating in value-based payment programs [134]. In all-payer samples preceding the addition of COPD as a condition of interest, a reduction in readmissions occurred not only for the HRRP targets, but also in non-targeted conditions [82,83]. However, evidence of spillover effects into non-Medicare patients has been inconsistent [82,135,136]. Readmissions for COPD were starting to trend down even before the HRRP penalties went into effect [137], though to date, no analysis of the HRRP's effect on COPD readmission rates since penalties became active readmission rates is currently published.

Our analysis seeks to answer two key questions using a nationally-representative, all-payer sample of discharges that spans the duration of the HRRP. Condition-specific as opposed to hospital-wide readmission measure have been evaluated and were found to penalize fewer hospitals [138], but the effect of adding individual conditions has not been assessed. In our main analysis, we will evaluate whether COPD readmission rates among Medicare patients decreased with the implementation of the HRRP compared to the other HRRP conditions and non-penalized conditions. Secondly, we will evaluate whether there is a significant spillover effect into the non-Medicare population. This approach fills a gap in the currently available literature evaluating the overall effect and incremental utility of adding COPD as a penalized condition to the HRRP.

Methods

Data Source and Inclusion Criteria

Discharge records from the Nationwide Readmissions Database (NRD) ranging January 2010 to December 2016 were obtained [84]. This database is constructed of an all-payer sample of discharges across multiple states (varying by year), and with applied weights, approximates over 50% of the national population [86]. We defined an index hospitalization in keeping with the HRRP methodology, limited to all patients ≥40 years old, with at least 30 days elapsed since the prior hospitalization, residents of the state in which they were hospitalized, not transferred the same day they were admitted, discharged alive and not against medical advice [87,88]. Because of the cross-sectional nature of the data, which does not provide identifiers that are consistent across years, we excluded index stays in January (which may have been readmissions from

December), or December (which could not be followed into January). For each condition of interest (AMI, CHF, COPD, PNA), we coded an indicator based on the ICD inclusion schema as outlined in the HRRP methodology reports [87,88]. We then grouped the conditions by the phase in which they entered HRRP penalties, with AMI, CHF, and PNA coded as “Phase 1”, COPD coded as “Phase 2”, and the residual as “non-HRRP”. In cases where the same patient was admitted multiple times across the year, each admission was included as long as it otherwise met the index admission inclusion criteria.

Measurements

A readmission was defined as return to any hospital for any cause, with some exceptions (*e.g.,* organ transplant, elective surgery, childbirth, or chemotherapy) as defined in the HRRP methodology reports [87,88]. Patient and hospital level variables are provided with the dataset, and included items including timing, sociodemographics, payer, discharge disposition, hospital ownership, teaching status, size, and location. In the payer variable, patients with managed Medicare (*i.e.,* Medicare Advantage plans) and dual-eligible patients were classified as Medicare, and those with managed Medicaid were classified as Medicaid, whereas private insurance included any commercial insurance [86]. We excluded self-pay and other (which includes Worker’s compensation and other government programs) from our analyses, which only represented 3% of all subjects [86]. These covariates were included for data description, but not incorporated into our models. Timing of the discharge was included on the monthly and quarterly level.

Interrupted Time Series

Time periods for the interrupted time series analysis are shown in Figure 11, developed from dates published in the *Federal Register* [66-69]. We defined each pre-policy period by the time before the proposed rule to include the condition was published. We defined the implementation period as the time between the proposed rule and the active penalty for each condition. We defined the post-policy period as the time from the active penalty for each condition to the end of available data in the analysis. To make comparisons between the two phases across time, we binned the time periods into four parts. In the full HRRP ITS, we defined the time that penalties were active for Phase 1 conditions as “partial penalty” and the time that penalties became active for COPD as well as “full penalty”.

Readmission rates were calculated at the monthly level. Using the bounds as described above, a series of piecewise regression models were fitted to estimate both the slopes of each time period and point estimates at key timepoints in the policy and compared for significant differences. Within the regression model, we included a fixed effect for periodicity by including time on a quarterly basis, as well as random intercepts for hospital clusters. We then completed difference-in-difference analyses to determine whether the rate of change of readmission rates in for each condition of interest differed from rates for the non-HRRP conditions unaffected by the policy. We also analyzed key subsets of interest by restricting the analysis to (a) Medicare patients (b) Medicaid patients, and (c) the privately insured. All analyses were performed in Stata version 15.1 (StataCorp, College Station, TX). The study was exempted from review based on its

use of deidentified, publicly-available data by the University of California, Los Angeles Institutional Review Board (IRB# 18-001208).

Results

Characteristics of the Study Sample

Among Medicare patients, an unweighted sample of 1,165,378 COPD hospitalizations occurred during the study period with an overall readmission rate of 18.2%. We referenced these stays against an aggregate of AMI (N=582,329), CHF (N=1,284,024), pneumonia (N=1,487,237), as well as the non-HRRP residual hospitalizations (N=22,044,760). For the COPD cohort, patient (Table 28 for Medicare, Table 29 for Medicaid, and Table 30 for private insurance) and hospital (Table 37) characteristics are shown. Over the course of the study period, the proportion of Medicare and Medicaid patients both increased, while the proportion of privately insured patients decreased. Lengths of stay in the COPD Medicare cohort were relatively stable (decreasing by a quarter of a day), with the proportion of patients using home health services increasing (20.6% in the pre-policy period and 23.3% in the full penalty phase) respectively. During the same time period, the proportion of government-controlled and for-profit hospitals both decreased, while private, non-profit hospitals increased. Teaching hospitals increased in the sample from 22.3% to 37.8% and hospitals in the sample became proportionally smaller over the 7 years of observation. The mean proportion of patient-days paid by Medicaid within hospitals also increased, from 16.1% in 2010 to 18.5% by 2016. It should be noted that the states included in each year's sample do vary, as shown in the NRD documentation, which may explain at least some of this variance [86].

Readmission Trends

A graph of the raw readmission rates for each condition and insurer is displayed in Figure 12 (Medicare), Figure 13 (Medicaid), and Figure 14 (private insurance), with aggregate raw readmission rates by study period found in Table 38. Readmission rates for each condition trended down overall over the observed time period. In our interrupted time series models, we first estimated the mean readmission rate within each study period (Table 39). In the Medicare population, COPD readmission rates decreased from 18.9% in the pre-HRRP period to 17.9% at the time Phase 1 HRRP penalties were enacted, further decreasing to 17.7% in the full penalty period. Comparing the same time periods, HRRP Phase 1 condition rates decreased from 18.2% pre-HRRP to 16.8% during the Phase 1 penalty period and 16.4% in the full penalty period, while non-HRRP condition readmission rates decreased from 13.6% to 12.9% at partial penalty and to 12.5% in the full penalty period.

Within Medicare patients, mean estimated readmissions for COPD decreased from 18.9% in the pre-HRRP phase to 17.7% in the full penalty phase the study period. While there was greater reduction for COPD than non-HRRP conditions (Table 40), this was not significant (-0.15%, P=0.291). Comparing COPD to the Phase 1 conditions, COPD rates did decline, though less rapidly than for the aggregate of CHF, AMI, and pneumonia (DID +0.63%, P<0.001). Comparing instantaneous slopes of readmission rate change at the transition point between partial and full penalties under HRRP (Table 41), the rapidity of change was non-significantly greater for COPD than for the Phase 1 conditions, decreasing by 0.026 percentage points per month faster (P=0.144). The

degree of slope change was not significantly different than the non-HRRP background conditions (DID +0.004, P=0.632).

In Medicaid patients, mean COPD readmission rates dropped by 1.23% from the pre-HRRP period to the full penalty period, while non-HRRP rates dropped by 1.16% over the same time (Table 39), a non-significant difference-in-differences of -0.07% (Table 40). There also was no significant difference the degree of readmission reduction for COPD when compared to Phase 1 conditions across these periods (DID +0.64%, P=0.108). At the time of transition from partial to full penalty, COPD rates were trending toward more rapid decline than non-HRRP (DID=0.017% per month, P=0.448) and the Phase 1 conditions (DID -0.058 per month, P=0.148), though not significantly so (Table 41).

Among the privately insured, COPD readmission rates actually increased between the pre-HRRP period and the ramp up to Phase 1, as did non-HRRP rates, the only subpopulation in which this was observed. However, by the full penalty phase (Table 40), there was a greater reduction in COPD than in the non-HRRP conditions (DID -0.54%, P=0.059), while a smaller magnitude of risk reduction was observed compared to the Phase 1 conditions (DID +0.32%, P=0.275). At the transition from partial to full penalty, the slope for COPD readmission rate change was non-significantly positive compared to both non-HRRP and Phase 1 conditions (Table 41).. A graphical representation of the estimated mean readmission rates by policy period and insurance type is found in Figure 15, and transition point estimates of readmission rates and slopes is shown in Figure 16.

Discussion

Our study evaluated the changes in readmission rates for COPD patients across various time points of the HRRP's inception, implementation, and active penalty phases. We observed a decline in readmission rates for COPD across the HRRP policy periods for each payer. Interestingly, within Medicare patients, the degree of readmission rate reduction in COPD patients was smaller than that of both the Phase 1 HRRP conditions and non-targeted conditions. In addition, we observed that the greatest drop in estimated mean COPD readmission rates had occurred by the time penalties became active for HRRP Phase 1 conditions, and only a small additional drop was observed when COPD penalties became active after October 2014. Taken together, the estimated mean differences in COPD readmission rates did not decline by a significantly greater magnitude or rate than background conditions in the period following the addition of the COPD penalty to the HRRP than they already were with the Phase 1 condition penalties in the target Medicare population.

We did observe a small, but non statistically significant spillover effect into Medicaid patients. The estimated mean readmission rate change was greater from the pre-HRRP period to the full penalty phase compared to non-HRRP conditions, but not compared to Phase 1 conditions. The rate of change in readmission rates increased in rapidity in the transitions between each phase compared to both the non-HRRP and Phase 1 conditions. Additional spillover was observed in the privately insured patients, where we observed significant relative reductions in COPD rates compared to the non-HRRP conditions and Phase 1 conditions, though the rates of change in reduction were not significantly different from either comparator.

These findings highlight that while the HRRP decreased readmission rates for COPD, the addition of COPD as a penalty increased neither the level nor rapidity of reduction compared to the changes seen in the other HRRP conditions in the Medicare population. This begs the question of whether inclusion of COPD as a penalized condition was necessary to reduce readmission rates. It may be that the threat of further penalties sufficiently influenced health system practices to reduce readmissions such that there was no marginal benefit on COPD readmission rates with the added penalty. Hospital leadership in a national survey reported that the HRRP influenced decisions to implement readmission reduction programs [139]. In the case of COPD, it may suggest an ecological effect of the HRRP on overall health system and hospital practices that began to affect readmission rates even without their specific penalization.

Readmission reduction programs would have largely been underway in hospitals seeking to reduce their risk for penalties in the other HRRP conditions prior to the addition of the COPD penalty. Many of the interventions used would not have been condition-specific, such as transitional care programs, disease self-management strategies, and other strategies targeted at adherence to prescribed treatment plans [92,128,140]. It certainly could also have been the case that health systems recognized that with the high frequency of COPD readmissions observed before the HRRP penalties were delineated, anticipation that COPD would be a logical extension of the policy, and COPD-specific programs were developed and deployed in advance of the policy's finalization. Though a high proportion of readmissions may be preventable [141], the HRRP does not take measures of potential avoidability into account for penalties. One question still in play will be where the floor lies for readmission in COPD and the other

HRRP conditions. The fact that both targeted and non-HRRP medical conditions, as well as surgical conditions [142] continue to trend down would suggest that this point has not been reached yet.

While not the subject of our analyses, the unintended consequences of the HRRP is a continued subject of debate. Mortality increase as a tradeoff for reductions in readmission has been a persistent concern, with conflicting evidence as to whether observed mortality in CHF, AMI, and pneumonia increased related to the HRRP [143,144]. The potential for safety-net hospitals to be disproportionately affected by penalties is another concern [74,78,145,146], particularly in COPD [122]. Study of the effects of the HRRP expansion to include COPD on these outcomes will require further study.

Concerns about the validity of readmission rates as a good measure of accountability for care quality in COPD have been raised [147]. Despite this, there are demonstrated correlations between COPD readmission rates and other markers of hospital quality and patient satisfaction, as well as association with readmissions in other conditions, further supporting the use of the HRRP as a policy lever to improve quality [148]. The simple reduction of readmission rates is likely an insufficient marker of improvements in healthcare quality regarding COPD management, and future iterations of alternate payment schema should account for markers other than readmission rates in their design.

Limitations

Our data do not allow for identification of which specific hospitals were included in the sample, therefore making it impossible to determine whether the effect of experiencing the HRRP penalty was met with a significant change in readmission rates,

which has been shown in the Medicare population [83]. In addition, inclusion of dual-eligible patients in the Medicare cohort may have skewed our observed readmission rates in the Medicare population, as dual-eligible beneficiaries have demonstrably higher healthcare utilization in other studies [149]. Furthermore, we were unable to account for observation stays in this dataset, which may be used to game readmission penalties, though in an analysis of the Phase 1 conditions, observation stays were not a substantial driver in readmission reduction [150].

We opted against attempting to risk standardize our estimates of readmission, instead using observed, unadjusted rates. Changes in the coding practices used by Medicare occurred in 2011 allowed the expansion from 10 to 25 diagnoses submitted with each claim, a change which is suggested to have influenced the risk scores applied substantially and led to exaggerated readmission reduction estimates [151]. In addition, the reliability of risk-standardization measure has been called into question, and in COPD, up to 55% of excess readmission penalties were tied to unreliability in the measure [100]. Our findings should be interpreted in the context, therefore, of risk unadjusted readmission rates.

Conclusion

The overall trend of readmission rates for COPD declined with the introduction and implementation of the HRRP across all payers. Within the targeted Medicare population, these rates did not decline significantly more than the comparators of previously penalized HRRP conditions of CHF, AMI, or pneumonia, nor than non-HRRP conditions. Significant spillover effect into the private insurance population on readmission reduction was observed for COPD, however, when compared both to non-

HRRP and other HRRP conditions. Further study as to the utility of adding new conditions to the HRRP as a lever to improve healthcare quality is needed.

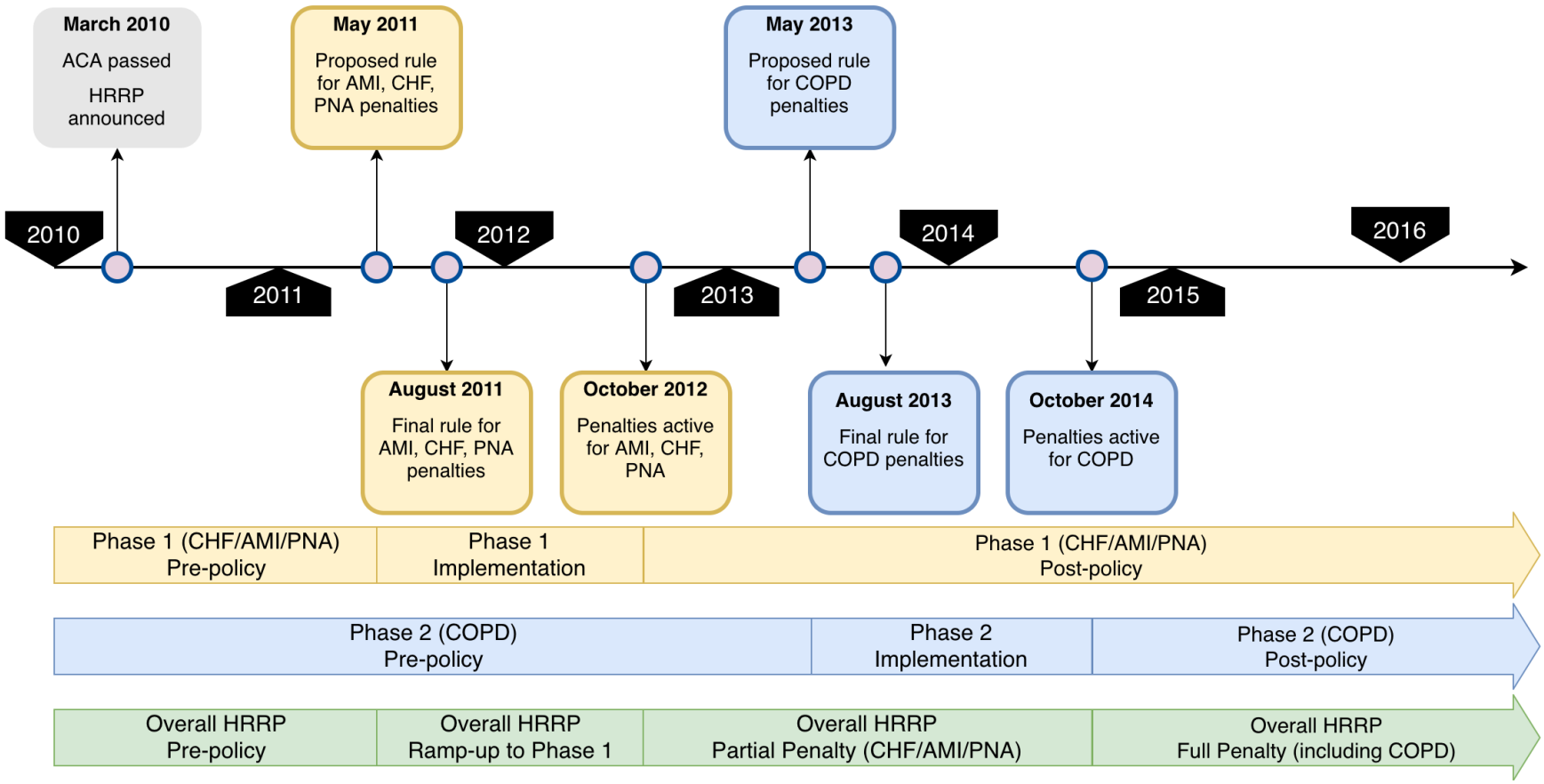

Figure 11: Timeline of HRRP key dates and set-up for interrupted time series period

Table 28: COPD patient-level characteristics by HRRP Period (Medicare Patients)

	Pre-Penalty	Ramp-Up	Partial Penalty	Full Penalty
Sex, *%*				
Male	41.0%	41.1%	41.0%	40.9%
Female	59.0%	58.9%	59.0%	59.1%
Age, *Mean ± SD*	72.4 ± 10.1	72.1 ± 10.1	72.0 ± 10.4	71.9 ± 11.0
Median household income, *%*				
1st Quartile	36.4%	37.2%	34.1%	35.3%
2nd Quartile	26.0%	25.4%	28.2%	27.2%
3rd Quartile	20.9%	21.1%	21.1%	22.0%
4th Quartile	15.3%	14.9%	15.2%	14.2%
Missing	1.5%	1.4%	1.3%	1.3%
Patient geographic location, *%*				
Central county metro area ≥1M	20.9%	20.8%	21.4%	21.5%
Fringe county metro area ≥1M	24.7%	25.2%	24.8%	25.1%
County metro area 250,000-999,999k	19.9%	20.1%	20.6%	22.1%
County metro area 50,000-249,999k	10.1%	10.2%	10.8%	10.7%
Micropolitan area	14.2%	14.0%	13.5%	11.8%
Non-metro/non-micropolitan (rural)	10.1%	9.8%	8.8%	8.8%
Number of admissions each patient had over a year, *Mean ± SD*	2.56 ± 1.85	2.61 ± 1.86	2.50 ± 1.86	2.50 ± 2.04
Number hospitals where each patient received care over a year, *Mean ± SD*	1.21 ± 0.46	1.21 ± 0.47	1.12 ± 0.38	1.20 ± 0.52
Discharge disposition, *%*				
Routine to home	62.2%	61.8%	60.4%	59.9%
Transfer to post-acute care	16.4%	16.3%	16.4%	16.2%
Home with home health services	20.6%	21.1%	22.4%	23.3%
Other	0.8%	0.7%	0.7%	0.6%
[§]**Length of Stay**, *Mean ± SD*	4.04 ± 2.10	3.88 ± 1.98	3.85 ± 2.04	3.76 ± 2.15

Note: Frequencies derived using weighted analysis.
[§]Geometric Mean and SD for log transformed variable presented

Table 29: COPD patient-level characteristics by HRRP Period (Medicaid Patients)

	Pre-Penalty	Ramp-Up	Partial Penalty	Full Penalty
Sex, *%*				
Male	35.6%	35.8%	36.8%	37.8%
Female	64.4%	64.2%	63.2%	62.2%
Age, *Mean ± SD*	55.9 ± 7.9	56.0 ± 7.6	56.1 ± 7.6	56.4 ± 7.8
Median household income, *%*				
1st Quartile	48.8%	50.2%	47.4%	48.5%
2nd Quartile	24.6%	24.1%	26.4%	24.9%
3rd Quartile	17.0%	16.5%	16.3%	17.2%
4th Quartile	7.8%	7.7%	8.3%	8.0%
Missing	1.8%	1.5%	1.5%	1.4%
Patient geographic location, *%*				
Central county metro area ≥1M	31.4%	31.0%	32.5%	33.6%
Fringe county metro area ≥1M	19.3%	20.8%	20.2%	20.1%
County metro area 250,000-999,999k	18.4%	18.3%	19.0%	20.7%
County metro area 50,000-249,999k	9.3%	9.0%	9.6%	9.4%
Micropolitan area	12.7%	12.3%	11.2%	9.3%
Non-metro/non-micropolitan (rural)	9.0%	8.7%	7.5%	6.8%
Number of admissions each patient had over a year, *Mean ± SD*	2.90 ± 2.30	3.02 ± 2.36	2.94 ± 2.37	2.89 ± 2.59
Number hospitals where patient received care over a year, *Mean ± SD*	1.30 ± 0.59	1.32 ± 0.61	1.18 ± 0.49	1.30 ± 0.68
Discharge disposition, *%*				
Routine to home	82.5%	82.0%	81.2%	80.4%
Transfer to post-acute care	6.6%	6.6%	6.2%	6.2%
Other	0.6%	0.6%	0.5%	0.4%
Home with home health services	10.3%	10.8%	12.0%	12.9%
§**Length of Stay**, *Mean ± SD*	3.73 ± 2.07	3.56 ± 1.91	3.57 ± 2.00	3.48 ± 2.09

Note: Frequencies derived using weighted analysis.
§Geometric Mean and SD for log transformed variable presented

Table 30: COPD patient-level characteristics by HRRP Period (Privately Insured Patients)

	Pre-Penalty	Ramp-Up	Partial Penalty	Full Penalty
Sex, *%*				
Male	41.7%	41.4%	42.1%	42.0%
Female	58.3%	58.6%	57.9%	58.0%
Age, *Mean ± SD*	60.8 ± 9.4	61.1 ± 9.2	60.9 ± 9.3	60.9 ± 9.8
Median household income, *%*				
1st Quartile	30.9%	31.2%	28.5%	30.6%
2nd Quartile	26.6%	25.8%	27.7%	27.1%
3rd Quartile	23.5%	23.7%	23.8%	24.9%
4th Quartile	17.4%	17.9%	18.4%	15.9%
Missing	1.5%	1.5%	1.6%	1.4%
Patient geographic location, *%*				
Central county metro area ≥1M	18.3%	19.1%	19.3%	19.9%
Fringe county metro area ≥1M	28.3%	28.9%	28.1%	27.6%
County metro area 250,000-999,999k	21.8%	21.6%	21.6%	22.7%
County metro area 50,000-249,999k	9.9%	9.3%	10.0%	10.0%
Micropolitan area	13.3%	13.1%	12.9%	11.2%
Non-metro/non-micropolitan (rural)	8.4%	8.0%	8.1%	8.5%
Number of admissions each patient had over a year, *Mean ± SD*	2.06 ± 1.56	2.14 ± 1.62	2.06 ± 1.62	2.02 ± 1.75
Number hospitals where patient received care over a year, *Mean ± SD*	1.15 ± 0.39	1.17 ± 0.41	1.09 ± 0.33	1.15 ± 0.45
Discharge disposition, *%*				
Routine to home	84.2%	82.8%	82.5%	81.7%
Transfer to post-acute care	4.5%	5.3%	5.2%	5.4%
Other	0.8%	0.8%	0.8%	0.7%
Home with home health services	10.4%	11.1%	11.6%	12.2%
[§]**Length of Stay**, *Mean ± SD*	3.64 ± 1.85	3.54 ± 1.79	3.53 ± 1.87	3.44 ± 1.97

Note: Frequencies derived using weighted analysis.
[§]Geometric Mean and SD for log transformed variable presented

Table 31: HRRP Phase 1 (CHF. AMI, PNA) patient-level characteristics by HRRP Period (Medicare Patients)

	Pre-Penalty	Ramp-Up	Partial Penalty	Full Penalty
Sex, *%*				
Male	47.6%	48.2%	48.9%	49.2%
Female	52.4%	51.8%	51.1%	50.8%
Age, *Mean ± SD*	76.8 ± 10.3	76.6 ± 10.3	76.5 ± 10.8	76.4 ± 11.6
Median household income, *%*				
1st Quartile	32.3%	32.7%	28.9%	30.0%
2nd Quartile	24.8%	24.3%	27.4%	26.4%
3rd Quartile	22.2%	22.5%	22.9%	23.9%
4th Quartile	19.4%	19.1%	19.5%	18.4%
Missing	1.4%	1.3%	1.3%	1.3%
Patient geographic location, *%*				
Central county metro area ≥1M	23.2%	22.4%	22.5%	22.3%
Fringe county metro area ≥1M	25.5%	25.5%	25.0%	25.7%
County metro area 250,000-999,999k	19.8%	20.4%	20.6%	21.9%
County metro area 50,000-249,999k	9.2%	9.4%	10.7%	10.8%
Micropolitan area	12.5%	12.6%	12.3%	10.8%
Non-metro/non-micropolitan (rural)	9.9%	9.6%	9.0%	8.6%
Number of admissions each patient had over a year, *Mean ± SD*	2.29 ± 1.59	2.30 ± 1.59	2.21 ± 1.57	2.19 ± 1.71
Number hospitals where patient received care over a year, *Mean ± SD*	1.20 ± 0.45	1.21 ± 0.45	1.12 ± 0.37	1.19 ± 0.49
Discharge disposition, *%*				
Routine to home	51.2%	51.0%	50.0%	50.9%
Transfer to post-acute care	26.1%	26.1%	25.8%	24.2%
Other	1.3%	1.3%	1.3%	1.2%
Home with home health services	21.5%	21.7%	23.0%	23.7%
§**Length of Stay**, *Mean ± SD*	4.37 ± 2.35	4.23 ± 2.25	4.19 ± 2.31	4.05 ± 2.41

Note: Frequencies derived using weighted analysis.
§Geometric Mean and SD for log transformed variable presented

Table 32: HRRP Phase 1 (CHF. AMI, PNA) patient-level characteristics by HRRP Period (Medicaid Patients)

	Pre-Penalty	Ramp-Up	Partial Penalty	Full Penalty
Sex, *%*				
Male	49.1%	51.0%	52.6%	54.8%
Female	50.9%	49.0%	47.4%	45.2%
Age, *Mean ± SD*	56.9 ± 9.9	56.8 ± 9.7	56.6 ± 9.7	56.3 ± 10.0
Median household income, *%*				
1st Quartile	46.5%	47.2%	43.4%	44.4%
2nd Quartile	23.1%	22.7%	25.1%	24.6%
3rd Quartile	18.2%	18.2%	18.6%	18.9%
4th Quartile	10.4%	10.3%	11.4%	10.8%
Missing	1.8%	1.6%	1.6%	1.4%
Patient geographic location, *%*				
Central county metro area ≥1M	38.7%	38.5%	39.1%	38.5%
Fringe county metro area ≥1M	18.7%	19.9%	19.2%	19.4%
County metro area 250,000-999,999k	17.1%	17.0%	18.4%	19.5%
County metro area 50,000-249,999k	7.7%	7.8%	8.1%	8.5%
Micropolitan area	10.2%	9.7%	9.0%	8.1%
Non-metro/non-micropolitan (rural)	7.6%	7.2%	6.2%	6.0%
Number of admissions each patient had over a year, *Mean ± SD*	2.53 ± 1.99	2.54 ± 1.98	2.44 ± 1.99	2.40 ± 2.18
Number hospitals where patient received care over a year, *Mean ± SD*	1.29 ± 0.57	1.29 ± 0.57	1.16 ± 0.46	1.27 ± 0.64
Discharge disposition, *%*				
Routine to home	76.5%	76.0%	75.8%	77.6%
Transfer to post-acute care	10.7%	10.5%	9.5%	8.1%
Other	1.4%	1.4%	1.5%	1.4%
Home with home health services	11.4%	12.2%	13.2%	13.0%
§**Length of Stay**, *Mean ± SD*	4.26 ± 2.52	4.11 ± 2.39	4.09 ± 2.51	3.90 ± 2.54

Note: Frequencies derived using weighted analysis.
§Geometric Mean and SD for log transformed variable presented

Table 33: HRRP Phase 1 (CHF. AMI, PNA) patient-level characteristics by HRRP Period (Privately Insured Patients)

	Pre-Penalty	Ramp-Up	Partial Penalty	Full Penalty
Sex, *%*				
Male	59.9%	61.1%	61.7%	62.1%
Female	40.1%	38.9%	38.3%	37.9%
Age, *Mean ± SD*	59.6 ± 10.6	59.6 ± 10.5	59.5 ± 10.6	59.3 ± 11.2
Median household income, *%*				
1st Quartile	27.2%	26.3%	23.9%	25.6%
2nd Quartile	24.1%	23.5%	25.8%	25.2%
3rd Quartile	24.2%	25.4%	25.5%	26.4%
4th Quartile	23.0%	23.4%	23.4%	21.5%
Missing	1.5%	1.5%	1.5%	1.4%
Patient geographic location, *%*				
Central county metro area ≥1M	22.6%	22.2%	22.9%	22.8%
Fringe county metro area ≥1M	28.4%	29.4%	27.9%	28.1%
County metro area 250,000-999,999k	21.0%	21.0%	21.1%	22.3%
County metro area 50,000-249,999k	9.0%	9.3%	10.2%	9.8%
Micropolitan area	11.3%	10.8%	10.4%	9.5%
Non-metro/non-micropolitan (rural)	7.7%	7.3%	7.6%	7.5%
Number of admissions each patient had over a year, *Mean ± SD*	1.73 ± 1.26	1.73 ± 1.27	1.67 ± 1.25	1.65 ± 1.34
Number hospitals where patient received care over a year, *Mean ± SD*	1.14 ± 0.37	1.14 ± 0.37	1.08 ± 0.30	1.12 ± 0.40
Discharge disposition, *%*				
Routine to home	83.2%	82.9%	82.4%	82.6%
Transfer to post-acute care	5.3%	5.3%	5.4%	5.1%
Other	1.7%	1.7%	1.8%	1.8%
Home with home health services	9.8%	10.1%	10.4%	10.5%
§**Length of Stay**, *Mean ± SD*	3.56 ± 1.87	3.45 ± 1.80	3.41 ± 1.89	3.30 ± 1.98

Note: Frequencies derived using weighted analysis.
§Geometric Mean and SD for log transformed variable presented

Table 34: Non-HRRP condition patient-level characteristics by HRRP Period (Medicare Patients)

	Pre-Penalty	Ramp-Up	Partial Penalty	Full Penalty
Sex, *%*				
Male	42.2%	42.4%	43.1%	43.7%
Female	57.8%	57.6%	56.9%	56.3%
Age, *Mean ± SD*	73.7 ± 11.0	73.5 ± 11.0	73.4 ± 11.3	73.4 ± 12.1
Median household income, *%*				
1st Quartile	30.4%	30.7%	27.6%	28.6%
2nd Quartile	24.7%	24.2%	27.0%	26.1%
3rd Quartile	22.7%	23.2%	23.4%	24.4%
4th Quartile	20.8%	20.5%	20.7%	19.6%
Missing	1.4%	1.4%	1.4%	1.3%
Patient geographic location, *%*				
Central county metro area ≥1M	24.9%	24.5%	24.9%	24.4%
Fringe county metro area ≥1M	26.3%	26.2%	25.5%	25.8%
County metro area 250,000-999,999k	19.9%	20.6%	20.7%	22.2%
County metro area 50,000-249,999k	8.9%	9.0%	10.2%	10.3%
Micropolitan area	11.2%	11.1%	10.6%	9.5%
Non-metro/non-micropolitan (rural)	8.8%	8.6%	8.1%	7.9%
Number of admissions each patient had over a year, *Mean ± SD*	1.97 ± 1.39	1.97 ± 1.39	1.92 ± 1.41	1.91 ± 1.52
Number hospitals where patient received care over a year, *Mean ± SD*	1.19 ± 0.44	1.19 ± 0.45	1.11 ± 0.37	1.18 ± 0.49
Discharge disposition, *%*				
Routine to home	55.5%	55.0%	53.1%	52.1%
Transfer to post-acute care	24.8%	25.2%	26.4%	26.8%
Other	1.1%	1.1%	1.0%	0.8%
Home with home health services	18.6%	18.8%	19.4%	20.3%
[§]**Length of Stay**, *Mean ± SD*	3.59 ± 2.16	3.55 ± 2.10	3.59 ± 2.18	3.59 ± 2.36

Note: Frequencies derived using weighted analysis.
[§]Geometric Mean and SD for log transformed variable presented

Table 35: Non-HRRP condition patient-level characteristics by HRRP Period (Medicaid Patients)

	Pre-Penalty	Ramp-Up	Partial Penalty	Full Penalty
Sex, *%*				
Male	43.2%	43.7%	45.3%	47.2%
Female	56.8%	56.3%	54.7%	52.8%
Age, *Mean ± SD*	53.4 ± 8.9	53.5 ± 8.9	53.5 ± 8.9	53.6 ± 9.5
Median household income, *%*				
1st Quartile	45.1%	45.1%	41.1%	41.3%
2nd Quartile	23.2%	22.7%	25.4%	24.6%
3rd Quartile	18.7%	19.2%	19.2%	20.0%
4th Quartile	11.3%	11.4%	12.6%	12.5%
Missing	1.7%	1.6%	1.6%	1.6%
Patient geographic location, *%*				
Central county metro area ≥1M	41.2%	41.0%	41.7%	40.4%
Fringe county metro area ≥1M	19.4%	19.8%	19.9%	20.2%
County metro area 250,000-999,999k	16.1%	16.5%	17.1%	18.7%
County metro area 50,000-249,999k	7.3%	7.5%	7.9%	8.1%
Micropolitan area	9.2%	8.8%	7.8%	7.2%
Non-metro/non-micropolitan (rural)	6.7%	6.4%	5.6%	5.3%
Number of admissions each patient had over a year, *Mean ± SD*	2.20 ± 1.78	2.22 ± 1.80	2.15 ± 1.82	2.10 ± 1.94
Number hospitals where patient received care over a year, *Mean ± SD*	1.28 ± 0.59	1.29 ± 0.61	1.16 ± 0.49	1.25 ± 0.65
Discharge disposition, *%*				
Routine to home	79.3%	79.3%	78.4%	77.7%
Transfer to post-acute care	9.6%	9.6%	9.7%	10.0%
Other	1.1%	1.0%	1.0%	0.8%
Home with home health services	10.1%	10.1%	10.9%	11.4%
[§]**Length of Stay**, *Mean ± SD*	3.71 ± 2.50	3.70 ± 2.55	3.70 ± 2.57	3.68 ± 2.73

Note: Frequencies derived using weighted analysis.
[§]Geometric Mean and SD for log transformed variable presented

Table 36: Non-HRRP condition patient-level characteristics by HRRP Period (Privately Insured Patients)

	Pre-Penalty	Ramp-Up	Partial Penalty	Full Penalty
Sex, *%*				
Male	45.1%	45.4%	46.3%	47.2%
Female	54.9%	54.6%	53.7%	52.8%
Age, *Mean ± SD*	55.7 ± 9.4	55.9 ± 9.4	56.1 ± 9.5	56.3 ± 10.2
Median household income, *%*				
1st Quartile	21.6%	21.7%	19.6%	21.6%
2nd Quartile	22.7%	22.1%	24.4%	24.2%
3rd Quartile	25.5%	26.1%	26.3%	27.0%
4th Quartile	28.7%	28.7%	28.4%	25.9%
Missing	1.5%	1.5%	1.4%	1.3%
Patient geographic location, *%*				
Central county metro area ≥1M	25.2%	25.1%	25.4%	24.9%
Fringe county metro area ≥1M	30.5%	30.7%	29.6%	29.3%
County metro area 250,000-999,999k	20.7%	21.0%	20.7%	22.1%
County metro area 50,000-249,999k	8.2%	8.2%	9.4%	9.2%
Micropolitan area	9.1%	8.9%	8.7%	8.1%
Non-metro/non-micropolitan (rural)	6.2%	6.1%	6.1%	6.3%
Number of admissions each patient had over a year, *Mean ± SD*	1.53 ± 1.07	1.54 ± 1.08	1.53 ± 1.09	1.53 ± 1.20
Number hospitals where patient received care over a year, *Mean ± SD*	1.11 ± 0.34	1.12 ± 0.35	1.07 ± 0.28	1.11 ± 0.38
Discharge disposition, *%*				
Routine to home	81.1%	80.3%	79.1%	78.4%
Transfer to post-acute care	5.1%	5.5%	6.0%	6.1%
Other	0.8%	0.8%	0.7%	0.7%
Home with home health services	13.0%	13.5%	14.1%	14.8%
[§]**Length of Stay**, *Mean ± SD*	2.84 ± 1.59	2.85 ± 1.58	2.89 ± 1.68	2.91 ± 1.86

Note: Unweighted N's displayed. Frequencies derived using weighted analysis.
[§]Geometric Mean and SD for log transformed variable presented

Table 37: Hospital characteristics for COPD patients by year

	2010 (N=1,412)	**2011** (N=1,398)	**2012** (N=1,320)	**2013** (N=1,433)	**2014** (N=1,470)	**2015** (N=1,732)	**2016** (N=1,699)
Hospital ownership/control, *%*							
Government, non-federal	19.4%	19.2%	16.5%	14.9%	15.2%	14.7%	13.5%
Private, non-profit	58.5%	58.1%	60.0%	63.2%	64.7%	66.3%	67.6%
Private, for-profit	22.1%	22.7%	23.5%	21.8%	20.1%	19.0%	18.9%
Hospital teaching status, *%*							
Metro, non-teaching	50.1%	50.1%	50.0%	48.7%	39.7%	37.6%	36.8%
Metro, teaching	22.3%	22.4%	24.7%	25.4%	36.9%	36.6%	37.8%
Non-metro, non-teaching	27.6%	27.5%	25.3%	25.9%	23.4%	25.8%	25.4%
Hospital geographic location, *%*							
Large metro area ≥1M	42.8%	43.7%	44.9%	43.1%	45.2%	43.2%	43.3%
Small metro area <1M	29.5%	28.8%	29.8%	31.0%	31.4%	31.1%	31.3%
Micropolitan area	15.4%	15.9%	15.1%	16.1%	14.2%	15.5%	15.2%
Non-metro/non-micropolitan (rural)	12.3%	11.6%	10.2%	9.8%	9.2%	10.2%	10.1%
Hospital bed size[a], *%*							
Small	23.9%	23.2%	23.0%	23.9%	29.4%	30.3%	30.5%
Medium	30.2%	31.8%	33.0%	31.6%	33.1%	33.5%	32.7%
Large	45.9%	45.0%	44.0%	44.5%	37.6%	36.3%	36.8%
Hospital total all-cause annual discharges, *Mean ± SD*	6,204 ± 6,333	6,263 ± 6,385	6,448 ± 6,473	6,280 ± 6,304	6,344 ± 6,447	6,205 ± 6,450	6,349 ± 6,558
Quartiles of Hospital total all-cause annual discharges, *%*							
1st Quartile (≤ 8,971)	59.9%	59.2%	57.7%	59.0%	58.6%	60.0%	59.2%
2nd Quartile (8,972 – 15,406)	21.0%	21.0%	22.0%	20.9%	21.2%	20.1%	20.2%
3rd Quartile (15,407 – 24,534)	12.7%	12.9%	13.6%	13.3%	13.0%	12.2%	12.9%
4th Quartile (≥24,535)	6.4%	6.9%	6.8%	6.7%	7.2%	7.7%	7.8%
Proportion of Medicaid patient-days, *Mean ± SD*	16.1% ± 10.3%	16.3% ± 10.8%	16.3% ± 10.9%	16.2% ± 10.6%	17.8% ± 11.6%	17.8% ± 11.6%	18.5% ± 11.8%
Medicaid proportion quartiles, *%*							
1st Quartile (≤ 10.6%)	35.5%	32.8%	34.3%	33.8%	28.9%	30.0%	26.9%
2nd Quartile (10.6% - 16.1%)	24.3%	27.0%	26.0%	27.0%	24.4%	23.3%	24.3%
3rd Quartile (16.1% - 23.9%)	22.8%	22.6%	21.2%	21.6%	24.0%	23.6%	24.0%
4th Quartile (≥ 23.9%)	17.3%	17.6%	18.5%	17.5%	22.7%	23.1%	24.9%

Note: Unweighted N's and Frequencies displayed for cohort proportions. N's are number of hospitals.
[a] Bed size grouping bounds varied by region and teaching status, as per NRD documentation [86]

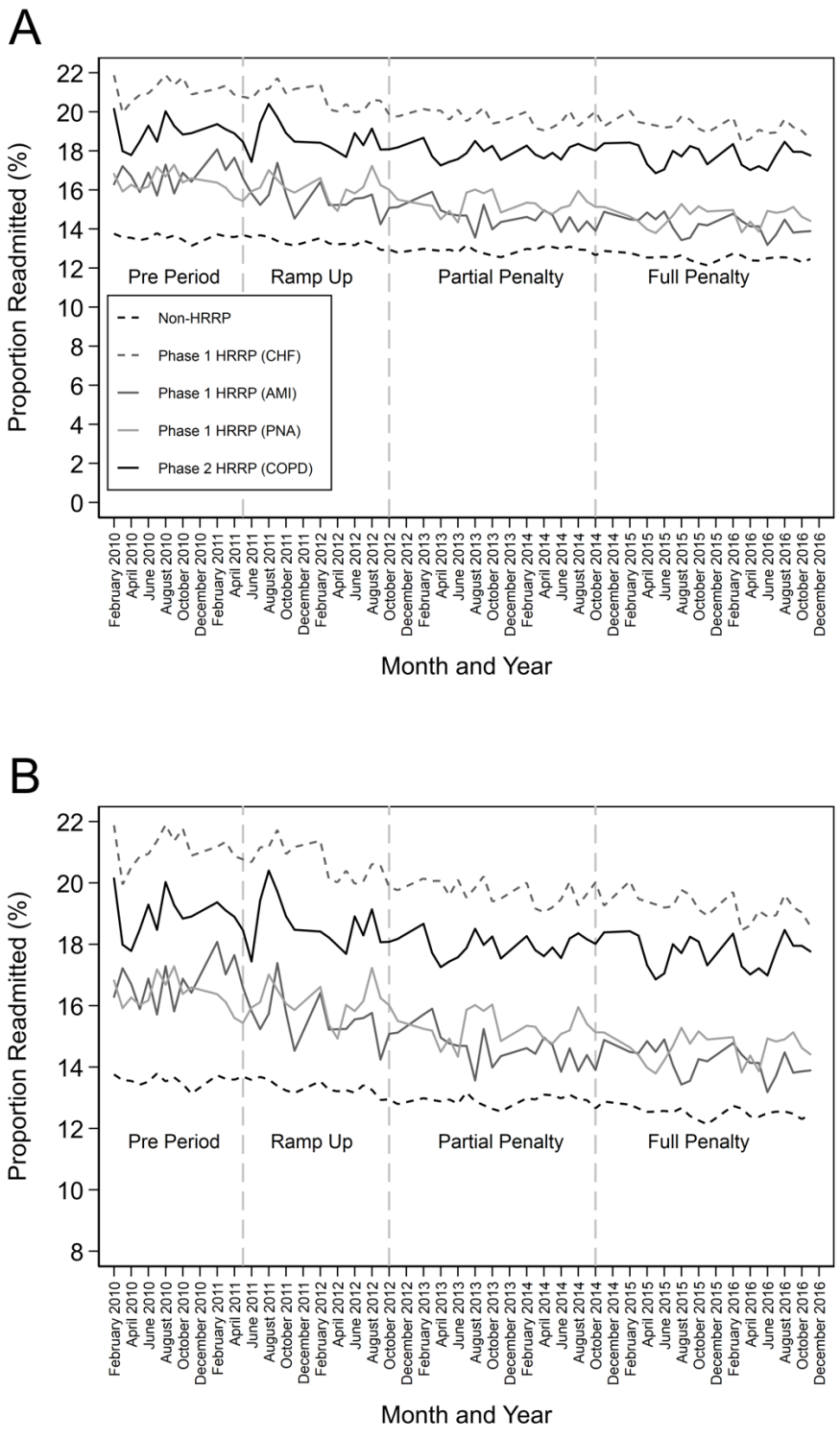

Figure 12: Raw readmission rates for Medicare patients over time for Non-HRRP and each HRRP condition (Panel A). Expanded view provided in Panel B

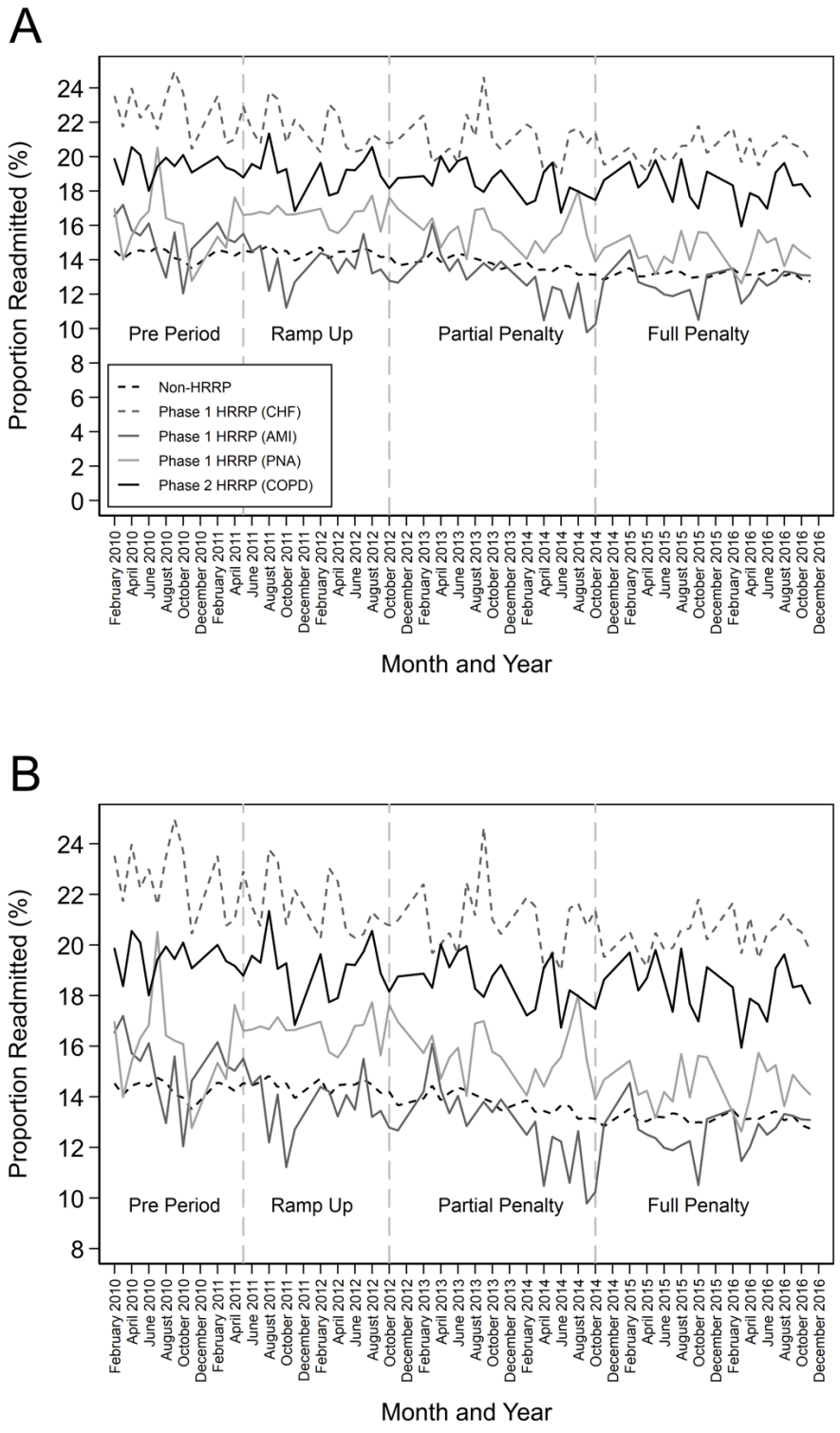

Figure 13: Raw readmission rates for Medicaid patients over time for Non-HRRP and each HRRP condition (Panel A). Expanded view provided in Panel B

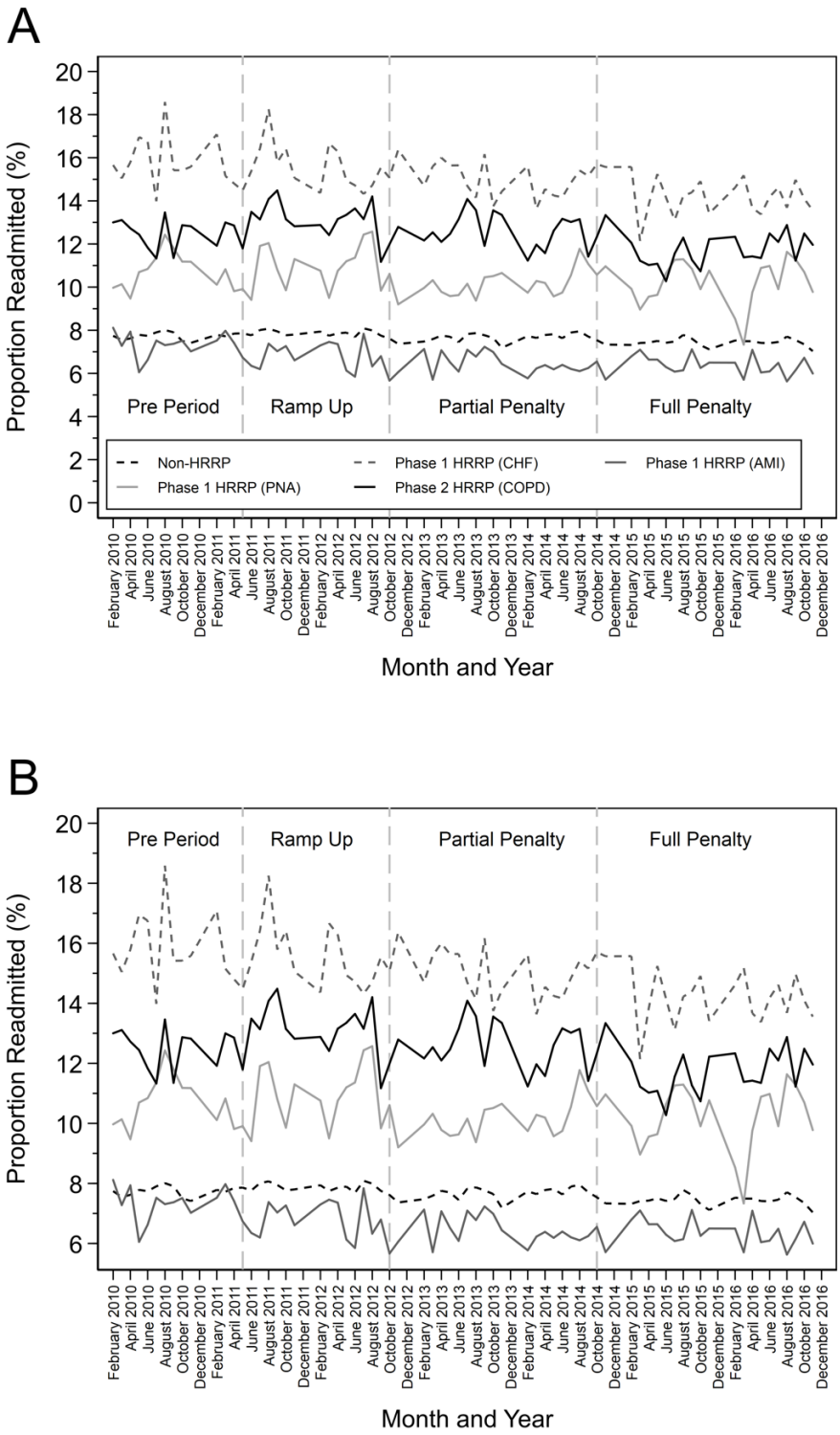

Figure 14: Raw readmission rates for privately insured patients over time for Non-HRRP and each HRRP condition (Panel A). Expanded view provided in Panel B

Table 38: Raw readmission rates by HRRP policy period and condition

	Overall	Pre-Policy	Ramp-Up	Partial Penalty	Full Penalty
Medicare					
Phase 2 (COPD)	(1,165,378) 18.2%	(210,875) 18.9%	(219,601) 18.6%	(320,594) 17.9%	(414,308) 17.7%
Phase 1 (AMI)	(582,329) 15.0%	(90,153) 16.8%	(104,116) 15.6%	(161,139) 14.7%	(226,921) 14.2%
Phase 1 (CHF)	(1,284,024) 20.0%	(219,823) 21.1%	(229,347) 20.7%	(346,972) 19.7%	(487,882) 19.2%
Phase 1 (PNA)	(1,487,237) 15.5%	(266,847) 16.4%	(286,908) 16.0%	(435,428) 15.3%	(498,054) 14.6%
Non-HRRP	(22,044,760) 13.0%	(3,709,989) 13.6%	(4,253,626) 13.4%	(6,055,340) 12.9%	(8,025,805) 12.5%
Medicaid					
Phase 2 (COPD)	(205,935) 18.7%	(35,231) 19.5%	(37,669) 19.1%	(55,912) 18.5%	(77,123) 18.2%
Phase 1 (AMI)	(79,432) 13.2%	(10,540) 15.2%	(12,863) 13.8%	(20,759) 12.8%	(35,270) 12.5%
Phase 1 (CHF)	(146,110) 21.1%	(22,890) 22.6%	(24,382) 21.6%	(38,738) 20.9%	(60,100) 20.4%
Phase 1 (PNA)	(154,052) 15.5%	(27,237) 15.9%	(28,168) 16.5%	(44,232) 15.8%	(54,415) 14.3%
Non-HRRP	(3,968,599) 13.8%	(614,806) 14.3%	(726,178) 14.5%	(1,068,091) 13.8%	(1,559,524) 13.1%
Private Insurance					
Phase 2 (COPD)	(187,959) 12.4%	(38,091) 12.6%	(35,576) 13.1%	(49,746) 12.5%	(64,546) 11.7%
Phase 1 (AMI)	(278,623) 6.7%	(45,569) 7.4%	(50,613) 6.8%	(75,326) 6.4%	(107,115) 6.4%
Phase 1 (CHF)	(175,641) 15.0%	(32,226) 15.8%	(31,945) 15.6%	(46,148) 15.0%	(65,322) 14.3%
Phase 1 (PNA)	(269,035) 10.4%	(54,065) 10.6%	(52,577) 10.8%	(75,267) 10.1%	(87,126) 10.1%
Non-HRRP	(9,720,163) 7.7%	(1,818,205) 7.7%	(1,960,624) 7.9%	(2,606,400) 7.7%	(3,334,934) 7.4%

Note: Unweighted N's displayed. Readmission rates generated using weighted analysis.

Table 39: Estimated mean differences in readmission rates by HRRP periods

	Period 1 Pre-HRRP Feb 2010 – Apr 2011	Period 2 Ramp-up May 2011 – Sep 2012	Period 3 Partial Penalty Oct 2012 – Sep 2014	Period 4 Full Penalty Oct 2014 – Nov 2016	Calculation 1 Period 3 - Period 1	Calculation 2 Period 4 - Period 1	Calculation 3 Period 4 - Period 3
Medicare Only							
COPD (N = 1,165,378)	18.9%	18.6%	17.9%	17.7%	-0.99%	-1.17%	-0.19%
PNA/AMI/CHF (N = 3,353,590)	18.2%	17.6%	16.8%	16.4%	-1.39%	-1.80%	-0.41%
All others (N = 22,044,760)	13.6%	13.3%	12.9%	12.5%	-0.64%	-1.02%	-0.39%
Medicaid only							
COPD (N = 205,935)	19.5%	19.1%	18.5%	18.2%	-0.93%	-1.23%	-0.30%
PNA/AMI/CHF (N = 379,594)	18.2%	17.8%	17.0%	16.3%	-1.18%	-1.87%	-0.69%
All others (N = 3,968,599)	14.3%	14.4%	13.8%	13.2%	-0.55%	-1.16%	-0.61%
Private insurance only							
COPD (N = 187,959)	12.6%	13.0%	12.5%	11.8%	-0.05%	-0.82%	-0.77%
PNA/AMI/CHF (N = 715,299)	10.7%	10.4%	9.8%	9.6%	-0.92%	-1.15%	-0.22%
All others (N = 9,720,163)	7.7%	7.9%	7.7%	7.5%	-0.07%	-0.29%	-0.22%

Table 40: Estimates of mean readmission rate over HRRP periods - DID analysis

	Phase 2	Phase 1	Non-HRRP	Comparison Phase2 vs Non-HRRP ΔΔ	*P*	Comparison Phase2 vs Phase1 ΔΔ	*P*
Medicare							
Δ(Partial-Pre)	-0.99%	-1.39%	-0.64%	-0.35%	0.386	0.40%	0.339
Δ(Full-Pre)	-1.17%	-1.80%	-1.02%	-0.15%	0.291	0.63%	<.001
Δ(Full-Ramp Up)	-0.83%	-1.28%	-0.82%	-0.01%	0.943	0.45%	0.005
Δ(Full-Partial)	-0.19%	-0.41%	-0.39%	0.20%	0.087	0.23%	0.073
Medicaid							
Δ(Partial-Pre)	-0.93%	-1.18%	-0.55%	-0.38%	0.179	0.25%	0.979
Δ(Full-Pre)	-1.23%	-1.87%	-1.16%	-0.07%	0.837	0.64%	0.108
Δ(Full-Ramp Up)	-0.81%	-1.46%	-1.29%	0.48%	0.185	0.65%	0.113
Δ(Full-Partial)	-0.30%	-0.69%	-0.61%	0.31%	0.238	0.39%	0.200
Private							
Δ(Partial-Pre)	-0.05%	-0.92%	-0.07%	0.02%	0.271	0.87%	0.020
Δ(Full-Pre)	-0.82%	-1.15%	-0.29%	-0.54%	0.059	0.32%	0.275
Δ(Full-Ramp Up)	-1.28%	-0.81%	-0.40%	-0.89%	0.001	-0.48%	0.104
Δ(Full-Partial)	-0.77%	-0.22%	-0.22%	-0.55%	0.016	-0.55%	0.028

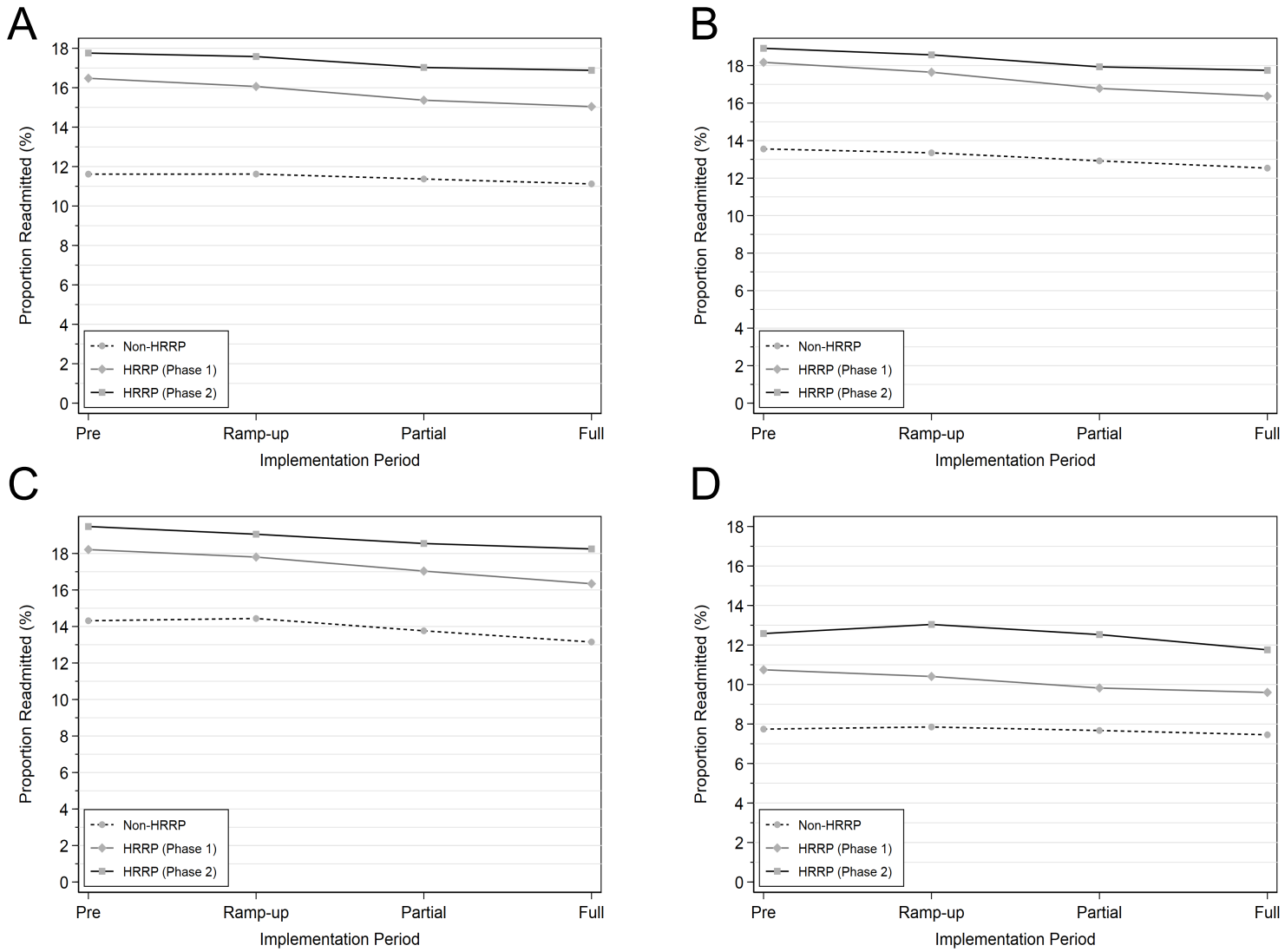

Figure 15: Estimated mean readmission rates within each HRRP period by (A) all payers, (B) Medicare, (C) Medicaid, and (D) private insurance

Table 41: Estimates of rates of changes in readmission rates at key HRRP transition points - DID Estimates

	Phase 2 (COPD)	Phase 1 (AMI, CHF, PNA)	Non-HRRP	Comparison Phase2 vs Non-HRRP		Comparison Phase2 vs Phase1	
				ΔΔ	***P***	**ΔΔ**	***P***
Medicare							
Δ(Oct '12-Apr '11)	-0.036%	-0.027%	0.002%	-0.038%	0.175	-0.009%	0.815
Δ(Oct '14-Apr '11)	-0.045%	-0.010%	-0.011%	-0.034%	0.278	-0.036%	0.235
Δ(Oct '14-May '11)	0.031%	0.030%	0.023%	0.008%	0.949	0.001%	0.990
Δ(Oct '14-Oct '12)	-0.009%	0.017%	-0.013%	0.004%	0.632	-0.026%	0.144
Medicaid							
Δ(Oct '12-Apr '11)	-0.075%	0.006%	-0.046%	-0.029%	0.800	-0.081%	0.310
Δ(Oct '14-Apr '11)	-0.043%	0.097%	0.003%	-0.046%	0.456	-0.139%	0.054
Δ(Oct '14-May '11)	-0.022%	0.092%	0.009%	-0.031%	0.616	-0.114%	0.104
Δ(Oct '14-Oct '12)	0.032%	0.090%	0.049%	-0.017%	0.448	-0.058%	0.148
Private Insurance							
Δ(Oct '12-Apr '11)	-0.015%	-0.028%	-0.002%	-0.013%	0.845	0.013%	0.771
Δ(Oct '14-Apr '11)	0.012%	-0.043%	-0.012%	0.024%	0.579	0.055%	0.291
Δ(Oct '14-May '11)	0.027%	-0.023%	0.001%	0.027%	0.593	0.050%	0.299
Δ(Oct '14-Oct '12)	0.027%	-0.015%	-0.009%	0.036%	0.232	0.042%	0.240

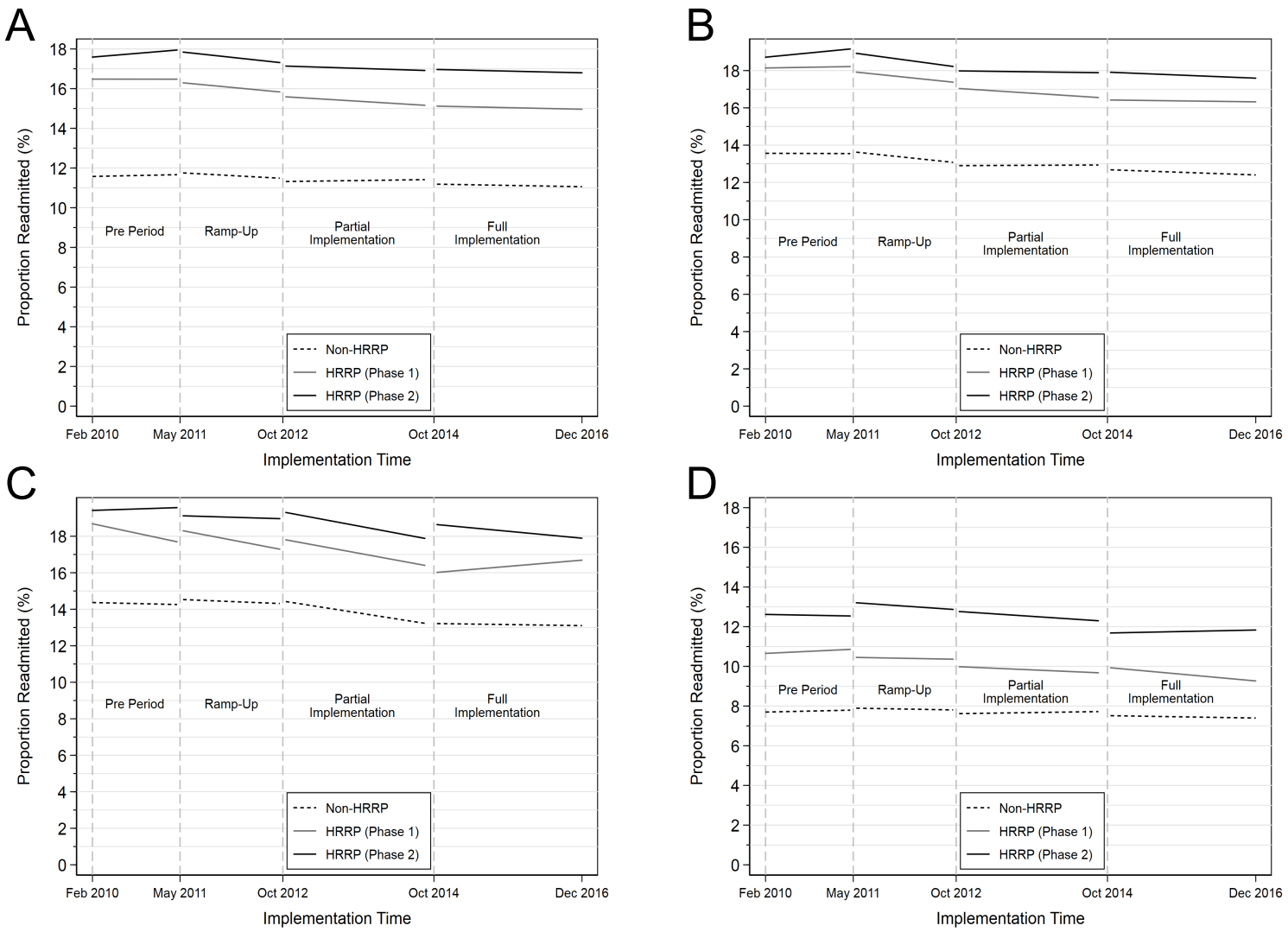

Figure 16: ITS Estimates of readmission rate over four time periods of HRRP by (A) all payers, (B) Medicare only, (C) Medicaid only, and (D) private insurance only

Chapter 7: Discussion and Future Work

In this set of analyses, we evaluated methods of measuring comorbidity as a factor portending risk for readmission in COPD patients, the differential effects of patient factors on the diagnosis at the time of readmission, and the effect of the HRRP on readmission rates in COPD. We sought to do so recognizing that a large portion of readmission reduction efforts for COPD patients revolved around COPD-specific disease management, while also recognizing the prevalence of comorbid illnesses these patients often have in clinical practice. Our objective was to better understand the ways we might operationalize comorbidity to understand the readmission risk and to determine for which causes patients may return to hospital. We also noted in clinical practice that readmission rates had not dropped as rapidly as we might have anticipated with the introduction of the HRRP, and as such, sought to evaluate the effect the penalties had on readmissions nationally. Readmission rates and other markers of quality of care (*e.g.,* patient satisfaction) have correlated in COPD hospitalizations [148]. Some debate remains about whether HRRP sufficiently improves quality of care delivery, particularly in current fee-for-service payment models [81,152,153]. Multimorbidity is described in patients with COPD, and seems to have at least some effect on health related quality of life [96,154], variability in health care utilization patterns [99,155], and mortality [156].

Operationalization of Comorbidity

In our first analysis, we compared the Charlson and Elixhauser comorbidity analyses' ability to estimate odds of readmission following COPD exacerbations. Prediction tools for mortality, readmission, and other intermediate outcomes have been

published in various disease states, including COPD, using a multitude of clinical and administrative data points with somewhat variable performance [157-162]. These tools are used by some centers, including the routine use of the LACE index at UCLA for discharge readmission risk estimation on the internal medicine services. Our primary aim was to determine which widely-used comorbidity aggregation tool would better serve for readmission risk estimation in COPD.

Our findings illustrated the importance of comorbidity in estimation of readmission odds using our administrative dataset. Either of the Charlson and Elixhauser indices could easily be applied to the use of a given patient's diagnoses. The Elixhauser model had a better model fit by information criteria, where lower values signify a better model [118,119]. Realistically, the values for both AIC and BIC in our models were not dramatically different from one another. When comparing candidate models with different primary independent variables, there is not another way using a null hypothesis test to determine significant differences between these models, however, and the information criterion ranking system was our best option for model selection. The likely reason the Elixhauser model was superior using our criteria is the level of detail provided in the index. While Charlson captures 19 comorbidity domains with weights of 1 to 6 points [104], Elixhauser captures 29 [108], and with the readmission-derived weights in the most recent AHRQ version [111], provides a much broader range of scores to describe the heterogeneity of comorbidity in the sample. We opted to carry the Elixhauser model forward into our second analysis in Chapter 5. There is clearly value in using comorbidity to estimate readmission odds in COPD. For health systems, understanding the makeup of their individual populations and their specific comorbidity

profiles could help determine where interventions need to be made in order to improve quality of care. On a broader level, the HRRP is a policy lever designed to improve quality of care by penalizing excessive readmissions for key conditions.

Debate around current risk adjustment models for deriving expected readmission rates is ongoing. Thompson and colleagues [100] analyzed the reliability of the HRRP's method of risk-standardizing readmission rates (RSSR), where they defined reliability as the ratio of between-hospital variation in readmission rates to the within-hospital variation, where high reliability would indicate a systematic difference between hospitals and low reliability a sign of random variations. In their study, they found the reliability for RSSRs in COPD to be only around 65%, and that 55% of excess payments from Medicare were tied to unreliable RSSR measures for COPD. Comorbidity index scores increase every year throughout our study. This may have correlated at least in part with changes in coding practices. In FY2011, CMS changed the number of reportable diagnoses for claims from 10 to 25. One recently published analysis posits that at least some of the observed drops in readmission rates after risk standardization may be related to this change rather than actual changes in hospital practices [151].

Taken together this raises concerns that the current risk stratification methods are insufficient to risk-standardize readmission rates and may result in penalties being assessed more from random variability than hospital quality and performance. When evaluating the CMS methodology for risk adjustment in COPD [88], there is some overlap between the Elixhauser domains and the comorbid conditions employed for risk adjustment. An interesting area of further study could be assessing how mappings

between the CMS risk adjustment categories and the Elixhauser domains could shore up reliability of the risk adjustment measures.

Differences in Readmission Diagnoses in COPD patients

In our second analysis, we evaluated the differential effects of patient and hospital factors for returning to hospital for non-COPD versus COPD diagnoses following an index COPD hospitalization. We were particularly interested in elucidating the makeup of these differences, having noted the bulk of COPD readmission reduction efforts have been focused on COPD-specific disease management. The findings in our analyses in Chapter 4 further highlighted the heterogeneity of comorbid illnesses in the COPD population that may differentially drive the cause for readmission after a COPD exacerbation.

Our analysis showed that 55% of returns to hospital following a COPD exacerbation would not have qualified as a COPD stay based on the HRRP criteria. Among these, several of the DRGs observed at the time of return could have been at least potentially related to the index COPD stay. The top DRG in every year of the study after 2010 with increasing proportions each year was sepsis, with pneumonia and other respiratory infections making up 3 to 4 of the top 10 conditions in every year of our study. Some of this may represent recoding to a higher severity DRG for reimbursement purposes (so-called “DRG creep” [124]), or perhaps a common anecdotally observed misconception among providers that HRRP penalties only apply to returns for the same diagnosis. Without clinical elements to validate the return diagnoses, determining what may be driving this is impossible within our data.

Our data show that the relative reduction in returns for recurrent COPD were greater over the course of the 7-year study period than those for other causes. This may be due in part to the effect of COPD-specific programs to reduce readmissions being deployed, but also illustrates the need to account for other etiologies of readmission after a COPD hospitalization. When approaching risk mitigation strategies for COPD readmissions, approaches limited to COPD-related disease management alone are unlikely to substantially reduce the trajectory of readmissions. Previous studies have argued for integration of strategies for comorbid condition management into the routine practice of COPD care [95,163,164]. Our analysis further reinforces the importance of comorbidity in understanding healthcare utilization. Employing models that use this information to develop integrated practice units, multispecialty clinics, and chronic care management programs may help facilitate better care delivery to such complex patients [22,23].

We know that at least a quarter of readmissions are potentially preventable based on an in-depth analysis of discharge records from a sample of academic medical centers [141]. Factors associated with preventability included health system communication failures, lack of advance care planning, and premature discharges or those without adequate post-discharge support in place. While our analysis was unable to determine which readmissions may or may not have been preventable using administrative discharge records and did not give us information about out-of-hospital deaths, analyzing sample of discharge records from our health system may be able to give us more insight about the preventability of our own readmissions for COPD.

Another interesting finding in this analysis that may lend itself to an additional manuscript is the differential in-hospital mortality rates between returns for COPD and non-COPD causes. Wadhera and colleagues published an analysis of Medicare patients, looking at changes in in and out of hospital mortality rates and readmissions after implementation of the HRRP penalty for congestive heart failure [143]. Within this context, analyzing the effects of policy changes (using national level data), or care management plans that may change hospitalization patterns (using local level data) on outcomes in COPD would be interesting to explore further, and could provide insights into the unintended consequences of the HRRP in this population.

Analysis of the Hospital Readmissions Reduction Program

In our third analysis, we evaluated the effects of the implementation of readmission penalties under the HRRP on readmission rates for COPD. While readmissions for COPD trended down, the difference in change from before to after the HRRP implemented COPD-specific penalties was not significantly different than the background secular change in non-HRRP-penalized conditions, nor compared to the change observed for CHF, AMI, or pneumonia. Our conclusion from this is that the HRRP likely influenced overall readmissions through ecological effects on health system behavior, and that these behavioral changes are not necessarily condition-specific.

This raises the question as to whether condition-specific measures are necessary to affect change upon health system behavior at all. More likely, what we observed was that the change in COPD readmission rate reduction started at the beginning of the implementation phase for the other HRRP conditions and kept pace

with the other conditions throughout the periods we analyzed. Certainly, there would have also been anticipation as to what the logical extension of the HRRP could be, and COPD was already known to be a top offender for readmissions before the proposed rule to include it as a penalized condition. By the time the penalty period for COPD had been reached, there already was a substantial reduction in readmission rates, and the relative effect of adding the penalty was small. While not part of our analysis, we could pick a single condition (whether one in the HRRP, like CHF, or an unrelated condition, like sepsis) to analyze as a benchmark, which could potentially give us more granular insight into condition-specific changes than looking at aggregates across multiple conditions. In another analysis, Zuckerman and colleagues explored the effect of using an all-cause hospital-wide readmission metric instead of condition-specific measures and found that that more hospitals would be penalized and that mean penalties would nearly double with this change, disproportionately affecting safety-net hospitals [138]. While our analysis did not find that adding the COPD penalty changed the magnitude or rate of change in readmission rates was different than the trends already in motion, the condition-specific methodology enables health systems to focus on individual problem areas, and is likely more reasonable for affecting quality improvement in care than a system-wide measure.

While not the primary focus of our analyses, we noted a sizeable association of patients enrolled in Medicaid with elevated readmission odds. This bolsters the concern expressed in multiple other published studies that the HRRP may differentially affect hospitals caring for populations with fewer economic resources [73,146]. At the same time, none of our models showed that increases in the proportion of Medicaid patient-days in

a given hospital were significantly associated with higher readmission odds. The overall trend of readmissions in safety-net hospitals have improved [78,145]. With ongoing Medicaid expansion under the ACA [165], it will be interesting to see how shifts in payer mix affect resources hospitals have available to care for patients and whether readmission rates and other outcomes of interest change. We initially wanted to include an analysis looking at the effect of Medicaid expansion on readmission rates, but the lack of uniformity of the states included in our sample from year to year precluded this. Using a small sample of State Inpatient Database data, which could provide insights on the differential payer mix across a broad sample of geographic locations while preserving the ability to make within-state analyses could be an interesting future direction, particularly within the context of HRRP changes in policy regarding penalties for hospitals with high proportions of dual-eligible patients. A recent analysis modeled dramatic changes in financial penalties under these proposed HRRP rule changes [166], but seeing how the policy change affects actual rates requires further analysis.

Teaching hospitals are another are of interest. We found non-significant trends toward slightly higher readmissions for COPD-related returns and slightly lower for non-COPD related returns in our second analysis. In our third analysis, we noted that the proportion of teaching hospitals is increasing, and that readmission rates in teaching hospitals have remained higher than those for non-teaching hospitals. This finding is congruent with previously published findings of readmission penalties in teaching hospitals [120], and will be the subject of an additional analysis we plan going forward.

Limitations and Methodologic Considerations

The NRD structure poses some issues in the interpretation of our findings. Ideally, we would have used a truly longitudinal database in order to better estimate our readmission outcomes. This would have enabled us to include January and December in our sample. While the loss of these two months of data did not substantially decrease the number of observations, we are left to wonder whether the prevalence of respiratory viruses during the winter months may have affected our findings. We also would have been able to estimate other potential outcomes of interest, such as longer-term readmissions. The use of thirty days by HRRP is somewhat arbitrary, and were the data available, we could have done additional sensitivity analyses to determine whether comorbidity in particular was well-suited to determine adverse outcomes farther out from the index discharge. In addition, the lack of outpatient data in the NRD prevents us from analyzing out-of-hospital events, including deaths.

Another concern related to the multiple pooled cross-sectional approach is the risk of introducing additional bias into the estimates, related to the possibility that there are repeated measurements that are unaccounted for. The NRD is aggregated from State Inpatient Databases, maintained by AHRQ's Healthcare Cost and Utilization Project, and because not all states reported their identifiers in the same way, the NRD cannot be used reliably to identify the same patient from year to year. Furthermore, the sample of states and hospitals changes from year to year (Table 1). Our findings must be interpreted within these limitations, and there is likely an unmeasurable quantity of autocorrelation in the results from unaccounted for repeated measurements. In our attempt to mitigate this (at least within-year) by using a three-level model such that

discharges would be clustered within patients within hospitals, we were unable to fit a model that would converge, and ultimately abandoned the approach.

We also considered using an iterative resampling approach to randomly select individual observations from within year where there were subjects with more than one discharge in a given year. For the COPD-specific analyses, sixty-seven percent of our data only had one observation in a year, while 19% had two (some of which were admission-readmission pairings). The remaining 14% ranged between 3 and 19 admissions in a year (Figure 17). We eventually determined that given we would not be able to correct fully for autocorrelation from unknown repeated patients across years, and that with the large sample, we were unlikely to see significant changes. Given the large amount of computing power already required for our models, the additional resources needed to take this approach (for what we anticipated would be very minor changes in our standard error estimates) did not appear worth it, and we ultimately did not proceed.

For better or worse, there are not any databases currently available that contain the breadth of sample that the NRD provides. We considered using a sample of Medicare research identifiable files or obtaining a sample of commercially insured discharge records from a service such as Optum Labs. Neither of these approaches would have readily allowed us to examine ecological level effects by having a sample of patients from multiple payers from the same hospitals and was ultimately deemed beyond the scope of this dissertation work but could be considered for future validation studies of our findings. Despite this, the NRD offers a unique perspective and these findings will add to the existing literature on COPD readmissions.

As specified in the overarching methods in Chapter 3, we set a threshold of 10% missing data *a priori* as the point at which we would consider imputation techniques. In the COPD analyses (Table 42), the largest proportion of missing data was in the income variable, of which 1.4% was missing. As such and given that income was only a covariate in our models, we did not employ imputation. In the full HRRP analysis, the only adjuster in our models was discharge quarter (to smooth our estimates for periodicity of change within a year), in which there was no missing data. Complete case analyses were used in our models, as outlined in Chapters 4-6.

Ongoing Study

With my new appointment at the Veterans Affairs (V.A.) Medical Center, we could build upon the analyses we did in the NRD using national V.A. data. There are a few advantages to this approach. First, the problem of rehospitalizations is prevalent in the V.A., particularly among those who are getting both non-VA and V.A. care simultaneously [167]. While the V.A. is not itself subject to the HRRP, public reporting of readmission measures in this system is still done, and readmission reduction is a quality priority [168]. Use of the V.A. database also has the advantage of being robust with clinical data elements, the opportunity to validate COPD hospitalizations as attributable to a confirmed COPD diagnosis, and the incorporation of both inpatient and outpatient care patterns, plus it is truly longitudinal, and therefore not restricted by the multiple cross-sections issue as in the NRD.

The problem of rehospitalization in patients with COPD is obviously more complex than can be answered with just secondary analysis of administrative data. Within any given health system, there are complex organizational factors that are in

play. Use of mixed-methods techniques to better understand the organizational milieu and care processes, particularly around discharge planning and transitions of care will be particularly valuable on an individual health system level. Working in collaboration with those in the UCLA health system, I hope to develop a better understanding of deficiencies and areas of improvement for our COPD care, something that will serve as excellent fodder for ongoing study in the next phase of my career.

Addressing social factors within the patient's home milieu will also enable better understanding of COPD outcomes, including readmissions. Social support an important factor in disease self-management in COPD and other chronic illnesses [169-171], though no clear link between support and hospital readmissions have been identified, and very little is known about the nature of social networks among COPD patients [172]. Engagement of informal caregiver networks may provide an important tool in improving the patient experience and for post-discharge outcomes after COPD exacerbations [44,45]. The potential advantages to this approach include both the reduction in direct healthcare costs by potentially reducing reliance on paid professional caregivers and use of post-acute care [43]. In addition, by increasing engagement of trusted support networks in self-management, we may promote buy-in and trust in ways that professional care services may not be able. Measuring informal caregiver networks and understanding their contribution to chronic disease management in COPD patients may be a powerful tool in the effort to improve COPD care delivery and reduce poor outcomes like excess readmissions.

Conclusion

In our analyses of the Nationwide Readmissions Database, we illustrate the importance of comorbidity in the understanding of readmissions risk in chronic obstructive pulmonary disease. We further expanded upon this finding by showing the relative differences in patient factors that portend readmissions for COPD-related and non-COPD related causes. These two findings together will add to the current body of literature by informing health system strategies to improve care delivery, and by illustrating potential ways to improve risk-stratified readmission rate methodology in the HRRP. Lastly, we showed that while readmission rates for COPD fell overall under the HRRP, these effects seem to be largely ecological in nature from the overall effect of the policy on health system behaviors, rather than the result of additional leverage from a condition-specific penalty. We also demonstrated that spillover effects of the HRRP extend into the privately insured, an encouraging finding that the policy itself is changing behavior on a systemic level not only restricted to Medicare populations. We have also generated a number of interesting future research questions from these analyses that will serve as an excellent springboard into future work in the understanding and improvement of COPD outcomes like readmissions.

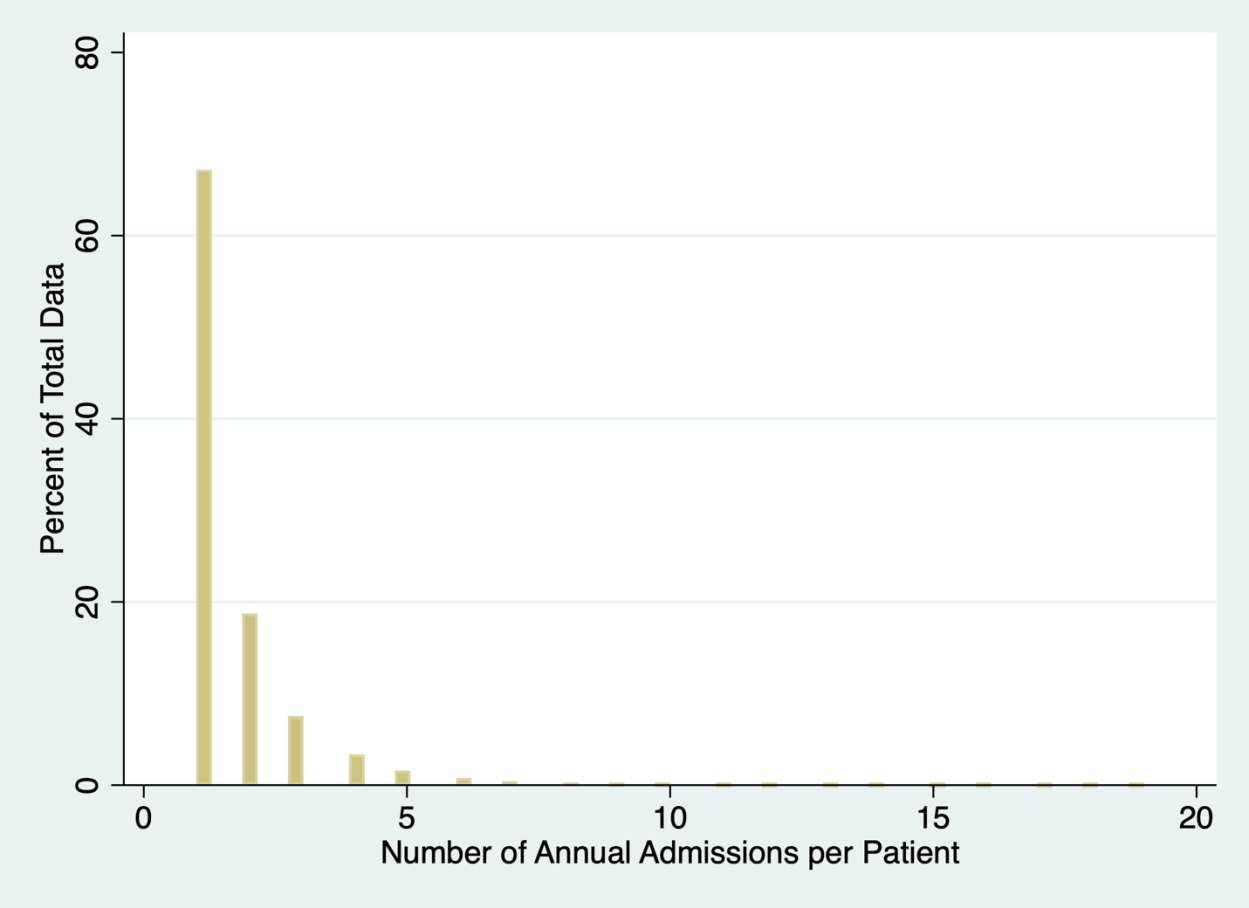

Figure 17: Number of annual admissions per patient in COPD dataset

Table 42: Proportion missing for variable used in multivariable models for COPD-specific analyses (Chapters 4 and 5)

Variable	(N) Proportion Missing
Sex	(0) 0.0%
Age	(0) 0.0%
[1]Income Quartile	(24,544) 1.4%
Payer	(3,407) 0.2%
Disposition	(0) 0.0%
LOS	(0) 0.0%
Non-invasive ventilation	(0) 0.0%
Mechanical ventilation	(0) 0.0%
Presence or placement of tracheostomy	(0) 0.0%
Cardiac arrest	(0) 0.0%
Performance of CPR	(0) 0.0%
Hospital ownership	(0) 0.0%
Hospital teaching status	(0) 0.0%
Hospital location	(0) 0.0%
Hospital Bed Size	(0) 0.0%
Annual Discharges	(0) 0.0%
Proportion patient-days paid by Medicaid	(1,588) 0.1%

[1]Missing values coded as unique category in multivariable models

Table 43: Proportion missing for variable used in multivariable models for COPD-specific analyses (Chapter 6)

Variable	(N) Proportion Missing
Sex	(0) 0.0%
Age	(0) 0.0%
[1]Income Quartile	(693,541) 1.4%
Payer	(88,086) 0.2%
Disposition	(0) 0.0%
LOS	(0) 0.0%
Hospital ownership	(0) 0.0%
Hospital teaching status	(0) 0.0%
Hospital location	(0) 0.0%
Hospital Bed Size	(0) 0.0%
Annual Discharge (per 10k)	(0) 0.0%
Proportion patient-days paid by Medicaid	(56,795) 0.1%

[1]Missing values coded as unique category in multivariable models

Appendices

Appendix A - Glossary of Abbreviations

Term	Definition
ACA	Patient Protection and Affordable Care Act
ACO	Accountable care organization
AHRQ	Agency for Healthcare Research and Quality
AMI	Acute myocardial infarction
BPAP	Bi-level positive airway pressure
CC	Complication or comorbidity
CCI	Charlson Comorbidity Index
CCS	Clinical Classification System
CHF	Congestive heart failure
CMS	Centers for Medicare and Medicaid Services
COPD	Chronic obstructive pulmonary disease
CPAP	Continuous positive airway pressure
CPR	Cardiopulmonary resuscitation
CVA	Cerebrovascular accident (stroke)
DID	Difference in differences analysis
DRG	Diagnosis Related Group
ECI	Elixhauser Comorbidity Index
ECMO	Extracorporeal membrane oxygenation
FFS	Fee-for-service
FY	Fiscal Year (Each begins October 1 of preceding calendar year)
HCUP	Healthcare Cost and Utilization Project
HRRP	Hospital Readmissions Reduction Program
ICD	International Classification of Diseases
IPU	Integrated practice unit
ITS	Interrupted time series
MCC	Major complication or comorbidity
MLM	Multi-level model
MV	Invasive mechanical ventilation
NOS	Not otherwise specified
NIV	Non-invasive positive pressure ventilation
NRD	Nationwide Readmissions Database
PNA	Pneumonia
THA	Total hip arthroplasty
TKA	Total knee arthroplasty
V.A.	Department of Veterans Affairs

Appendix B - Hospital Readmission Reduction Program Diagnostic Codes

Table 44: ICD-9 Diagnostic Codes for COPD for admissions prior to 10/1/2015

Code	Description
491.21	Obstructive chronic bronchitis; With (acute) exacerbation; acute exacerbation of COPD, decompensated COPD, decompensated COPD with exacerbation
491.22	Obstructive chronic bronchitis; with acute bronchitis
491.8	Other chronic bronchitis. Chronic: tracheitis, tracheobronchitis.
491.9	Unspecified chronic bronchitis
492.8	Other emphysema; emphysema (lung or pulmonary): NOS, centriacinar, centrilobular, obstructive, panacinar, panlobular, unilateral, vesicular. MacLeod's syndrome; Swyer-James syndrome; unilateral hyperlucent lung
493.20	Chronic obstructive asthma; asthma with COPD, chronic asthmatic bronchitis, unspecified
493.21	Chronic obstructive asthma; asthma with COPD, chronic asthmatic bronchitis, with status asthmaticus
493.22	Chronic obstructive asthma; asthma with COPD, chronic asthmatic bronchitis, with (acute) exacerbation
496	Chronic: nonspecific lung disease, obstructive lung disease, obstructive pulmonary disease (COPD) NOS. NOTE: This code is not to be used with any code from categories 491-493.
518.81*	Other diseases of lung; acute respiratory failure; respiratory failure NOS
518.82*	Other diseases of lung; acute respiratory failure; other pulmonary insufficiency, acute respiratory distress
518.84*	Other diseases of lung; acute respiratory failure; acute & chronic respiratory failure
799.1*	Other ill-defined & unknown causes of morbidity & mortality; respiratory arrest, cardiorespiratory failure

**Principal diagnosis when combined with secondary diagnosis of AECOPD (491.21, 491.22, 493.21, or 493.22). Excluded if concomitant diagnosis of lung or heart/lung transplantation (procedure codes 33.50, 33.51, 33.52, 33.6, or diagnosis code V42.6).*

Adapted from HRRP methodology report [87].
See Figure 3 for overall inclusion schema.

Table 45: ICD-10 Diagnostic Codes for COPD for admissions on or after 10/1/2015

Code	Description
J41.8	Mixed simple and mucopurulent chronic bronchitis
J42	Unspecified chronic bronchitis
J43.0	Unilateral pulmonary emphysema [MacLeod's syndrome]
J43.1	Panlobular emphysema
J43.2	Centrilobular emphysema
J43.8	Other emphysema
J43.9	Emphysema, unspecified
J44.0	Chronic obstructive pulmonary disease with acute lower respiratory infection
J44.1	Chronic obstructive pulmonary disease with (acute) exacerbation
J44.9	Chronic obstructive pulmonary disease, unspecified
J96.00*	Acute respiratory failure, unspecified whether hypoxia or hypercapnia
J96.01*	Acute respiratory failure with hypoxia
J96.02*	Acute respiratory failure with hypercapnia
J96.20*	Acute and chronic respiratory failure, unspecified whether with hypoxia or hypercapnia
J96.21*	Acute and chronic respiratory failure with hypoxia
J96.22*	Acute and chronic respiratory failure with hypercapnia
J96.90*	Respiratory failure, unspecified, unspecified whether with hypoxia or hypercapnia
J96.91*	Respiratory failure, unspecified with hypoxia
J96.92*	Respiratory failure, unspecified with hypercapnia
R09.2*	Respiratory arrest

**Principal diagnosis when combined with secondary diagnosis of AECOPD (J44.0 or J44.1).*
Excluded if concomitant diagnosis of lung or heart/lung transplantation (procedure codes 0BYC0Z0, 0BYC0Z1, 0BYC0Z2, 0BYD0Z0, 0BYZD0Z1, 0BYD0Z2, 0BYZF0Z0, 0BYZF0Z1, 0BYF0Z2, 0BYG0Z0, 0BYG0Z1, 0BYG0Z2, 0BYH0Z0, 0BYH0Z1, 0BYH0Z2, 0BYJ0Z0, 0BYJ0Z1, 0BYJOZ2, 0BYK0Z0, 0BYK0Z1, 0BYK0Z2, 0BYL0Z0, 0BYL0Z1, 0BYL0Z2, 0BYM0Z0, 0BYM0Z1, 0BYM0Z2 or diagnosis codes Z94.2 or Z94.3).

Adapted from HRRP methodology report [88].
See Figure 3 for overall inclusion schema.

Table 46: ICD-9 Diagnostic Codes for pneumonia for admissions prior to 10/1/2015

Code	Description
480.0	Pneumonia due to adenovirus
480.1	Pneumonia due to respiratory syncytial virus
480.2	Pneumonia due to parainfluenza virus
480.3	Pneumonia due to SARS-associated coronavirus
480.8	Pneumonia due to other virus not elsewhere classified
480.9	Viral pneumonia, unspecified
481	Pneumonia due to Streptococcus pneumoniae
482.0	Pneumonia due to Klebsiella pneumoniae
482.1	Pneumonia due to Pseudomonas
482.2	Pneumonia due to Haemophilus influenzae
482.30	Pneumonia due to Streptococcus, unspecified
482.31	Pneumonia due to Streptococcus, group A
482.32	Pneumonia due to Streptococcus, group B
482.39	Pneumonia due to other Streptococcus
482.40	Pneumonia due to Staphylococcus, unspecified
482.41	Methicillin susceptible pneumonia due to Staphylococcus aureus
482.42	Methicillin resistant pneumonia due to Staphylococcus aureus
482.49	Other Staphylococcus pneumonia
482.81	Pneumonia due to anaerobes
482.82	Pneumonia due to Escherichia coli
482.83	Pneumonia due to other gram-negative bacteria
482.84	Pneumonia due to Legionnaires' disease
482.89	Pneumonia due to other specified bacteria
482.9	Bacterial pneumonia, unspecified
483.0	Pneumonia due to mycoplasma pneumoniae
483.1	Pneumonia due to chlamydia
483.8	Pneumonia due to other specified organism
485	Bronchopneumonia, organism unspecified
486	Pneumonia, organism unspecified
487.0	Influenza with pneumonia
488.11	Influenza due to identified 2009 H1N1 influenza virus with pneumonia
507.0	Pneumonitis due to inhalation of food or vomitus
038.0*	Streptococcal septicemia
031.10*	Staphylococcal septicemia, unspecified
038.11*	Methicillin susceptible Staphylococcus aureus septicemia

Code	Description
038.12*	Methicillin resistant Staphylococcus aureus septicemia
038.19*	Other staphylococcal septicemia
038.2*	Streptococcus pneumoniae septicemia
038.3*	Septicemia due to anaerobes
038.40*	Septicemia due to gram-negative organism, unspecified
038.41*	Septicemia due to Haemophilus Influenzae
038.42*	Septicemia due to Escherichia coli
038.43*	Septicemia due to pseudomonas
038.44*	Septicemia due to Serratia
038.49*	Other septicemia due to gram-negative organisms
038.8*	Other specified septicemias
038.9*	Unspecified septicemia
995.91*	Sepsis

* Principal discharge diagnosis codes included in cohort if combined with a secondary diagnosis of pneumonia coded as present on admission (POA) and no secondary diagnosis of severe sepsis (995.92 Severe sepsis or 785.52 Septic shock) coded as POA is present

Adapted from HRRP methodology report [87].
See Figure 3 for overall inclusion schema.

Table 47: ICD-10 Diagnostic Codes for pneumonia for admissions on or after 10/1/2015

Code	Description
A48.1	Legionnaires' disease
J10.00	Influenza due to identified influenza virus with unspecified type of pneumonia
J10.01	Influenza due to other identified influenza virus with the same other identified influenza virus pneumonia
J10.08	Influenza due to other identified influenza virus with other specified pneumonia
J11.00	Influenza due to unidentified influenza virus with unspecified type of pneumonia
J11.08	Influenza due to unidentified influenza virus with specified pneumonia
J12.0	Adenoviral pneumonia
J12.1	Respiratory syncytial virus pneumonia
J12.2	Parainfluenza virus pneumonia
J12.3	Human metapneumovirus pneumonia
J12.91	Pneumonia due to SARS-associated coronavirus
J12.89	Other viral pneumonia
J12.91	Viral pneumonia, unspecified
J13	Pneumonia due to Streptococcus pneumoniae
J14	Pneumonia due to Haemophilus influenzae
J15.0	Pneumonia due to Klebsiella pneumoniae
J15.1	Pneumonia due to Pseudomonas species
J15.20	Pneumonia due to Staphylococcus species, unspecified
J15.211	Pneumonia due to methicillin-susceptible Staphylococcus aureus
J15.212	Pneumonia due to methicillin-resistant Staphylococcus aureus
J15.29	Pneumonia due to other Staphylococcus species
J15.3	Pneumonia due to Streptococcus species, group B
J15.4	Pneumonia due to other streptococci
J15.5	Pneumonia due to Escherichia coli
J15.6	Pneumonia due to other aerobic Gram-negative bacteria
J15.7	Pneumonia due to Mycoplasma pneumoniae
J15.8	Pneumonia due to other specified bacteria
J15.9	Unspecified bacteria pneumonia
J16.0	Chlamydial pneumonia
J16.8	Pneumonia due to other specified infectious organisms
J18.0	Bronchopneumonia, unspecified organism
J18.1	Lobar pneumonia, unspecified organism

Code	Description
J18.8	Other pneumonia, unspecified organism
J18.9	Pneumonia, unspecified organism
J69.0	Pneumonitis due to inhalation of food and vomit
A02.1*	Salmonella sepsis
A22.7*	Anthrax sepsis
A26.7*	Erysipelothrix sepsis
A32.7*	Listeria sepsis
A40.0*	Sepsis due to streptococcus, group A
A40.1*	Sepsis due to streptococcus, group B
A40.3*	Sepsis due to Streptococcus pneumoniae
A40.8*	Other streptococcal sepsis
A40.9*	Streptococcal sepsis, unspecified
A41.01*	Sepsis due to methicillin-susceptible Staphylococcus aureus
A41.02*	Sepsis due to methicillin-resistant Staphylococcus aureus
A41.1*	Sepsis due to other specified staphylococcus
A41.2*	Sepsis due to unspecified staphylococcus
A41.3*	Sepsis due to Haemophilus influenzae
A41.4*	Sepsis due to anaerobes
A41.50*	Gram-negative sepsis, unspecified
A41.51*	Sepsis due to Escherichia coli
A41.52*	Sepsis due to Pseudomonas
A41.53*	Sepsis due to Serratia
A41.59*	Other Gram-negative sepsis
A41.81*	Sepsis due to Enterococcus
A41.89*	Other specified sepsis
A42.7*	Actinomycotic sepsis
A54.86*	Gonococcal sepsis
B37.7*	Candidal sepsis

** Principal discharge diagnosis codes included in cohort if combined with a secondary diagnosis of pneumonia coded as present on admission (POA) and no secondary diagnosis of severe sepsis (R65.20) or septic shock (R65.21) coded as POA is also present*

Adapted from HRRP methodology [88].
See Figure 3 for overall inclusion schema.

Table 48: ICD-9 Diagnostic Codes for acute myocardial infarction for admissions prior to 10/1/2015

Code	Description
410.00	Acute myocardial infarction of anterolateral wall, initial episode of care
410.01	Acute myocardial infarction of anterolateral wall, episode of care unspecified
410.10	Acute myocardial infarction of other anterior wall, episode of care unspecified
410.11	Acute myocardial infarction of other anterior wall, initial episode of care
410.20	Acute myocardial infarction of inferolateral wall, episode of care unspecified
410.21	Acute myocardial infarction of inferolateral wall, initial episode of care
410.30	Acute myocardial infarction of inferoposterior wall, episode of care unspecified
410.31	Acute myocardial infarction of inferoposterior wall, initial episode of care
410.40	Acute myocardial infarction of other inferior wall, episode of care unspecified
410.41	Acute myocardial infarction of other inferior wall, initial episode of care
410.50	Acute myocardial infarction of other lateral wall, episode of care unspecified
410.51	Acute myocardial infarction of other lateral wall, initial episode of care
410.60	True posterior wall infarction, episode of care unspecified
410.61	True posterior wall infarction, initial episode of care
410.70	Subendocardial infarction, episode of care unspecified
410.71	Subendocardial infarction, initial episode of care
410.80	Acute myocardial infarction of other specified sites, episode of care unspecified
410.81	Acute myocardial infarction of other specified sites, initial episode of care
410.90	Acute myocardial infarction of unspecified site, episode of care unspecified
410.91	Acute myocardial infarction of unspecified site, initial episode of care

Adapted from HRRP methodology report [87].
See Figure 3 for overall inclusion schema.

Table 49: ICD-10 Diagnostic Codes for acute myocardial infarction for admissions on or after 10/1/2015

Code	Description
I21.01	ST elevation (STEMI) myocardial infarction involving left main coronary artery
I21.02	ST elevation (STEMI) myocardial infarction involving left anterior descending coronary artery
I21.09	ST elevation (STEMI) myocardial infarction involving other coronary artery of anterior wall
I21.11	ST elevation (STEMI) myocardial infarction involving right coronary artery
I21.19	ST elevation (STEMI) myocardial infarction involving other coronary artery of inferior wall
I21.21	ST elevation (STEMI) myocardial infarction involving left circumflex coronary artery
I21.29	ST elevation (STEMI) myocardial infarction involving other sites
I21.3	ST elevation (STEMI) myocardial infarction involving unspecified site
I21.4	Non-ST elevation (NSTEMI) myocardial infarction

Adapted from HRRP methodology [88].
See Figure 3 for overall inclusion schema.

Table 50: ICD-9 Diagnostic Codes for congestive heart failure for admissions prior to 10/1/2015

Code	Description
402.01	Malignant hypertensive heart disease with heart failure
402.11	Benign hypertensive heart disease with heart failure
402.91	Unspecified hypertensive heart disease with heart failure
404.01	Hypertensive heart and chronic kidney disease, malignant, with heart failure and with chronic kidney disease stage I through stage IV, or unspecified
404.03	Hypertensive heart and chronic kidney disease, malignant, with heart failure and with chronic kidney disease stage V or end stage renal disease
404.11	Hypertensive heart and chronic kidney disease, benign, with heart failure and with chronic kidney disease stage I through stage IV, or unspecified
404.13	Hypertensive heart and chronic kidney disease, benign, with heart failure and chronic kidney disease stage V or end stage renal disease
404.91	Hypertensive heart and chronic kidney disease, unspecified, with heart failure and with chronic kidney disease stage I through stage IV, or unspecified
404.93	Hypertensive heart and chronic kidney disease, unspecified, with heart failure and chronic kidney disease stage V or end stage renal disease
428.0	Congestive heart failure, unspecified
428.1	Left heart failure
428.20	Systolic heart failure, unspecified
428.21	Acute systolic heart failure
428.22	Chronic systolic heart failure
428.23	Acute on chronic systolic heart failure
428.30	Diastolic heart failure, unspecified
428.31	Acute diastolic heart failure
428.32	Chronic diastolic heart failure
428.33	Acute on chronic diastolic heart failure
428.40	Combined systolic and diastolic heart failure, unspecified
428.41	Acute combined systolic and diastolic heart failure
428.42	Chronic combined systolic and diastolic heart failure
428.43	Acute on chronic combined systolic and diastolic heart failure
428.9	Heart failure, unspecified

Eligibility excluded if ICD-9-CM procedure codes for transplant (33.6, 37.51), or mechanical circulatory support (37.60, 37.62, 37.65, 37.66, 37.68) or diagnostic codes (V42.1, V43.21, V43.22) are present.

Adapted from HRRP methodology report [87].
See Figure 3 for overall inclusion schema.

Table 51: ICD-10 Diagnostic Codes for congestive heart failure for admissions on or after 10/1/2015

Code	Description
I11.0	Hypertensive heart disease with heart failure
I13.0	Hypertensive heart and chronic kidney disease with heart failure and stage 1 through stage 4 chronic kidney disease, or end stage renal disease
I50.1	Left ventricular failure
I50.20	Unspecified systolic (congestive) heart failure
I50.21	Acute systolic (congestive) heart failure
I50.22	Chronic systolic (congestive) heart failure
I50.23	Acute on chronic systolic (congestive) heart failure
I50.30	Unspecified diastolic (congestive) heart failure
I50.31	Acute diastolic (congestive) heart failure
I50.32	Chronic diastolic (congestive) heart failure
I50.33	Acute on chronic diastolic (congestive) heart failure
I50.40	Unspecified combined systolic (congestive) and diastolic (congestive) heart failure
I50.41	Acute combined systolic (congestive) and diastolic (congestive) heart failure
I50.42	Chronic combined systolic (congestive) and diastolic (congestive) heart failure
I50.43	Acute on chronic combined systolic (congestive) and diastolic (congestive) heart failure
I50.9	Heart failure, unspecified

Eligibility excluded if ICD-10-PCS procedure codes for transplant (02YA0Z0, 02YA0Z1, 02YA0Z2), or mechanical circulatory support (02HA0QZ, 02HA0RS, 02HA0RZ, 02HA3QZ, 02HA3RS, 02HA3RZ, 02HA4QZ, 02HA4RS, 02HA4RZ) or diagnostic codes (Z94.1 or Z95.811) are present

Adapted from HRRP methodology [88].
See Figure 3 for overall inclusion schema.

Table 52: Clinical Classification System diagnostic and procedure codes for always planned readmissions excepted from HRRP penalties for all admissions 2010-2016

Code	Description
Procedure 64	Bone marrow transplant
Procedure 105	Kidney transplant
Procedure 134	Cesarean section
Procedure 135	Forceps, vacuum, and breech delivery
Procedure 176	Other organ transplantation
Diagnosis 45	Maintenance chemotherapy
Diagnosis 194	Forceps delivery
Diagnosis 196	Normal pregnancy and/or delivery
Diagnosis 254	Rehabilitation

Adapted from HRRP methodology reports [87,88]
See Figure 3 for overall exclusion schema.

Table 53: Clinical Classification System procedure codes for potentially planned readmissions excepted from HRRP penalties for admissions prior to 10/1/2015

Code	*Description*
1	Incision and excision of central nervous system
3	Laminectomy; excision of intervertebral disc
5	Insertion of catheter or spinal stimulator and injection into spinal cord
9	Other operating room therapeutic nervous system procedures
10	Thyroidectomy; partial or complete
12	Other therapeutic endocrine procedures
33	Other operating room therapeutic procedures on nose, mouth, or pharynx
36	Lobectomy or pneumonectomy of lung
38	Other diagnostic procedures of lung and bronchus
40	Other diagnostic procedures of respiratory tract and mediastinum
43	Heart valve procedures
44	Coronary artery bypass graft (CABG)
45	Percutaneous transluminal coronary angioplasty (PTCA)
49	Other operating room heart procedures
51	Endarterectomy of vessel of head and neck
52	Aortic resection, replacement, or anastomosis
53	Varicose vein stripping of lower limb
55	Peripheral vascular bypass
56	Other vascular bypass and shunt, non-cardiac
59	Other operating room therapeutic procedures of vessels of head and neck
66	Procedures on spleen
67	Other therapeutic procedures of hemic or lymphatic system
74	Gastrectomy
78	Colorectal resection
79	Local excision of large intestinal lesion (non-endoscopic)
84	Cholecystectomy and common bile duct exploration
85	Inguinal or femoral hernia repair
86	Other hernia repair
99	Other operating room gastrointestinal therapeutic procedures
104	Nephrectomy
106	Genitourinary incontinence procedures
107	Extracorporeal lithotripsy
109	Procedures on the urethra
112	Other therapeutic procedures of urinary tract
113	Transurethral resection of prostate (TURP)
114	Open prostatectomy
119	Oophorectomy

Code	*Description*
120	Other operations on ovary
124	Hysterectomy
129	Repair of cystocele and rectocele, obliteration of vaginal vault
132	Other operating room therapeutic procedures of the female organs
142	Partial excision of bone
152	Arthroplasty of knee
153	Arthroplasty of hip
154	Arthroplasty of joint other than hip or knee
158	Spinal fusion
159	Other diagnostic procedures of musculoskeletal system
166	Lumpectomy or quadrantectomy of breast
167	Mastectomy
170	Excision of skin lesion
172	Skin graft

Adapted from HRRP methodology reports [87]
See Figure 3 for overall exclusion schema.

Table 54: Clinical Classification System procedure codes for potentially planned readmissions excepted from HRRP penalties for admissions after 10/1/2015

Code	*Description*
1	Incision and excision of central nervous system
3	Laminectomy; excision of intervertebral disc
5	Insertion of catheter or spinal stimulator and injection into spinal cord
9	Other operating room therapeutic nervous system procedures
10	Thyroidectomy; partial or complete
12	Other therapeutic endocrine procedures
33	Other operating room therapeutic procedures on nose, mouth, or pharynx
36	Lobectomy or pneumonectomy of lung
38	Other diagnostic procedures of lung and bronchus
40	Other diagnostic procedures of respiratory tract and mediastinum
43	Heart valve procedures
44	Coronary artery bypass graft (CABG)
45	Percutaneous transluminal coronary angioplasty (PTCA)
49	Other operating room heart procedures
51	Endarterectomy of vessel of head and neck
52	Aortic resection, replacement, or anastomosis
53	Varicose vein stripping of lower limb
55	Peripheral vascular bypass
56	Other vascular bypass and shunt, non-cardiac
59	Other operating room therapeutic procedures of vessels of head and neck
66	Procedures on spleen
67	Other therapeutic procedures of hemic or lymphatic system
74	Gastrectomy
78	Colorectal resection
79	Local excision of large intestinal lesion (non-endoscopic)
84	Cholecystectomy and common bile duct exploration
85	Inguinal or femoral hernia repair
86	Other hernia repair
99	Other operating room gastrointestinal therapeutic procedures
104	Nephrectomy
106	Genitourinary incontinence procedures
107	Extracorporeal lithotripsy
109	Procedures on the urethra

Code	*Description*
112	Other therapeutic procedures of urinary tract
113	Transurethral resection of prostate (TURP)
114	Open prostatectomy
119	Oophorectomy
120	Other operations on ovary
124	Hysterectomy
129	Repair of cystocele and rectocele, obliteration of vaginal vault
132	Other operating room therapeutic procedures of the female organs
142	Partial excision of bone
152	Arthroplasty of knee
153	Arthroplasty of hip
154	Arthroplasty of joint other than hip or knee
158	Spinal fusion
159	Other diagnostic procedures of musculoskeletal system
166	Lumpectomy or quadrantectomy of breast
167	Mastectomy
172	Skin graft
175	Other operating room skin/soft tissue, fascia or breast therapeutic procedures

Adapted from HRRP methodology reports [87,88].
See Figure 3 for overall exclusion schema.

Table 55: ICD-9 procedure codes for potentially planned readmissions excepted from HRRP penalties for admissions prior to 10/1/2015

Codes	Description
30.1, 30.29, 30.3, 30.4, 31.74, 34.6	Laryngectomy, revision of tracheostomy, scarification of pleura (from AHRQ CCS Procedure category 42 - Other OR Rx procedures on respiratory system and mediastinum)
38.18	Endarterectomy of vessel of leg
55.03, 55.04	Percutaneous nephrostomy with and without fragmentation
94.26, 94.27	Electroconvulsive therapy

Adapted from HRRP methodology reports [87].
See Figure 3 for overall exclusion schema.

Table 56: ICD-10 procedure codes for potentially planned readmissions excepted from HRRP penalties for admissions after 10/1/2015

Code	Description
0CBR4ZZ, 0CBS7ZZ, 0CBS8ZZ	Laryngectomy
0B5N0ZZ, 0B5N3ZZ, 0B5N4ZZ, 0B5P0ZZ, 0B5P3ZZ, 0B5P4ZZ, 0BW10FZ, 0BW13FZ, 0BW14FZ	Revision of tracheostomy
0TC03ZZ, 0TC04ZZ, 0TC13ZZ, 0TC14ZZ, 0TC33ZZ, 0TC34ZZ, 0TC43ZZ, 0TC44ZZ	Nephrostomy
0T9030Z, 0T9130Z	Kidney procedures
GZB0ZZZ, GZB1ZZZ, GZB2ZZZ, GZB3ZZZ, GZB4ZZZ	Electroconvulsive therapy

Adapted from HRRP methodology reports [88].
See Figure 3 for overall exclusion schema.

Table 57: Clinical Classification System codes for acute conditions or complications of care negating the planned readmission designation from HRRP penalties for admissions prior to 10/1/2015

Code	Description
1	Tuberculosis (TB)
2	Septicemia (except in labor)
3	Bacterial infection, unspecified site
4	Mycoses
5	Infection
7	Viral infection
8	Other infections, including parasitic
9	Sexually transmitted infections (STI) other than HIV or hepatitis
54	Gout and other crystal arthropathies
55	Fluid and electrolyte disorders
60	Acute post-hemorrhagic anemia
61	Sickle cell anemia
63	Diseases of white blood cells
76	Meningitis (other than TB or STI)
77	Encephalitis (other than TB or STI)
78	Other CNS infection including poliomyelitis
82	Paralysis
83	Epileptic convulsions
84	Headache including migraine
85	Coma, stupor, and brain damage
87	Retinal detachments/defects, vascular occlusion, and retinopathy
89	Blindness and vision defects
90	Inflammation or infection of eye (other than ST or STI)
91	Other eye disorders
92	Otitis media and related conditions
93	Conditions associated with dizziness or vertigo
99	Hypertension with complications
100	Acute myocardial infarction
102	Nonspecific chest pain
104	Other and ill-defined heart disease
107	Cardiac arrest and ventricular fibrillation
109	Acute cerebrovascular disease
112	Transient cerebral ischemia
116	Aortic and peripheral arterial embolism or thrombosis
118	Phlebitis, thrombophlebitis, and thromboembolic disease
120	Hemorrhoids
122	Pneumonia (other than TB or STI)
123	Influenza

Code	Description
124	Acute and chronic tonsillitis
125	Acute bronchitis
126	Other upper respiratory infections
127	Chronic obstructive pulmonary disease and bronchiectasis
128	Asthma
129	Aspiration pneumonitis due to food or vomitus
130	Pleurisy, pneumothorax, or pulmonary collapse
131	Respiratory failure, insufficiency, or arrest (adult)
135	Intestinal infection
137	Disease of mouth, excluding dental
139	Gastroduodenal ulcer except hemorrhage
140	Gastritis and duodenitis
142	Appendicitis and other appendiceal conditions
145	Intestinal obstruction without hernia
146	Diverticulosis and diverticulitis
148	Peritonitis and intestinal abscess
153	Gastrointestinal hemorrhage
154	Noninfectious gastroenteritis
157	Acute and unspecified renal failure
159	Urinary tract infections
165	Inflammatory conditions of the male genital organs
168	Inflammatory conditions of the female pelvic organs
172	Ovarian cyst
197	Skin and subcutaneous tissue infections
198	Other inflammatory condition of the skin
225	Joint disorders and dislocations due to trauma
226	Fracture of the neck of the femur or hip
227	Spinal cord injury
228	Skull and facial fractures
229	Fracture of upper limb
230	Fracture of lower limb
232	Sprains and strains
233	Intracranial injury
234	Crushing injury or internal injury
235	Open wounds of head, neck, and trunk
237	Complication of device, implant, or graft
238	Complications of surgical procedures or medical care
239	Superficial injury or contusion
240	Burns
241	Poisoning by psychotropic agent
242	Poisoning by other medications and drugs

Code	Description
243	Poisoning by non-medicinal substances
244	Other injuries and conditions due to external causes
245	Syncope
246	Fever of unknown origin
247	Lymphadenitis
249	Shock
250	Nausea and vomiting
251	Abdominal pain
252	Malaise and fatigue
253	Allergic reactions
259	Residual codes, unclassified
650	Adjustment disorders
651	Anxiety disorders
652	Attention-deficit, conduct, and disruptive behavior disorders
653	Delirium, dementia, and amnestic and other cognitive disorders
656	Impulse control disorders, not elsewhere classified
658	Personality disorders
660	Alcohol-related disorders
661	Substance-related disorders
662	Suicide attempt and intentional self-inflicted injuries
663	Screening and history of mental health and substance abuse
670	Miscellaneous mental health disorders

Adapted from HRRP methodology reports [87].
See Figure 3 for overall exclusion schema.

Table 58: Clinical Classification System codes for acute conditions or complications of care negating the planned readmission designation from HRRP penalties for admissions after 10/1/2015

Code	Description
1	Tuberculosis (TB)
2	Septicemia (except in labor)
3	Bacterial infection, unspecified site
4	Mycoses
5	Infection
7	Viral infection
8	Other infections, including parasitic
9	Sexually transmitted infections (STI) other than HIV or hepatitis
54	Gout and other crystal arthropathies
55	Fluid and electrolyte disorders
60	Acute post-hemorrhagic anemia
61	Sickle cell anemia
63	Diseases of white blood cells
76	Meningitis (other than TB or STI)
77	Encephalitis (other than TB or STI)
78	Other CNS infection including poliomyelitis
82	Paralysis
83	Epileptic convulsions
84	Headache including migraine
85	Coma, stupor, and brain damage
87	Retinal detachments/defects, vascular occlusion, and retinopathy
89	Blindness and vision defects
90	Inflammation or infection of eye (other than ST or STI)
91	Other eye disorders
92	Otitis media and related conditions
93	Conditions associated with dizziness or vertigo
99	Hypertension with complications
102	Nonspecific chest pain
104	Other and ill-defined heart disease
107	Cardiac arrest and ventricular fibrillation
109	Acute cerebrovascular disease
112	Transient cerebral ischemia
116	Aortic and peripheral arterial embolism or thrombosis
118	Phlebitis, thrombophlebitis, and thromboembolic disease
120	Hemorrhoids
122	Pneumonia (other than TB or STI)

Code	Description
123	Influenza
124	Acute and chronic tonsillitis
125	Acute bronchitis
126	Other upper respiratory infections
127	Chronic obstructive pulmonary disease and bronchiectasis
128	Asthma
129	Aspiration pneumonitis due to food or vomitus
130	Pleurisy, pneumothorax, or pulmonary collapse
131	Respiratory failure, insufficiency, or arrest (adult)
135	Intestinal infection
137	Disease of mouth, excluding dental
139	Gastroduodenal ulcer except hemorrhage
140	Gastritis and duodenitis
142	Appendicitis and other appendiceal conditions
145	Intestinal obstruction without hernia
146	Diverticulosis and diverticulitis
148	Peritonitis and intestinal abscess
153	Gastrointestinal hemorrhage
154	Noninfectious gastroenteritis
157	Acute and unspecified renal failure
159	Urinary tract infections
165	Inflammatory conditions of the male genital organs
168	Inflammatory conditions of the female pelvic organs
172	Ovarian cyst
197	Skin and subcutaneous tissue infections
198	Other inflammatory condition of the skin
225	Joint disorders and dislocations due to trauma
226	Fracture of the neck of the femur or hip
227	Spinal cord injury
228	Skull and facial fractures
229	Fracture of upper limb
230	Fracture of lower limb
232	Sprains and strains
233	Intracranial injury
234	Crushing injury or internal injury
235	Open wounds of head, neck, and trunk
237	Complication of device, implant, or graft
238	Complications of surgical procedures or medical care
239	Superficial injury or contusion
240	Burns

Code	Description
241	Poisoning by psychotropic agent
242	Poisoning by other medications and drugs
243	Poisoning by non-medicinal substances
244	Other injuries and conditions due to external causes
245	Syncope
246	Fever of unknown origin
247	Lymphadenitis
249	Shock
250	Nausea and vomiting
251	Abdominal pain
252	Malaise and fatigue
253	Allergic reactions
259	Residual codes, unclassified
650	Adjustment disorders
651	Anxiety disorders
652	Attention-deficit, conduct, and disruptive behavior disorders
653	Delirium, dementia, and amnestic and other cognitive disorders
656	Impulse control disorders, not elsewhere classified
658	Personality disorders
660	Alcohol-related disorders
661	Substance-related disorders
662	Suicide attempt and intentional self-inflicted injuries
663	Screening and history of mental health and substance abuse
670	Miscellaneous mental health disorders

Adapted from HRRP methodology reports [88].
See Figure 3 for overall exclusion schema.

Table 59: ICD-9 codes for acute conditions or complications of care negating the planned readmission designation from HRRP penalties for admissions prior to 10/1/2015

Code	Description
032.82	Diptheric myocarditis
036.40	Meningococcal carditis, unspecified
036.41	Meningococcal pericarditis
036.42	Meningococcal endocarditis
036.43	Meningococcal myocarditis
074.20	Coxsackie carditis, unspecified
074.21	Coxsackie pericarditis
074.22	Coxsackie endocarditis
074.23	Coxsackie myocarditis
112.81	Candidal endocarditis
115.03	Histoplasma capsulatum pericarditis
115.04	Histoplasma capsulatum endocarditis
115.13	Histoplasma dubosii pericarditis
115.14	Histoplasma dubosii endocarditis
115.93	Histoplasma unspecified pericarditis
115.94	Histoplasma unspecified endocarditis
130.3	Toxoplasma myocarditis
391.0	Acute rheumatic pericarditis
391.1	Acute rheumatic endocarditis
391.2	Acute rheumatic myocarditis
391.8	Other rheumatic heart disease, unspecified
391.9	Acute rheumatic heart disease, unspecified
392.0	Rheumatic chorea with heart involvement
398.0	Rheumatic myocarditis
398.90	Rheumatic heart disease, unspecified
398.99	Other rheumatic heart diseases
420.0	Acute pericarditis in diseases classified elsewhere
420.90	Acute pericarditis, unspecified
420.91	Acute idiopathic pericarditis
420.99	Other acute pericarditis
423.0	Hemopericardium
423.1	Adhesive pericarditis

Code	Description
423.2	Constrictive pericarditis
423.3	Cardiac tamponade
429.0	Myocarditis, unspecified
426.0	Atrioventricular (AV) block, complete
426.10	AV block, unspecified
426.11	First degree AV block
426.12	Mobitz II AV block
426.13	Other second degree AV block
426.2	Left bundle branch hemiblock
426.3	Other left bundle branch block
426.4	Right bundle branch block
426.50	Bundle branch block, unspecified
426.51	Right bundle branch block with left posterior fascicular block
426.52	Right bundle branch block with left anterior fascicular block
426.53	Other bilateral bundle branch block
426.54	Trifascicular block
426.6	Other heart block
426.7	Anomalous AV excitation
426.81	Lown-Ganong-Levine syndrome
426.82	Long QT syndrome
426.9	Conduction disorder, unspecified
427.2	Paroxysmal tachycardia, unspecified
427.69	Other premature beats
427.89	Other specified cardiac dysrhythmias
427.9	Cardiac dysrhythmia, unspecified
785.0	Tachycardia, unspecified
398.91	Rheumatic heart failure (congestive)
428.0	Congestive heart failure, unspecified
428.1	Left heart failure
428.20	Systolic heart failure, unspecified
428.21	Acute systolic heart failure
428.23	Acute on chronic systolic heart failure
428.30	Diastolic heart failure, unspecified
428.31	Acute diastolic heart failure
428.40	Combined systolic and diastolic heart failure, unspecified

Code	Description
428.41	Acute combined systolic and diastolic heart failure
428.43	Acute on chronic combined systolic and diastolic heart failure
428.9	Heart failure unspecified
574.00	Calculus of gall bladder with acute cholecystitis without obstruction
574.01	Calculus of gall bladder with acute cholecystitis with obstruction
574.30	Calculus of bile duct with acute cholecystitis without obstruction
574.31	Calculus of bile duct with acute cholecystitis with obstruction
574.60	Calculus of gallbladder & bile duct with acute cholecystitis without obstruction
574.61	Calculus of gallbladder & bile duct with acute cholecystitis with obstruction
574.80	Calculus of gallbladder & bile duct with acute and chronic cholecystitis without obstruction
574.81	Calculus of gallbladder & bile duct with acute and chronic cholecystitis with obstruction
575.0	Acute cholecystitis
575.12	Acute and chronic cholecystitis
576.1	Cholangitis
577.0	Acute pancreatitis

Adapted from HRRP methodology reports [87].
See Figure 3 for overall exclusion schema.

Table 60: ICD-10 diagnostic codes for acute conditions or complications of care negating the planned readmission designation from HRRP penalties for admissions after 10/1/2015

Code	Description
A36.81, A39.50, A39.51, A39.52, A39.53, B33.20, B33.21, B33.22, B33.23, B37.6, B58.81, I01.0, I01.1, I01.8, I01.9, I02.0, I09.0, I09.89, I09.9, I30.0, I30.1, I30.8, I30.9, I31.0, I31.1, I31.2, I31.4, I32, I33.0, I33.9, I39, I40.0, I40.1, I40.8, I40.9, I41, I51.4	Peri-endo-, and myocarditis and cardiomyopathy
I21.01, I21.02, I21.09, I21.11, I21.19, I21.21, I21.29, I21.3, I21.4	Acute myocardial infarction
I44.0, I44.1, I44.2, I44.30, I44.4, I44.5, I44.60, I44.69, I44.7, I45.0, I45.10, I45.19, I45.2, I45.3, I45.4, I45.5, I45.6, I45.81, I45.9	Dysrhythmias
I09.91, I50.1, I50.20, I50.21, I50.23, I50.30, I50.31, I50.33, I50.40, I50.41, I50.43, I50.9	Congestive heart failure, non-hypertensive
K80.00, K80.01, K80.12, K80.13, K80.30, K80.31, K80.32, K80.33, K80.36, K80.37, K80.42, K80.43, K80.46, K80.47, K80.62, K80.63, K80.66, K80.67, K81.0, K81.2, K83.0	Biliary tract disease
K85.0, K85.1, K85.2, K85.3, K85.8, K85.9	Pancreatic disorders

Adapted from HRRP methodology reports [88].
See Figure 3 for overall exclusion schema.

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