DETECTING CAUSE OF READMISSION: A BIG DATA ANALYTICS APPROACH

A Thesis Presented

By

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ABSTRACT

Rehospitalizations within a month discharge lead to tremendous cost to health system in the United States. The Hospital readmission is a constant source of researchers' analysis particular in the US where the hospitals face increased pressure to reduce avoidable readmissions under the federal value-based purchasing program. The readmission rate has dropped since the penalty was acted but it is largely owning to the decline in readmissions to the original hospital. Patients readmitted to a different hospital experienced longer hospital stays. On the other hand, patients with comorbid mental and physical illness are particularly vulnerable to readmission.

This study had two research aims: Aim 1: To compare different-hospital readmissions among Medicare and non-Medicare patients with three kinds of primary diagnosis: congestive heart failure (CHF), acute myocardial infarction (AMI), and pneumonia; and Aim 2: To examine the effect of comorbid serious mental illness (SMI) on the risk of 30-day rehospitalization among medical and surgical cohorts.

In Aim 1, we used California Patient Discharge Data from 2010 to 2014. The study sample was composed of three cohorts: congestive heart failure, acute myocardial infarction, and pneumonia inpatients. The main outcome is different-hospital readmissions for each cohort. In Aim 2, we examined hospital discharge records in 2014 from National Readmission Database for medical and surgical inpatients. The main outcome of interest was 30-day readmission among medical and surgical inpatients with comorbid SMI (n = 561,395) and without a comorbid SMI diagnosis (n = 5,767,218).

Results: In Aim 1, we found the rates of changing hospital in Medicare group were less than that observed in non-Medicare group of CHF, AMI and pneumonia cohort. A consistent decreasing trend of different-hospital readmission with readmission interval was found. Several significant predictors were identified in a multivariate analysis. In Aim 2,

we found patients with SMI had higher odds of readmission within 30 days of discharge compared to those without SMI for both medical and surgical hospitalizations.

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1. INTRODUCTION

Nearly one-fifth of Medicare beneficiaries are readmitted within 30 days [1]. The Centers for Medicare and Medicaid Services (CMS) estimates that readmissions cost Medicare $26 billion annually, of which $17 billion is potentially avoidable [1]. On 1 October 2012, mandated by Section 3025 of the Affordable Care Act to establish the Medicare Hospital Readmissions Reduction Program (HRRP), the Centers for Medicare and Medicaid Services (CMS) implemented a strategy of linking quality to payment that relies on financial penalties to improve inpatient care quality and reduce cost [2]. CMS measures a hospital's excess readmission ratio by comparing its readmission performance to the national average, adjusted for patients' clinical risk factors at the time of the index admission [3]. The Medicare Payment Advisory Commission identified congestive heart failure (CHF), acute myocardial infarction (AMI) and pneumonia as common, costly, and potentially preventable causes of readmission, and suggested that Congress and CMS should implement policies address these high readmission rates [4]. Therefore, these three conditions were selected as targets for which hospitals with excessive all-cause rehospitalization within 30 days of discharge were penalized by CMS [5]. This policy has increased the interest in investigating more evidence and attributes of rehospitalizations. Numerous studies were conducted on rehospitalizations, most of which focused on patient-level risk factors with various clinical conditions [6-11]. However, most of them of lump same-hospital and different-hospital readmission together and ignore the fact the different-hospital readmission may be triggered by different clinical and social circumstance [12-14].

Different-hospital readmissions constitute 18-29% of overall readmissions [3]. These different-hospital readmissions brought higher costs (median additional $ 1308 per person) to the patients readmitted in a different hospital than those who readmitted to the index hospital [15]. Further, readmission to a different hospital may contribute to a lack of continuity of clinical information regarding treatment decisions, leading to delayed medical decision making, duplicated diagnostic tests or treatments, and poorer outcomes [16, 17]. Moreover, among readmitted surgical patients, those returning to the index hospital where their surgery took place can achieve improved survival. However, existing literature does not present the breadth of different hospital readmission pattern as it has been restricted to specific conditions, a small number of hospitals, and the Medicare population [3]. There is no investigation regarding the patterns and determinants of non-index hospital readmissions within the Medicare and non-Medicare population. A better understanding of the patterns and determinants of different-hospital readmissions could shed light on opportunities for improving care quality for patients.

Another important issue is the disparity in rates of medical/surgical readmission for patients with serious mental illness (SMI) compared to patients without SMI. In 2016, there were an estimated 18.3% of the U.S. adults suffering mental illness, and there were 4.2% of all adults in U.S have more serious mental illness. Among adults with mental disorders, around 68% have comorbid medical conditions [18]. After a general hospital stay, patients with SMI may fail to have proper follow-up medical treatment and self-care, which increases their risk for rehospitalization [19].

There is a growing body of literature examining the relationship between SMI and medical/surgical readmissions. Prior studies found SMI comorbidity among patients with cardiovascular disease, pneumonia, diabetes and chronic kidney disease is associated with increased risk of 30-readmissions and beyond [5, 20-22]. Many studies presented results of multivariate analysis of the relationship between SMI and 30-day readmission controlling for potentially confounding demographic and clinical conditions. Most of them found the odds of patients with SMI readmitting were significantly higher than for those without SMI [22-27]. In a study of readmissions among medical/surgical patients, medical patients with comorbid SMI had higher odds of rehospitalization at 7, 30, 60, 90 and 180 days compared to those without a comorbid SMI diagnosis, but among surgical inpatients with SMI, there was no difference in readmission [28]. This existing research was restricted to a limited scope of hospitals, and ought to be expanded to a national examination.

In this study, we had two aims to better understand readmissions. In the first aim, we used a statewide hospital discharge database to examine non-index readmissions. We examined index admissions for CHF, AMI, and Pneumonia—the three leading causes of readmissions [29-31]. We investigated the change of readmission rate for each cohort over different readmission intervals through 5 years. We compared patterns of non-index readmissions for Medicare and non-Medicare populations over time from 2010 to 2014. We also examined predictors of non-index readmissions to better understand what factors underlie different hospital destinations for patients' readmissions. In the second aim, we examined the relationship between SMI and medical/surgical readmissions. We compared demographic and clinical characteristics of patients with and without a comorbid SMI diagnosis. We divided the cohort into medical and surgical cohorts and studied the patients who had 30-day readmission separately. We examined the top 15 primary diagnoses for medical and surgical index admissions and readmissions. Finally, we examined the impact of a comorbid SMI diagnosis on 30-day readmissions for medical and surgical hospitalizations using unadjusted and adjusted logistic regression models.

2. METHOD

2.1 Data and study sample classification

To accomplish our aims, we used data from two sources. For Aim 1, we used the California Patient Discharge Data for years 2010 through 2014 [32], and for Aim 2, we used the National Readmission Database (NRD) for 2014 [33].

2.1.1 Aim 1 California dataset

The California Office of Statewide Health Planning and Development (OSHPD) provides dataset comprised of a record for each inpatient discharged from a California-licensed hospitals including general acute care, acute psychiatry, chemical dependency recovery, and psychiatric health facilities. These data include unique identifiers for each patient so that we can track patients across hospitals over time. For each inpatient admission, data include: clinical characteristics (e.g. type of care (i.e. acute care, skilled nursing, psychiatric care, chemical dependency recovery care, physical rehabilitation care), principal diagnosis/procedure defined by ICD-9 codes, Major Diagnostic Category (MDC), Diagnostic Related Group (DRG), days from admission to principal procedure), admission and discharge characteristics (e.g. length of stay, date and source/type of admission) demographic characteristics (e.g. age, gender, sex, race, ethnicity, ZIP code of residence, disposition (i.e. routine, acute/other care within the admitting hospital, skilled nursing within the admitting hospital, acute care at another hospital, other care at another hospital, skilled nursing at another facility, residential care facility, prison, left against medical advice, died, home health service), total charges), and hospital characteristics (e.g. ZIP code and county, bed size, teaching status, and hospital ownership).

The study sample included all patients who had a hospital inpatient stay and were discharged alive from California with an initial diagnosis of AMI, CHF, or Pneumonia. We focused on these three index conditions when we examined index and non-index hospital readmissions. We limited the scope of discharge date between February 1, 2010 and November 30, 2014 to capture any potential readmission within 30 days of an index discharge. We excluded patients who: did not reside in California, left against medical advice or transferred to another acute hospital, died during their inpatient stay, were transferred to another hospital within in a day, and were admitted with a primary diagnosis of mental diseases and disorders (i.e. MDC 19).

2.1.2 Aim 2 NRD dataset

The National Readmission Database (NRD) is sponsored by the Agency for Healthcare Research as part of the Healthcare Cost and Utilization Project (HCUP). The NRD is derived from HCUP State Inpatient Databases and includes weighted discharge data with over 100 clinical and nonclinical variables for each hospital stay. Data are from 21 geographically diverse states accounting for 49.3% of the U.S. population. It includes approximately 14 million unweighted discharges (49.1% of all U.S. discharges) corresponding to 36 million annual discharges nationwide. The NRD includes all discharge records of patients treated in U.S. community hospitals excluding rehabilitation and long-term acute care facilities. Discharge weights are provided to obtain national estimates. We used NRD data from 2014 for examining the association between comorbid SMI and readmissions.

For Aim 2, we identified medical and surgical readmissions based on the methodology provided by HCUP [34]. We excluded hospitalization designated as "planned" readmissions (obstetrics/pregnancy, chemotherapy, transplant procedures), patients admitted with a primary psychiatric diagnosis, those admitted for a primary or secondary diagnosis of dementia, those under the age of 18 or over the age of 100, those who died in the hospital, patients with less than 24 hours' stay in the hospital, those who transferred to another hospital, and those who left against medical advice because clinically they would be difficult to engage in future intervention strategies aimed at reducing readmissions. For patients with multiple readmissions within 30 days, we only include the first readmission.

2.2 Outcome measure and explanatory variables

2.2.1 Aim 1: CHF/AMI/pneumonia readmissions

The main outcome measure for Aim 1 was CHF, AMI and pneumonia patients' different-hospital readmission. and the trends of non-index readmission for these three diagnoses. We classified readmissions into indexed and non-index based on whether the patient got readmitted to the same hospital from where he/she was discharged.

2.2.2 Aim 2: National readmissions with comorbid SMI

The main outcome measure for Aim 2 was all-cause 30 readmissions. Covariates were selected based on a review of existing studies on rehospitalization for the cohort of patients with mental illness [28]. Variables were constructed into three sets: patient demographics, clinical, and hospital characteristics. For patient demographics, age, gender, primary insurance (i.e. Medicare, Medicaid, Private, other), location (urban, metropolitan, micro metropolitan, or rural), and income level (i.e. \$1-39,999, \$40,000-50,999, \$51,000-65,999, >=\$66,000) were considered. Hospital characteristics were the number of beds, hospital location (urban, metropolitan, micro metropolitan, or rural), teaching status, and ownership (government, non-profit private, or investor-owned). Clinical characteristics included the number of Elixhauser comorbidities.

2.3 ANALYSIS

2.3.1 Aim 1 Analysis: California CHF/AMI/pneumonia readmissions

The main aim is to detect the relationship between multiple predictors and the different-hospital readmission. We constructed the data structure based on the data we prepared. We identified the admissions which were followed by a readmission within 7, 10, 15, 20, 25, 30 days. Then, we identified three cohorts of patients with admissions for: CHF (MSDRGs 291 to 293), AMI (MSDRGs 280 to 285) and Pneumonia (MSDRGs 193 to 195). For each of the diagnosis cohorts, we divided them into Medicare and non-Medicare group, and identified those who had readmitted to hospitals other than those they were discharged from (i.e. “different-hospitals”).

Prior to the main analysis, some preliminary analysis was conducted. First, we calculated the readmission rates on readmission intervals of 7, 10, 15, 20, 25, 30, 45, 60 days for CHF, AMI and pneumonia cohorts across five years (2010-2014). Next, we examined the proportion of different-hospital readmission within 7, 10, 15, 20, 25, 30, 45, 60 days for CHF, AMI and pneumonia on each year in our study period (2010-2014). We compared the proportion of 30-day different-hospital readmission in 2010 and 2014 using chi-square test. We compared the proportion of 30-day different-hospital readmission among Medicare and non-Medicare patients for each of CHF, AMI pneumonia cohort. We hypotheses that both Medicare and non-Medicare patients are equally likely to be readmitted to non-index hospitals.

Mixed-effect logistic regression models were used to examine the association of patient level characteristics with different-hospital readmissions and accounted for patient clustering within hospitals. The binary dependent variable was defined as whether a 30-day readmission was non-index or not. We considered a set of patient level explanatory variables related to age (above or below 65), gender, whether the patient was readmitted for same or different initial diagnosis, whether the index admission took place through emergency department or elsewhere, Charlson comorbidity index, urban/rural status of patients’ residence, and admission year (i.e. 2010, 2011, 2012, 2013, 2014), readmission time window (0-7days, 8-10 days, 11-15 days, 16-20 days, 21-25 days, 26-30 days). We also examined hospital characteristics including the hospitals' ownership (nonprofit, investor or public), number of beds, and teaching status. We examined the interaction between the age group and the readmission time window. Adjusted odds ratios and 95% confidence intervals were calculated for each of the explanatory variables to explain their association with the predictive outcome of non-index re-hospitalization. Additionally, z-statistics and associated p-values were used to determine whether the predictor variables were significantly associated with the readmission outcome to a non-index hospital. Analysis were implemented in R-studio (version1.1.419) [35] and StataSE 14 [36]. where all the statistical tests were two-tailed and performed at the 0.05 level of significance.

2.3.2 Aim 2 analysis: national readmissions with comorbid SMI

The primary aim of this study is to examine the association between comorbid SMI and the readmission. The Federal Register defines SMI as a significant and chronic impairment in major domains resulting in persistent problems with cognition, mood, and life functioning [37]. As such, this study operationally defined SMI to encompass comorbid diagnoses of schizophrenia, bipolar disorder, and major depression. This definition of SMI has also been used in other studies examining SMI and subsequent medical readmissions [28, 38, 39].

Before performing our aim analysis to examining the association of comorbid SMI with readmissions, we did some preliminary studies. Descriptive statistics were calculated for all of the study variables characteristics of patients and hospital. Each characteristic was compared among patients with SMI and those without SMI using F-test for continuous variables (age, length of stay, number of medical/surgical admissions) and chi-square test for categorical variables (age group, gender, primary insurance categories (i.e. Medicare, Medicaid, Private, other), patient location (i.e. urban, small metropolitan, micro metropolitan, rural area), median household income quartile (i.e. $1-39,999, $40,000-50,999, $51,000-65,999, >=$66,000), hospital size (i.e. small, medium, large), hospital location (i.e. urban, small metropolitan, micro metropolitan, rural area), teaching status (i.e. metro non teach, metro teach, non-metro), hospital ownership (i.e. government, non-profit, investor-owned). Next, we documented top 15 All Patient Refined Diagnosis Related Groups (APR-DRG) in medical index admissions and 30-day medical readmissions, as well as top 15 APR-DRG in surgical index admissions and 30-day surgical readmissions. Then, we examined the frequencies and rates of 30-day readmissions for medical, surgical index admissions, and subset by CHF, AMI, pneumonia, and COPD. Lastly, we performed logistic regressions to get the unadjusted and adjusted odds ratios for rehospitalization by comorbid SMI. For adjusted logistic regression model, we controlled for demographic characteristics (i.e. age, categories of insurance, patient residence location, income quartile level), hospital characteristics (hospital size in terms of number of beds, hospital location, hospital teaching status, hospital ownership), and clinical characteristics (number of elixhauser comorbidities and 25 comorbidities, psychosis and depression were excluded). We also tested the interaction between SMI and drug and the interaction between SMI and alcohol.

3. RESULT

3.1 Aim 1 California CHF/AMI/pneumonia readmissions

3.1.1 CHF, AMI and pneumonia readmission rates

Figure 1, Figure 2, and Figure 3 show the readmission rates on readmission intervals of 7, 10, 15, 20, 25, 30, 45, 60 days for CHF, AMI and pneumonia readmissions over 5 years respectively. The analytic sample for Aim 1 included a total of 270,854 CHF, 76,168 AMI and 224,729 pneumonia patients who had an index admission and discharged alive between February 2010 and November 2014. Across all three conditions, over each of the five years, readmission rates increased with increasing readmission-time intervals. Average 30-day readmission rates were 21.78%, 18.85% and 13.87% over the five years for CHF, AMI and pneumonia, respectively. CHF 30-day readmission rate decreased by 9.04%, the AMI 30-day readmission rate decreased by 10.54%, but the pneumonia 30-day readmission rate increased by 2.37% from 2010 to 2014. After the HRRP was established in 2012, the 30-day readmission rate of CHF decreased by 4.6%, the 30-day readmission rate of AMI decreased by 0.78%, and the one of pneumonia decreased by 0.62% over 2012 - 2014.

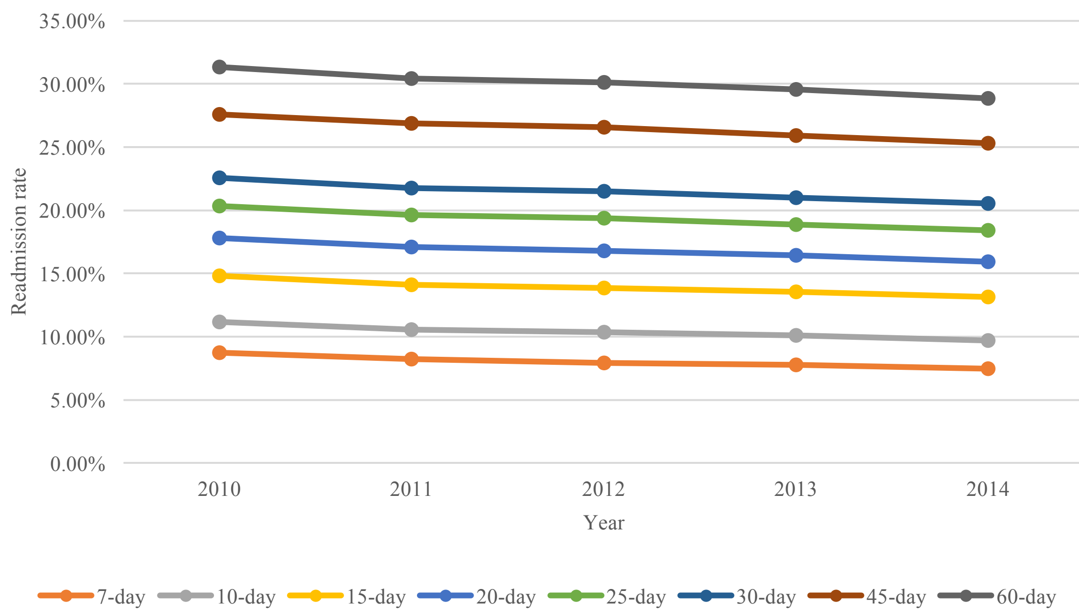

Figure 1: CHF readmission rate for different intervals (2010-2014)

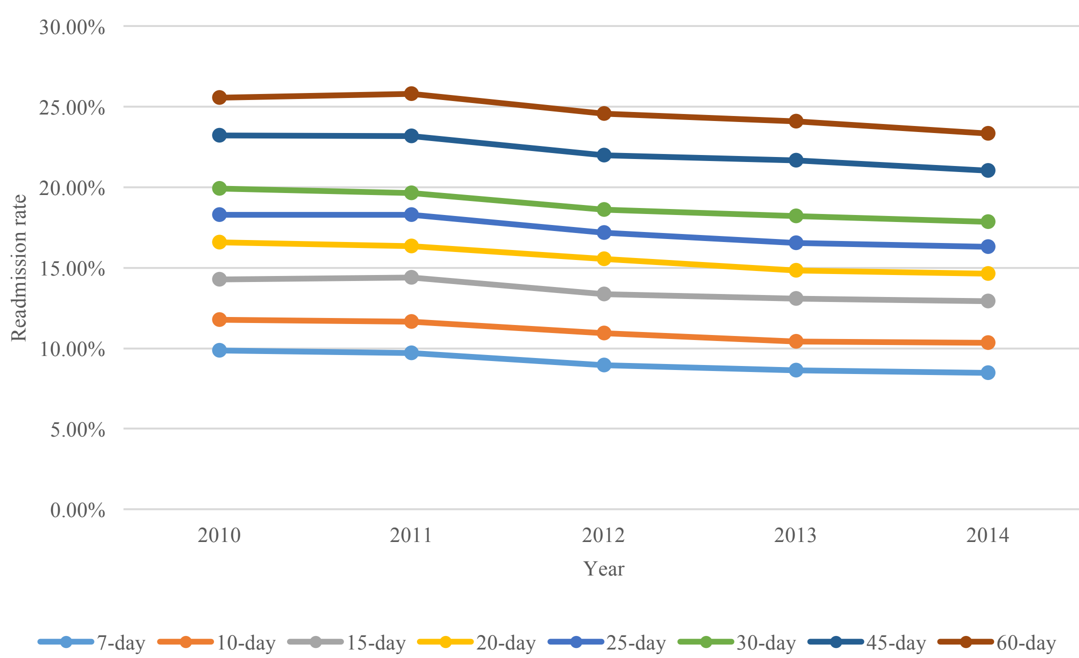

Figure 2: AMI readmission rate for different intervals (2010-2014)

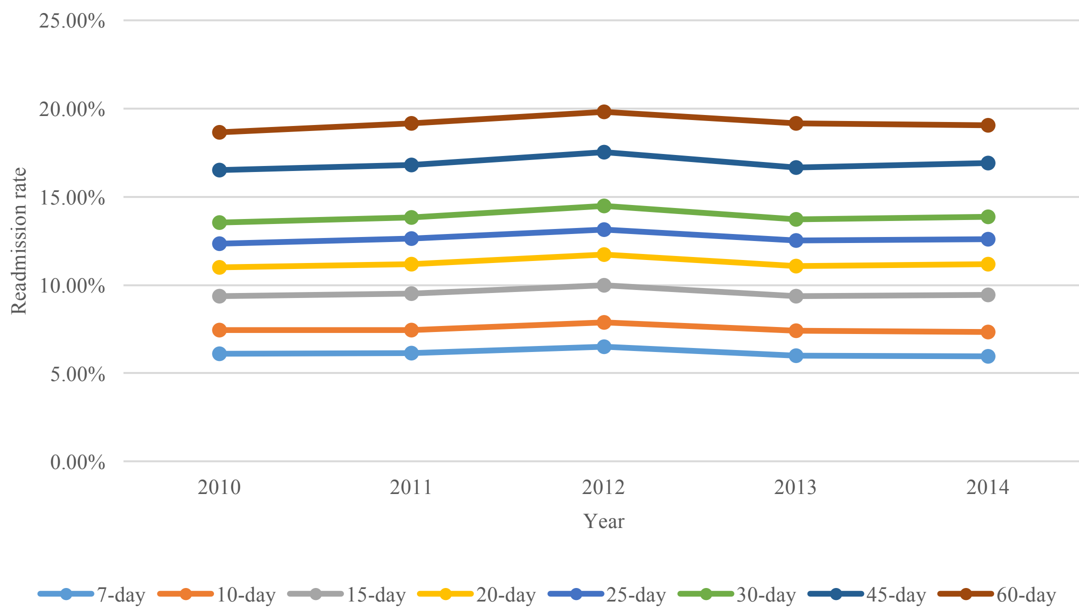

Figure 3: Pneumonia readmission rate for different intervals (2010-2014)

3.1.2 Association of Medicare status related to non-index readmission

Figures 4, 5, and 6 display trends from 2010-2014 of different-hospital readmissions within 7, 10, 15, 20, 25, 30, 45, and 60-days for patients with CHF, AMI and pneumonia. For all readmission intervals, the average rates of changing hospital increased by 14.54%, 5.32%, 7.77% for CHF, AMI and pneumonia respectively. In 2010, 23.26% of rehospitalizations for patients with CHF were to non-index hospitals in 2010; this grew by 12.51% to 26.47% to non-index hospitals in 2014. In the same study period, among patients with AMI, different-hospital readmissions grew by 3.28% (31.40% in 2010 to 32.43% in 2014). And among patients with pneumonia, different-hospital readmissions grew by 8.04% (21.39% in 2010 to 23.11% in 2014). In Table 1, we observed significant increases in readmissions to non-index hospitals from 2010 to 2014 among patients with CHF ($p < 0.001$) and pneumonia ($p = 0.01435$).

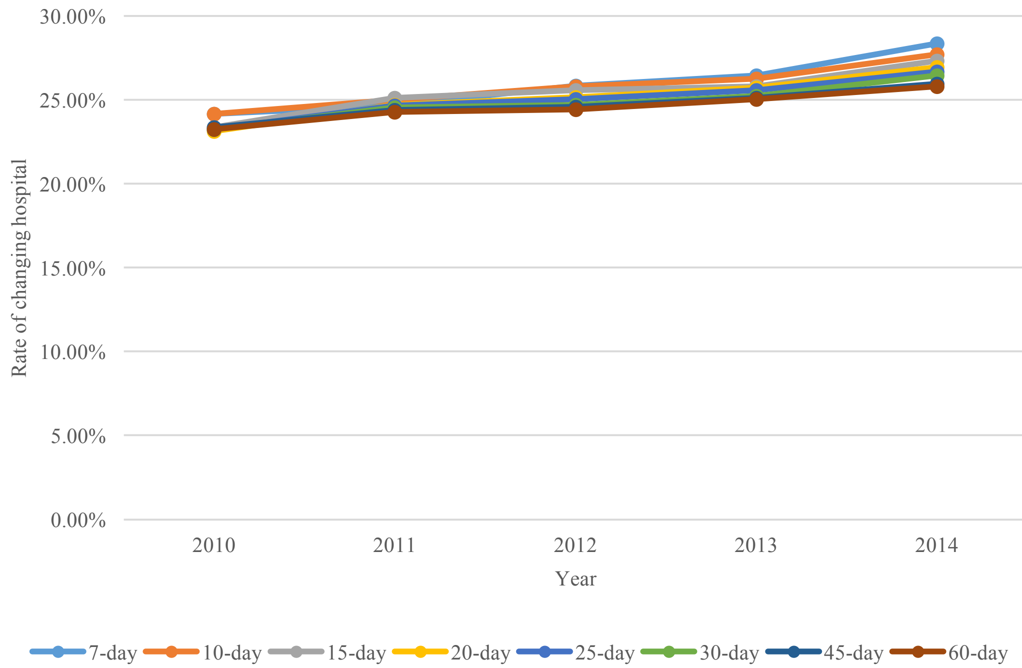

Figure 4: The rate of changing hospital in CHF readmission for different intervals (2010-2014)

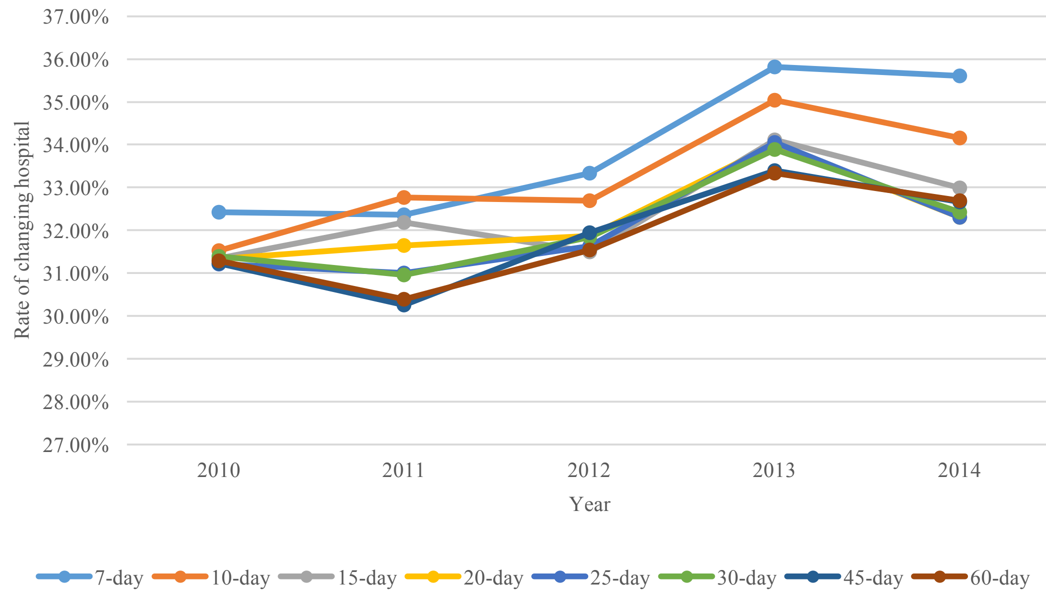

Figure 5: The rate of changing hospital in AMI readmission for different intervals (2010-2014)

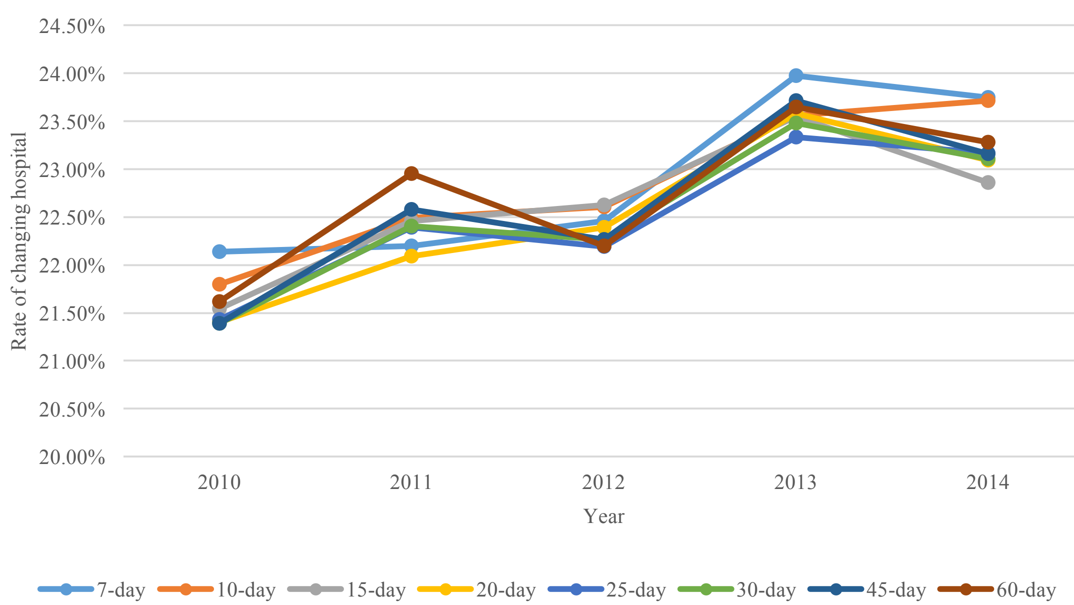

Figure 6: The rate of changing hospital in Pneumonia readmission for different intervals (2010-2014)

Table 1. Comparison of 2010 and 2014 rates of changing hospital for 30-day readmitted patietnts with CHF, AMI and pneumonia			
	2010	2014	p-value
CHF	23.26%	26.47%	<0.001
AMI	31.40%	32.43%	0.3931
pneumonia	21.39%	23.11%	0.01435

In Table 2, we display all-cause 30-day readmission rates to non-index hospitals for patients with CHF, AMI, and pneumonia, by Medicare-payor status. Among the Medicare group 43,597 CHF, 11,948 AMI and 24,582 pneumonia patients were readmitted to either an index or a non-index hospital within 30-day of discharge across 2010-2014. In case of non-Medicare group, these numbers were smaller with 21,878 CHF, 4,116 AMI and 11,787 pneumonia readmissions within 30-day window, almost 50%, 34% and 48% less than that observed in Medicare group of CHF, AMI and pneumonia cohort respectively. We saw higher readmission rate to non-index hospitals for patients without Medicare as a primary payer (p-value<0.001). In particular, the differences between the Medicare and non-Medicare group are even prominent for CHF and AMI patients compared to the pneumonia patients.

Table 2. Percentage of 30-day different hospital readmission associated with three clinical condition among medicare and non-Medicare patients

	CHF (n=65,475)			AMI (n=16,064)			Pneumonia (n=36,369)		
Year	Medicare (n=43,597)	non-Medicare (n=21,878)	P-value	Medicare (n=11,948)	non-Medicare (n=4,116)	P-value	Medicare (n=24,582)	non-Medicare (n=11,787)	P-value
2010	19.99%	30.31%	<0.001	28.91%	38.86%	<0.001	20.25%	23.91%	<0.001
2011	20.89%	31.99%	<0.001	28.82%	38.22%	<0.001	20.59%	26.24%	<0.001
2012	21.06%	32.11%	<0.001	28.94%	40.19%	<0.001	20.66%	25.62%	<0.001
2013	21.83%	31.88%	<0.001	30.62%	42.71%	<0.001	22.02%	26.64%	<0.001
2014	21.93%	34.47%	<0.001	29.41%	40.81%	<0.001	22.27%	26.72%	<0.001

In Figures 7 through 12, we display patterns of different-hospital readmission rates for patients admitted for CHF, AMI, and pneumonia, by year and Medicare payor status. In Figure 7, we show the rate of readmission to different-hospital hospitals for Medicare patients with CHF decreased with longer readmission intervals in each year except for 2011, when there was an increasing trend is found until 15-day readmission window (Figure 7).

A decreasing rate of readmission to non-index hospitals was also observed with longer readmission intervals among CHF patients without Medicare (Figure 8). In Figure 9, we showed the rate of readmission to a different hospital decreased with longer readmission intervals 2011 and 2013 for Medicare patients with AMI (Figure 9). Though, in 2012 and 2014 this decreasing trend is not that prominent, rather an increase in the percentage is found beyond 20-day readmission window. In Figure 10, a decreasing trend of readmission to a different hospital with longer readmission intervals was observed among AMI patients without Medicare (Figure10). In Figure 12, we show the similar decreasing trend of non-index readmission rate with readmission interval was also observed for non-Medicare patients with pneumonia in all but 2011 where an increasing trend is observed (Figure 12). However, the tendency of Medicare counterpart of pneumonia patients being readmitted to different hospitals stays nearly same with the change of readmission interval (Figure 11).

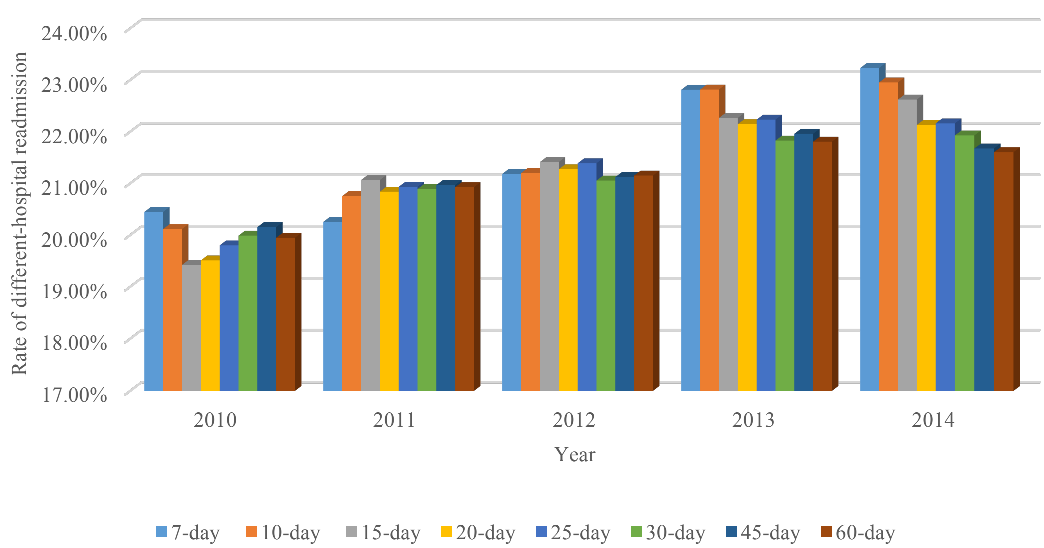

Figure 7: Pattern of non-index readmission rate across different intervals, Medicare CHF patients

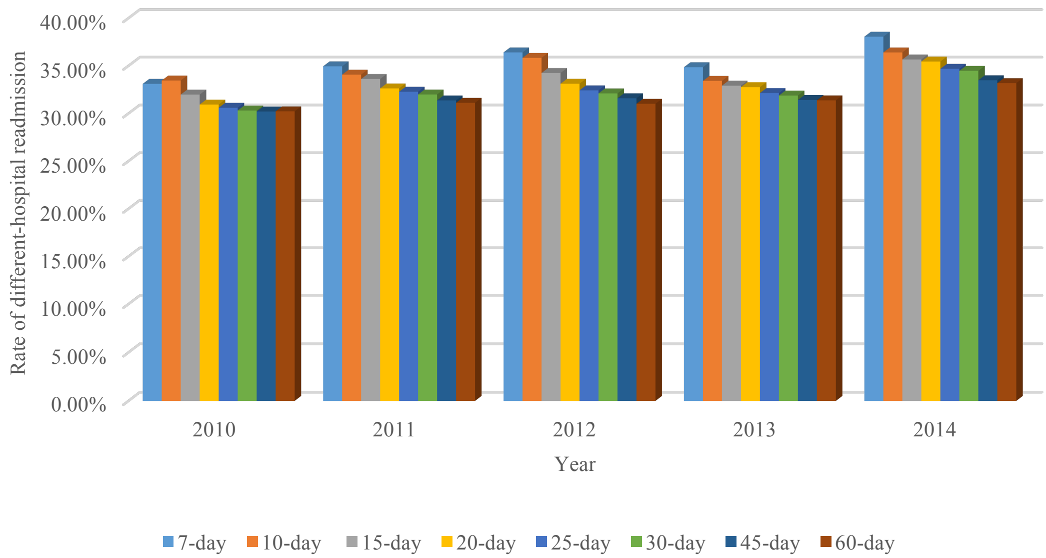

Figure 8: Pattern of non-index readmission rate across different intervals, non-Medicare CHF patients

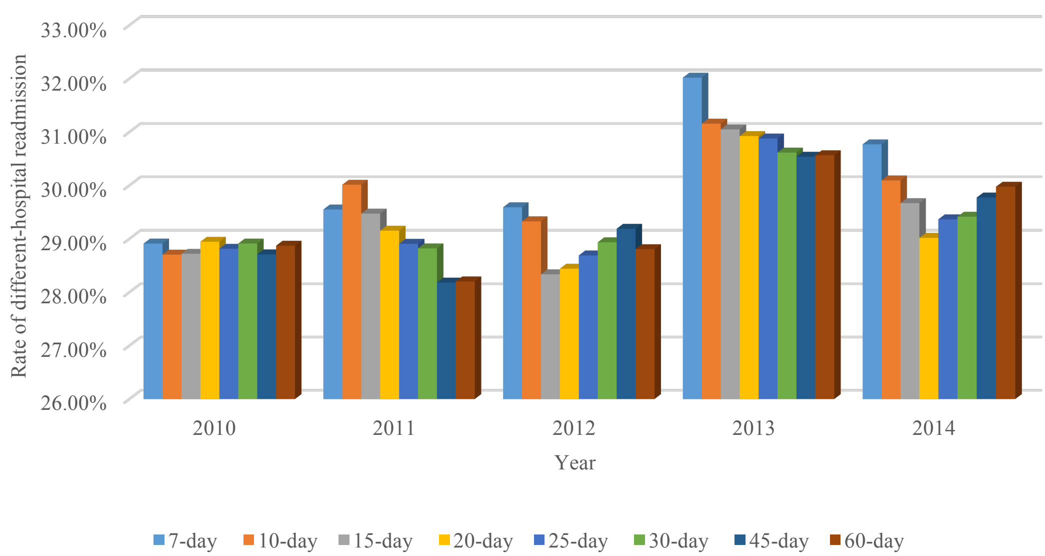

Figure 9: Pattern of different-hospital readmission rate across different intervals, Medicare AMI patients

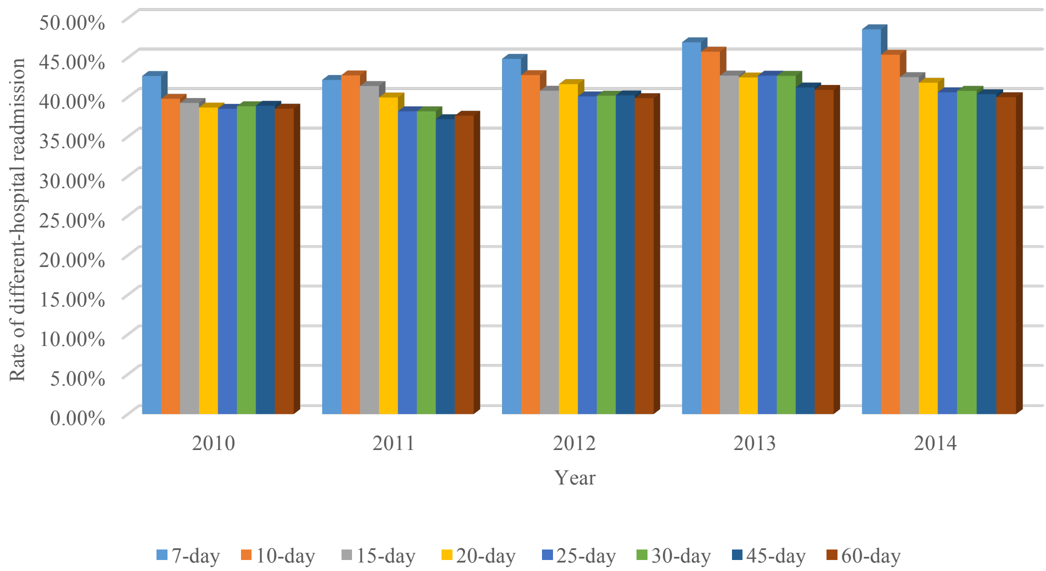

Figure 10: Pattern of different-hospital readmission rate across different intervals, non-Medicare AMI patients

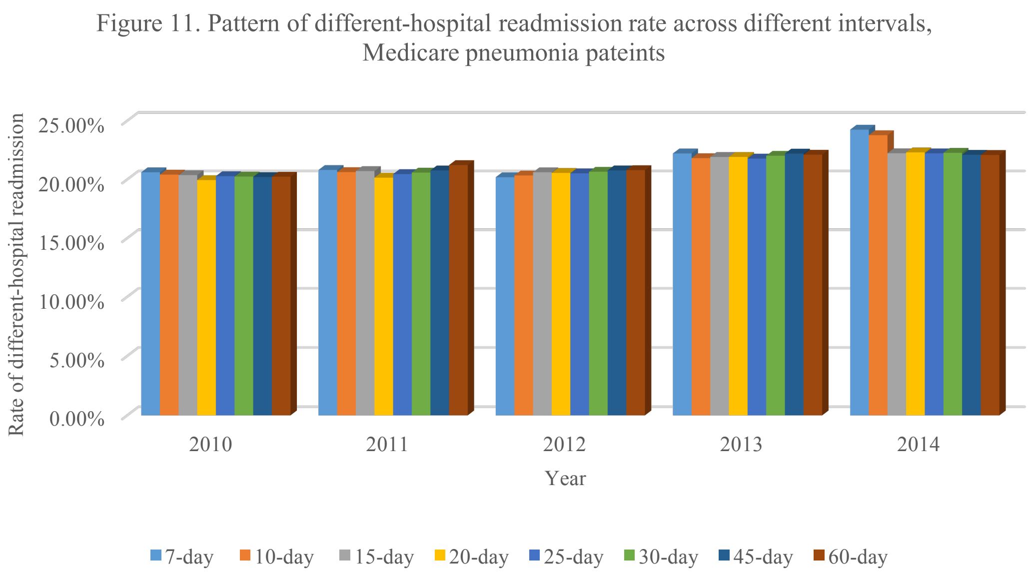

Figure 11: Pattern of different-hospital readmission rate across different intervals, Medicare pneumonia patients

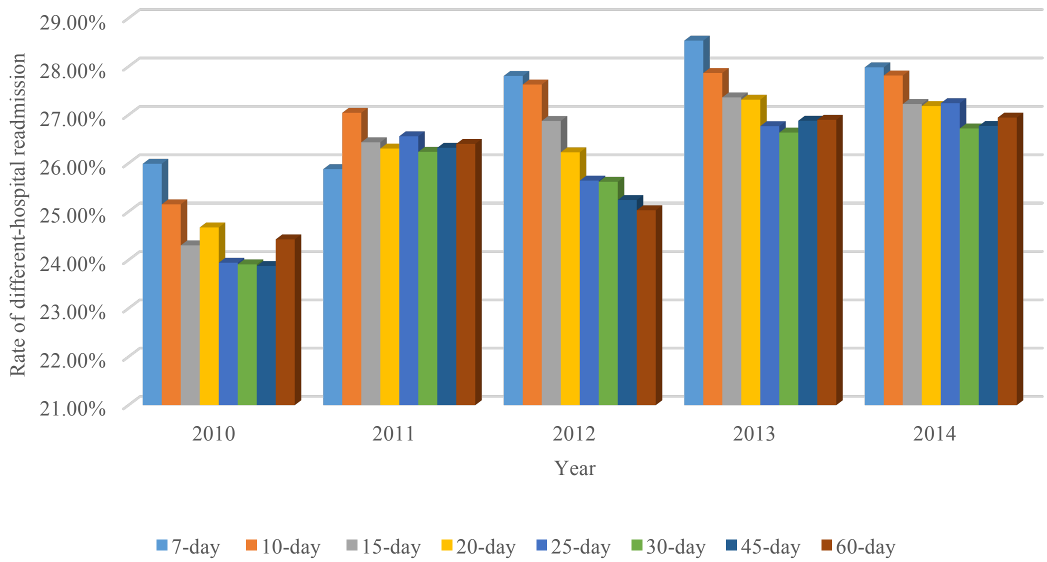

Figure 12: Pattern of different-hospital readmission rate across different intervals, non-Medicare pneumonia patients

3.1.3 Multivariate statistical analysis: factors significantly associated with 30-day non-index hospital readmission rate

In table 3, we display the results of multivariable mixed effect logistic regression models of odds of 30-day non-index readmissions for patients with CHF, AMI and pneumonia. We treated hospital as random effect. 34,389, 8,182, 19,468 observations were included in training sample for CHF, AMI and pneumonia cohort. 292, 266, 288 hospitals were considered for each mixed effect logistic regression.

Table 3. Odds Ratios for 30 day non-index hospital readmission for patients with CHF, AMI and pneumonia (2010-2014)

	CHF (n=34,389)			AMI (n=8,182)			Pneumonia (n=19,468)		
	OR	CI	P	OR	CI	P	OR	CI	P
Demographic characteristics									
Gender (male)	1.1392	1.0815-1.2001	<0.001	1.0961	0.9898-1.2138	0.078	1.0861	1.0123-1.1654	0.022
Emergency department	0.9599	0.8772-1.0505	0.374	0.5082	0.4355-0.5930	<0.001	0.9309	0.8266-1.0483	0.237
Same condition	0.6744	0.6338-0.7241	<0.001	1.1754	0.9405-1.4690	0.155	0.72	0.6341-0.8176	<0.001
Metropolitan (patient)	0.859	0.6561-1.1246	0.269	0.9711	0.6595-1.4300	0.882	1.2886	0.9392-1.7681	0.116
age >= 65	0.6357	0.5359-0.7542	<0.001	0.6806	0.4669-0.9922	0.045	0.9338	0.7338-1.1883	0.577
Clinical characteristics									
Charlson comorbidity index	0.9483	0.9335-0.9633	<0.001	0.9288	0.9041-0.9539	<0.001	0.989	0.9727-1.0056	0.193
Readmission interval									
7 day	1.4269	1.2327-1.6516	<0.001	1.3031	0.9314-1.8231	0.122	1.1815	0.9547-1.4621	0.125
8-10 day	1.1807	0.9921-1.4051	0.061	0.7326	0.4772-1.1247	0.155	1.1799	0.9083-1.5326	0.215
11-15 day	1.1663	0.9920-1.3712	0.063	0.7817	0.5244-1.1652	0.227	1.0709	0.8419-1.3621	0.577
16-20 day	1.0589	0.8933-1.2552	0.509	1.0326	0.6786-1.5713	0.881	1.131	0.8826-1.4494	0.331
21-25 day	1.0609	0.8885-1.2668	0.513	0.9821	0.6380-1.5118	0.935	1.0181	0.7822-1.3252	0.894
26-30 day									
Interaction of readmission interval and age >= 65									
7 day, >=65	0.8154	0.6748-0.9854	0.035	0.8997	0.5989-1.3517	0.611	0.7747	0.5940-1.0103	0.059
8-10 day, >=65	0.9998	0.7951-1.2574	0.999	1.4189	0.8455-2.3812	0.185	0.6427	0.4596-0.8987	0.01
11-15 day, >=65	0.935	0.7565-1.1555	0.534	1.1492	0.7088-1.8632	0.573	0.7604	0.5607-1.0311	0.078
16-20 day, >=65	1.0601	0.8495-1.3228	0.606	0.9101	0.5476-1.5126	0.716	0.7301	0.5323-1.0013	0.051

21-25 day, >=65	1.1335	0.9015-1.4252	0.284	1.0631	0.6313-1.7903	0.818	0.8924	0.6399-1.2447	0.503
26-30 day, >=65									
Admission Year									
2010									
2011	1.0785	0.9967-1.1669	0.06	1.03	0.8812-1.2040	0.71	1.0242	0.9199-1.1402	0.663
2012	1.0712	0.9889-1.1604	0.092	1.0355	0.8840-1.2131	0.665	1.0705	0.9598-1.1940	0.221
2013	1.1636	1.0741-1.2605	<0.001	1.1412	0.9744-1.3366	0.101	1.096	0.9811-1.2242	0.105
2014	1.2052	1.1092-1.3096	<0.001	1.0441	0.8842-1.2329	0.611	1.1367	1.0110-1.2781	0.105
Hospital Characteristics									
Ownership									
Non-profit									
Investor	2.0328	1.6914-2.4429	<0.001	2.1858	1.7257-2.7686	<0.001	2.3335	1.8632-2.9226	<0.001
Public	0.9168	0.7468-1.1255	0.406	1.2496	0.9545-1.6359	0.105	0.9168	0.7159-1.1741	0.451
Teaching status	1.4681	1.0842-1.9878	0.013	1.2803	0.8835-1.8553	0.192	1.3631	0.9295-1.9991	0.113
Number of beds	0.8169	0.7272-0.9176	0.001	0.6837	0.5759-0.8117	<0.001	0.7667	0.6688-0.8789	<0.001

Across all three conditions, the index hospitals' ownership (investor) had a significant association with increased odds of 30-day different-hospital readmission (investor hospital for CHF: OR = 2.0328, CI = 1.6914-2.4429, p-value < 0.001; investor hospital for AMI: OR = 2.1858, CI = 1.7257-2.7686, p-value < 0.001; investor hospital for pneumonia: OR = 2.3335, CI = 1.8632-2.9226, p-value < 0.001). The number of beds had a significant association with lower risk of changing hospital during 30-day readmission number of beds for CHF: OR = 0.8169, CI = 0.7272-0.9176, p-value < 0.001; number of beds for AMI: OR = 0.6837, CI = 0.5759-0.8117, p-value < 0.001; number of beds for pneumonia: OR = 0.7667, CI = 0.6688-0.8789, p-value < 0.001). Among patients with CHF, increased the odds of readmitting to a different hospital were related to male sex (OR = 1.1392, CI = 1.0815-1.2001, p-value < 0.001), admitted in 2013 (OR = 1.1636, CI = 1.0741-1.2605, p < 0.001) and 2014 (OR= 1.2052, CI = 1.1092-1.3096, p-value < 0.001), readmitted within 0-7-day (OR = 1.4269, CI = 1.2327-1.6516, p-value < 0.001). Readmitting with a same condition (OR = 0.6744, CI = 0.6338-0.7241, p-value < 0.001) and age greater than 65 (OR = 0.6357, CI = 0.5359-0.7542, p-value < 0.001) was associated with lower odds of changing hospital. Additionally, the teaching status of index hospital had significant association with CHF patients changing hospital(OR = 1.4681, CI = 1.0842-1.9878, p-value = 0.013). Among patients with AMI, the patients who went through an emergency department in index admission and aged greater than 65 had lower odds of changing hospital (emergency department: OR = 0.5082, CI = 0.4355-0.5930, p-value < 0.001; age>=65: OR = 0.6806, CI = 0.4669-0.9922, p-value < 0.045). Among patients with pneumonia, only readmitting for a different primary diagnosis in readmission was significantly associated with lower odds of changing hospital (OR = 0.72, CI = 0.6341-0.8176, p-value < 0.001). Same trend of odds of admission years was also occurred in pneumonia cohort but they were not significant for all 5 years. The interaction of readmission time window and if the patient is older than 65 years old were also examined. All of the interactions had non-significant association with changing hospital except CHF readmission within 0-7-day window and pneumonia readmission within 8-10-window interacting with age greater 65 (CHF readmission in 0-7-day & age > 65: OR = 0.8154, CI = 0.6748-0.9854, p-value < 0.001; pneumonia readmission in 8-10-day & age > 65: OR = 0.6427, CI = 0.4596-0.8987, p-value = 0.01). The intra-class correlation coefficients for CHF, AMI and pneumonia are 0.084, 0.090 and 0.122 respectively.

3.2 Aim 2: Analysis of national readmissions with comorbid SMI

Table 4 describes demographic, clinical and hospital characteristics of the sample for patients with and without a comorbid SMI diagnosis for medical/surgical index admissions.

Table 4. Patients with and without a serious mental illness from indexed hospitalizations by demographic, clinical, and hospital characteristics (N=6,136,373)

		No Serious Mental Illness (n=5,609,223)		Serious Mental Illness (n=527,150)		
		n (mean)	% (sd)	n (mean)	% (sd)	p value
Demographic Characteristics						
Age		62.27	17.17	56.01	16.25	<0.001
Age_group						
	18-35	489102	8.72	66057	12.53	<0.001
	36-50	827587	14.75	116729	22.14	<0.001

51-65	1681168	29.96	193775	36.76	<0.001
66-85	2158704	38.47	132388	25.11	<0.001
>86	454710	8.1	18201	3.45	<0.001
Gender					
Male	2,659,046	47.40	213,248	40.45	<0.001
Female	2,950,177	52.60	313,902	59.55	
Primary Payor					
Medicare	2,968,355	53.00	275,543	52.35	<0.001
Medicaid	699,205	12.49	120,283	22.85	<0.001
Private	1,473,844	26.32	88,003	16.72	<0.001
Other	458,295	8.19	42,491	8.07	0.005
Patient Location (PL_NCHS)[1]					
Urban, ≥ 1 million population (n=3,341,110)	3,039,666	54.37	301,444	57.56	<0.001
Metro, 50,000-999,999 population (n=1,907,420)	1,751,044	31.32	156,376	29.86	<0.001
Micro (n=467,606)	430,775	7.71	36,831	7.03	<0.001
Rural (n=397,799)	368,752	6.60	29,047	5.55	<0.001
Median Household Income Quartile					
Q1 -- ($ 1 - 39,999) (n=1,552,489)	1,552,489	28.17	164,606	31.80	<0.001
Q2 -- ($ 40,000 - 50,999) (n=1,620,737)	1,481,064	26.87	139,673	26.98	0.092
Q3 -- ($51,000 - 65,999) (1,399,471)	1,283,620	23.29	115,851	22.38	<0.001
Q4-Highest (1,291,635)	1,194,128	21.67	97,507	18.84	<0.001
Clinical Characteristics					
Index length of Stay (in days)-Medical	4.94	5.44	5.70	7.21	<0.001
Index length of Stay (in days)-Surgical	5.99	7.71	8.49	12.11	<0.001
Chronic Conditions (Index only)	5.54	3.24	7.01	3.27	<0.001
Medical Admission	3,495,851	62.51	407,290	77.51	<0.001
Surgical Admission	2,096,981	37.49	118,184	22.49	<0.001
Hospital Characteristics					
bed size					
Small	806,213	14.38	75,346	14.30	0.112
Medium	1,604,802	28.62	146,817	27.86	<0.001
Large	3,196,814	57.01	304,872	57.85	<0.001
location					
Urban, > 1 million population (n=3,564,364)	3,245,814	57.88	318,550	60.44	<0.001
Metro, 50,000-999,999 population (n=2,127,597)	1,957,643	34.91	169,954	32.25	<0.001
Micro (n=318,532)	291,153	5.19	27,379	5.19	0.925
Rural (n=124,371)	113,219	2.02	11,152	2.12	<0.001
teaching status					
Metro non teach	1,701,739	30.35	160,472	30.45	0.123
Metro teach	3,501,718	62.44	328,032	62.24	0.004
Non metro	404,372	7.21	38,531	7.31	0.007
Ownership					
Government, nonfederal	729,112	13.00	67,980	12.90	0.033
Private, not-profit	3,988,246	71.12	373,454	70.86	<0.001
Private, investor-owned	890,471	15.88	85,601	16.24	<0.001

The patients with a comorbid SMI diagnosis were much younger (mean of 6.26 years) than the group without comorbid SMI (mean = 62.27, SD = 17.17 *versus* mean = 56.01, SD = 16.25; p-value <0.001).

A higher proportion of patients with SMI diagnoses were in age group of 18 - 35 (12.53% versus 8.72%, p < 0.001), 36-50 (22.14% versus 14.75%, p < 0.001), 51-65 (36.76% versus 29.96%, p < 0.001), female (59.55% versus 52.60%, p < 0.001), insured by Medicaid (22.85% versus 12.49%, p < 0.001), living an urban area (60.44% versus 57.88%, p < 0.001), and had lower household income (31.80% versus 28.17%, p < 0.001). Those with a comorbid SMI diagnosis had longer stays in hospital for both medical admissions (mean = 5.70, SD = 7.21 versus mean = 4.94, 5.44; p-value < 0.001) and surgical admissions (mean = 8.49, SD = 12.11 *versus* mean = 5.99, SD = 7.71; p-value < 0.001), a greater number of chronic conditions (mean = 7.01, SD = 3.27 *versus* mean = 5.54, SD = 3.24; p-value <0.001), and a higher proportion of admissions were for medical versus surgical reasons (77.51% versus 62.51%; p-value < 0.001) compared to those who without comorbid SMI. Patients with comorbid SMI were more likely to go to hospitals located in urban area and owned by private investor (means and p-values).

Table 5 and Table 6 list top 15 All Patient Refined Diagnosis Related Groups (APR-DRG) in index medical admissions and 30-day readmissions after index medical admissions. Heart failure (index admission: 5.42%, readmission: 8.21%), septicemia & disseminated infections (index admission: 7.77%, readmission: 7.80%), pneumonia (index admission: 4.76%, readmission: 3.39%) and chronic obstructive pulmonary disease (index admission:5.42%, readmission: 8.21%) were among the top 5 most common primary diagnoses for both medical index admissions and 30-day readmissions. In table 7, we compared the proportions of Septicemia & disseminated infections, Heart Failure, pneumonia and COPD in index admissions and readmissions. The proportion of heart failure (p-value < 0.001), pneumonia (p-value < 0.001) and COPD (p-value < 0.001) had significant differences between index admissions and readmissions.

Table 5. Top 15 APR-DRG for medical index admissions (n = 4,002,304)

Rank	Frequency	Percentage	APRDRG	Diagnosis
1	310,979	7.77	720	Septicemia & disseminated infections
2	216,791	5.42	194	Heart failure
3	190,484	4.76	139	Other pneumonia
4	189,403	4.74	140	Chronic obstructive pulmonary disease
5	150,427	3.76	383	Cellulitis & other bacterial skin infections
6	123,463	3.09	460	Renal failure
7	119,411	2.99	45	CVA & precerebral occlusion w infarct
8	116,598	2.92	201	Cardiac arrhythmia & conduction disorders
9	102,896	2.57	463	Kidney & urinary tract infections
10	78,060	1.95	282	Disorders of pancreas except malignancy
11	76,625	1.92	133	Pulmonary edema & respiratory failure
12	75,437	1.89	244	Diverticulitis & diverticulosis
13	73,849	1.85	420	Diabetes
14	72,779	1.82	247	Intestinal obstruction
15	68,814	1.72	249	Non-bacterial gastroenteritis, nausea & vomiting

Table 6. Top 15 APR-DRG for medical readmissions within 30 days (n = 737,308)

Rank	Frequency	Percentage	APRDRG	Diagnosis
1	60533	8.21	194	Heart failure
2	57490	7.8	720	Septicemia & disseminated infections
3	31744	4.31	140	Chronic obstructive pulmonary disease
4	30334	4.12	460	Renal failure
5	24994	3.39	139	Other pneumonia
6	19679	2.67	721	Post-operative, post-traumatic, other device infections
7	19613	2.66	133	Pulmonary edema & respiratory failure
8	17434	2.37	201	Cardiac arrhythmia & conduction disorders
9	15943	2.16	383	Cellulitis & other bacterial skin infections
10	15497	2.1	254	Other digestive system diagnoses
11	15455	2.1	463	Kidney & urinary tract infections
12	14326	1.94	420	Diabetes
13	13150	1.78	248	Major gastrointestinal & peritoneal infections
14	12770	1.73	282	Disorders of pancreas except malignancy
15	12584	1.71	247	Intestinal obstruction

Table 7. Comparison of prevalence of APR-DRG between medical index admission and medical readmission			
	Index admission(4,002,304)	Readmission (737,308)	p-value
Septicemia & disseminated infections	7.77%	7.80%	0.4227
Heart Failure	5.42%	8.21%	<0.001
Pneumonia	4.76%	3.39%	<0.001
COPD	4.73%	4.31%	<0.001

Table 8 and Table 9 list the top 15 APR-DRGs for surgical index admissions and 30-day readmissions after index surgical admissions. the top 5 most common reasons for index admission were knee (12.13%) and hip (7.74%) joint replacements, small and large bowel procedures (5.35%), dorsal and lumbar fusion (4.02%), and cholecystectomy (3.9%); top 5 diagnoses amongst 30-day readmissions following surgical admission were: vascular procedures (including percutaneous cardiovascular) (10.53%), infection (7.89%), and small and large bowel procedures (6.75%). Table 10 shows significant differences between proportions of vascular procedure, small & large bowel procedures, and hip joint replacement in index admissions and those in readmissions.

Table 8. Top 15 APR-DRG for surgical index admission within 30 days (n = 2,311,212)

Rank	Frequency	Percentage	APRDRG	Diagnosis
1	280,350	12.13	302	Knee joint replacement
2	178,984	7.74	301	Hip joint replacement
3	123,591	5.35	221	Major small & large bowel procedures
4	92,968	4.02	304	Dorsal & lumbar fusion proc except for curvature of back
5	90,110	3.9	263	Laparoscopic cholecystectomy
6	89,497	3.87	174	Percutaneous cardiovascular procedures w AMI
7	64,830	2.8	308	Hip & femur procedures for trauma except joint replacement
8	61,335	2.65	175	Percutaneous cardiovascular procedures w/o AMI
9	54,703	2.37	313	Knee & lower leg procedures except foot
10	54,591	2.36	173	Other vascular procedures
11	46,263	2	710	Infectious & parasitic diseases including hiv w o.r. Procedure
12	42,736	1.85	315	Shoulder, upper arm & forearm procedures
13	41,408	1.79	403	Procedures for obesity
14	38,254	1.65	513	Uterine & adnexa procedures for non-malignancy except leiomyoma
15	37,087	1.6	519	Uterine & adnexa procedures for leiomyoma

Table 9. Top 15 APR-DRG for surgical readmission within 30 days (n = 176,385)

Rank	Frequency	Percentage	APRDRG	Diagnosis
1	11,906	6.75	221	Major small & large bowel procedures
2	7,782	4.41	173	Other vascular procedures
3	7,385	4.19	175	Percutaneous cardiovascular procedures w/o AMI
4	7,130	4.04	710	Infectious & parasitic diseases including HIV w O.R. Procedure
5	6,789	3.85	711	Post-op, post-trauma, other device infections w O.R. Procedure
6	5,300	3.01	791	O.R. Procedure for other complications of treatment
7	4,562	2.59	301	Hip joint replacement
8	4,102	2.33	305	Amputation of lower limb except toes
9	4,015	2.28	263	Laparoscopic cholecystectomy
10	3,983	2.26	313	Knee & lower leg procedures except foot
11	3,759	2.13	951	Moderately extensive procedure unrelated to principal diagnosis
12	3,705	2.1	21	Craniotomy except for trauma
13	3,410	1.93	174	Percutaneous cardiovascular procedures w AMI
14	2,990	1.7	314	Foot & toe procedures
15	2,896	1.64	121	Other respiratory & chest procedures

Table 10. Comparison of prevalence of APR-DRG between surgical index admission and medical readmission

	Index admission(n = 2,311,212)	Readmission (n = 176,385)	p-value
Vascular procedure	8.89%	10.53%	<0.001
small & large bowel procedures	5.35%	6.75%	<0.001
Hip joint replacement	7.74%	2.59%	<0.001

Table 11 presents frequencies and rates of 30-day readmissions for medical, surgical index admissions and subset by CHF, AMI, pneumonia, and COPD. Across all medical admissions, patients with comorbid SMI had significantly higher readmission rates compared to those without SMI (23.19% versus 13.82%; p-value < 0.001). CHF (30.66% versus 19.03%; p-value < 0.001), AMI (27.18% versus 16.56%; p-value < 0.001), pneumonia (21.66% versus 12.74%; p-value < 0.001) and COPD (30.66% versus 19.03%; p-value < 0.001) patients with SMI had higher rates of 30 day readmissions compared to those without SMI. As also shown in Table 11, among surgical patients, those with comorbid SMI had higher readmission rates than patients without SMI across all diagnoses

(19.31% versus 9.35%; p-value < 0.001). The readmission rates of patients with a compared to those without a comorbid SMI diagnosis.

Table 11. Frequency and rate of readmission by SMI status at index hospitalization (N=6,328,613)

	No serious mental illness (n =5,767,218)		Serious mental illness diagnosis (n = 561,395)		P value
	n	%	n	%	
Medical admission (N = 3,998,701)	3,568,081		430,620		
30-day readmission, all medical	492,987	13.82	99,845	23.19	<0.001
30-day readmission, CHF	37,652	19.03	4,343	30.66	<0.001
30-day readmission, AMI	8,554	16.56	915	27.18	<0.001
30-day readmission, Pneumonia	23,298	12.74	4,168	21.66	<0.001
30-day readmission, COPD	21,220	15.47	5,131	26.42	<0.001
Surgical admission (N = 2,311,229)	2,182,206		129,023		
30-day readmission, all surgical	204,069	9.35	24,911	19.31	<0.001
30-day readmission, hip replacement	5,368	4.07	601	10.49	<0.001
30-day readmission, knee replacement	8,929	3.59	905	7.80	<0.001

The percentages represent the proportion of patients with/without SMI who are rehospitalized within 30 days.

Table 12 shows the unadjusted odds ratios for the impact of SMI status on odds of medical and surgical 30-day readmissions. We found that compared to patients without SMI, those with SMI had 1.86 (CHF) to 2.74 (hip replacement) greater odds of 30-day readmission. Patients with SMI in surgical group had an even higher odds ratio than those whose index admissions were medical.

Table 12. Unadjusted odds Ratios for readmission by SMI status at index hospitalization (N=6,328,613)

	Odds Ratio	Confidence Interval	P-value
Medical admissions (n=3,998,701)			
30-day readmission all medical(n=592,832)	1.8756	1.8495-1.9020	<0.001
30-day readmission, CHF (n=41,995)	1.86	1.7791-1.9446	<0.001
30-day readmission, AMI (n=9,469)	1.869	1.7052-2.0485	<0.001
30-day readmission, Pneumonia (n=27,466)	1.8675	1.7910-1.9473	<0.001
30-day readmission, COPD (n=26,351)	1.945	1.8643-2.0291	<0.001
Surgical admissions (n=2,311,229)			
30-day readmission, all surgical (n=228,980)	2.3291	2.2753-2.3842	<0.001
30-day readmission, hip replacement (n=5,969)	2.7479	2.4621-3.0668	<0.001
30-day readmission, knee replacement (n=9,834)	2.2631	2.0787-2.4638	<0.001

Table 13 shows adjusted odds ratios and 95% confidence intervals of the impact of SMI status on 30-day readmissions for medical patients. Table 17 shows adjusted odds ratios and 95% confidence intervals of the impact of SMI status on 30-day readmissions for surgical patients. Even after adjusting for demographic, clinical and hospital characteristics, comorbid SMI status was still significantly associated with increased odds of 30-day readmissions for both medical and surgical cohorts (medical cohort: OR = 1.801, CI = 1.7746-1.8278, p-value < 0.001; surgical cohort: OR = 1.9465, CI = 1.9017-1.9925, p-value < 0.001). Among medical readmissions, being between 51 and 65 years old (OR = 1.048, CI = 1.0297-1.0666, p-value < 0.001), having public insurance (OR = 1.308, CI = 1.2875-1.3289, p-value < 0.001), living in metropolitan area (OR = 1.0614, CI = 1.0386-1.0848, p-value < 0.001), having household income between $40,000 and $65,999 (OR = 1.0527, CI = 1.0322-1.0736, p-value < 0.001), having 1 (OR = 1.1056, CI = 1.0869-1.1245, p-value < 0.001), 2 (OR = 1.179, CI = 1.1562-1.2023, p-value < 0.001), and more than 2 (OR = 1.179, CI = 1.1562-1.2023, p-value < 0.001) comorbidities was associated with increased risk of 30-day readmissions, whereas being female (OR = 0.936, CI = 0.9292-0.9428, p-value < 0.001), admitting at small (OR = 0.9255, CI = 0.9025-0.9490, p-value < 0.001) or medium (OR = 0.9555, CI =0.9325-0.979, p-value <0.001) hospitals and the hospital located in small metropolitans (OR = 0.9378, CI = 0.9120-0.9643, p-value < 0.001), micro metropolitans (OR = 0.9023, CI = 0.8687-0.9372, p-value < 0.001) and rural area (OR = 0.9209, CI = 0.8812-0.9623, p-value) was associated with lower risk of 30-day readmissions. Most comorbidities were associated with an increased odds of 30-day readmissions except alcohol abuse (OR = 0.9796, CI = 0.9627-0.9969, p-value = 0.021), Hypertension (OR = 0.9423, CI = 0.9335-0.9511, p-value <0.001), and obesity (OR = 0.9341, CI = 0.9251-0.9431, p-value < 0.001). Both of interaction of SMI & drug abuse and interaction of SMI & alcohol abuse had lower odds of readmission compared to the one with only comorbid SMI diagnosis (SMI & drug: OR = 1.016, CI = 0.9895-1.0433, p-value = 0.238; SMI & alcohol: OR = 1.1638, CI = 1.1244-1.2046, p-value < 0.001). Among surgical admissions, the patients who had public insurance (OR = 1.3051, CI = 1.2797-1.3311, p-value < 0.001), resided in metropolitan with population of 50,000-999,999 (OR = 1.0502, CI = 1.0225-1.0787, p-value <0.001), had household income in groups of

$40,000 - 50,999 (OR = 1.1149, CI = 1.0838-1.1468, p-value < 0.001), $51,000 - 65,999 (OR = 1.0722, CI = 1.0435-1.1017, p-value < 0.001), and greater than $66,000 (OR = 1.037, CI = 1.0119-1.0628, p-value = 0.004), and had 1 (OR = 1.1836, CI = 1.1572-1.2106, p-value < 0.001), 2 (OR = 1.3679, CI = 1.3348-1.4018, p-value < 0.001), and more than 2 comorbidities (OR = 1.1968, CI = 1.1692-1.2251, p-value < 0.001) had greater odds of readmission within 30 days. While those who were 51-65 years old (OR = 0.9201, CI = 0.8974-0.9434, p-value <0.001) and 66-85 years old (OR = 0.8727, CI = 0.8494-0.8967, p-value < 0.001), female (OR = 0.8935, CI = 0.8837-0.9034, p-value < 0.001), treated in small (OR = 0.8191, CI = 0.7697-0.8717, p-value < 0.001) or medium-size hospitals (OR = 0.9151, CI = 0.8870-0.9441, p-value < 0.001), hospitalized in metropolitans with population of 50,000-999,999 (OR = 0.9341, CI = 0.9026-0.9666, p-value < 0.001), micro metropolitans (OR = 0.8672, CI = 0.8106-0.9277, p-value < 0.001), and rural areas (OR = 0.8154, CI = 0.7432-0.8947, p-value <0.001) had lower odds of readmission within 30 days. Comorbid hypertension (OR = 0.9088, CI = 0.8943-0.9235, p-value <0.001), hypothyroidism (OR = 0.9373, CI = 0.9205-0.9544, p-value <0.001), and obesity (OR = 0.9318, CI = 0.9158-0.9482, p-value <0.001) were associated with lower odds of 30-day readmission, whereas other comorbidities were associated with greater odds of 30-day readmissions. Both interaction of SMI & drug abuse and interaction of SMI & alcohol abuse were associated with lower odds of readmission compared to the one only with comorbid SMI diagnosis (SMI & drug: OR = 0.9448, CI = 0.8887-1.0044, p-value = 0.069; SMI & alcohol: OR = 0.974, CI = 0.9088-1.0440, p-value = 0.457).

Table 13. Adjusted odds ratios and 95% confidence intervals of 30-day hospital readmission in medical index admissions (N = 3,930,500)

		Odds Ratio	Confidence Interval	P-value
SMI		1.801	1.7746-1.8278	<0.001
age group				
	18-35			
	36-50	1.0241	1.0075-1.0410	0.004
	51-65	1.048	1.0297-1.0666	<0.001
	66-85	0.949	0.9311-0.9672	<0.001
	>=86	0.8502	0.8307-0.8701	<0.001
Female gender		0.936	0.9292-0.9428	<0.001
primary insurance				

Public	1.308	1.2875-1.3289	<0.001
Private			
Other	0.9155	0.8923-0.9394	<0.001
patient location			
Urban, > 1 million population (n=2,207,091)			
Metro, 50,000-999,999 population (n=1,217,638)	1.0614	1.0386-1.0848	<0.001
Micro (n=301,889)	1.0556	1.0223-1.0900	0.001
Rural (n=257,080)	1.0333	1.0001-1.0676	0.049
income quartile			
Q1 -- ($ 1 - 39,999)			
Q2 -- ($ 40,000 - 50,999)	1.0527	1.0322-1.0736	<0.001
Q3 -- ($51,000 - 65,999)	1.037	1.0188-1.0554	<0.001
Q4 -- ($66,000+)	1.0132	0.9975-1.0293	0.1
Bed size			
Small	0.9255	0.9025-0.9490	<0.001
Medium	0.9555	0.9325-0.9791	<0.001
Large			
Location			
Urban, > 1 million population (n=2,305,533)			
Small Metro, 50,000-999,999 population (n=1,346,414)	0.9378	0.9120-0.9643	<0.001
Micro (n=239,085)	0.9023	0.8687-0.9372	<0.001
Rural (n=107,669)	0.9209	0.8812-0.9623	<0.001
Teaching status			
Metro non teach			
Metro teach	1.0733	1.0511-1.0959	<0.001
Non metro	1		
Ownership			
Government, nonfederal			
Private, not-profit	0.9554	0.9251-0.9866	0.005
Private, investor-owned	0.9999	0.9645-1.0365	0.994
Number of elixhauser comorbidities			
0			
1	1.1056	1.0869-1.1245	<0.001
2	1.179	1.1562-1.2023	<0.001
>=3	1.1968	1.1692-1.2251	<0.001
Comorbidities			
SMI & drug abuse interaction	1.016	0.9895-1.0433	0.238
Drug abuse	1.0447	1.0213-1.0688	<0.001

SMI & alcohol abuse interaction	1.1638	1.1244-1.2046	<0.001
Alcohol abuse	0.9796	0.9627-0.9969	0.021
AIDS	1.1364	1.0767-1.1994	<0.001
Deficiency anemias	1.2418	1.2295-1.2542	<0.001
Rheumatoid arthritis/collagen vascular diseases	1.123	1.1035-1.1429	<0.001
Chronic blood loss anemia	1.182	1.1515-1.2134	<0.001
Congestive heart failure	1.2783	1.2651-1.2916	<0.001
Chronic pulmonary disease	1.1411	1.1302-1.1522	<0.001
Coagulopathy	1.1427	1.1277-1.1580	<0.001
Diabetes, uncomplicated	1.0794	1.0691-1.0898	<0.001
Diabetes with chronic complicated	1.1991	1.1819-1.2166	<0.001
Hypertension, uncomplicated and complicated	0.9423	0.9335-0.9511	<0.001
Hypothyroidism	0.9893	0.9782-1.0005	0.061
Liver disease	1.2563	1.2358-1.2771	<0.001
Lymphoma	1.6185	1.5698-1.6687	<0.001
Fluid and electrolyte disorders	1.0851	1.0763-1.0939	<0.001
Metastatic cancer	1.9613	1.9140-2.0097	<0.001
Other neurological disorders	1.0026	0.9894-1.0160	0.699
Obesity	0.9341	0.9251-0.9431	<0.001
Paralysis	1.0977	1.0766-1.1191	<0.001
Peripheral vascular disorders	1.1341	1.1168-1.1516	<0.001
Pulmonary circulation disorders	1.1357	1.1155-1.1562	<0.001
Renal failure	1.3755	1.3623-1.3888	<0.001
Solid tumor without metastasis	1.5704	1.5427-1.5986	<0.001
Peptic ulcer disease excluding bleeding	1.5337	1.3417-1.7530	<0.001
Valvular disease	1.023	1.0080-1.0382	<0.001
Weight loss	1.2917	1.2719-1.3117	<0.001

Table 14. Adjusted odds ratios and 95% confidence intervals of 30-day hospital readmission in surgical index admissions (N = 2,270,418)

	Odds Ratio	Confidence Interval	P-value
SMI	1.9465	1.9017-1.9925	<0.001
Age group			
18-35			
36-50	0.9812	0.9572-1.0057	0.131
51-65	0.9201	0.8974-0.9434	<0.001
66-85	0.8727	0.8494-0.8967	<0.001
>=86	0.9993	0.9660-1.0338	0.97
Female gender	0.8935	0.8837-0.9034	<0.001
Primary insurance			
Public	1.3051	1.2797-1.3311	<0.001
Private			
Other	1.0396	1.0067-1.0735	<0.001
Patient location			
Urban, > 1 million population (n=1,237,244)			
Metro, 50,000-999,999 population (n=740,378)	1.0502	1.0225-1.0787	<0.001
Micro (n=177,342)	1.0112	0.9755-1.0482	0.543
Rural (n=149,281)	0.979	0.9388-1.0209	0.321
Income quartile			
Q1 -- ($ 1 - 39,999)			
Q2 -- ($ 40,000 - 50,999)	1.1149	1.0838-1.1468	<0.001
Q3 -- ($51,000 - 65,999)	1.0722	1.0435-1.1017	<0.001
Q4 -- ($66,000+)	1.037	1.0119-1.0628	0.004
Bed size			
Small	0.8191	0.7697-0.8717	<0.001
Medium	0.9151	0.8870-0.9441	<0.001
Large			
Location			
Urban, > 1 million population(n=1,366,690)			
Small Metro, 50,000-999,999 population (n=834,785)	0.9341	0.9026-0.9666	<0.001
Micro (n=89,122)	0.8672	0.8106-0.9277	<0.001
Rural (n=20,632)	0.8154	0.7432-0.8947	<0.001
Teaching status			
Metro non teach			
Metro teach	1.1255	1.0939-1.1580	<0.001
Non metro	1		

Ownership			
Government, nonfederal			
Private, not-profit	0.9422	0.9026-0.9836	0.007
Private, investor-owned	1.0722	1.0175-1.1298	0.009
Number of elixhauser comorbidities			
0			
1	1.1836	1.1572-1.2106	<0.001
2	1.3679	1.3348-1.4018	<0.001
>=3	1.5008	1.4538-1.5494	<0.001
Comorbidities			
SMI & drug abuse interaction	0.9448	0.8887-1.0044	0.069
Drug abuse	1.1423	1.1016-1.1845	<0.001
SMI & alcohol interaction	0.974	0.9088-1.0440	0.457
alcohol abuse	1.0045	0.9740-1.0359	0.776
AIDS	1.1601	1.0450-1.2878	0.005
Deficiency anemias	1.1652	1.1459-1.1848	<0.001
Rheumatoid arthritis/collagen vascular diseases	1.1093	1.0799-1.1394	<0.001
Chronic blood loss anemia	1.0619	1.0111-1.1152	0.016
Congestive heart failure	1.3444	1.3148-1.3747	<0.001
Chronic pulmonary disease	1.148	1.1295-1.1667	<0.001
Coagulopathy	1.1828	1.1588-1.2073	<0.001
Diabetes, uncomplicated	1.1007	1.0832-1.1185	<0.001
Diabetes with chronic complicated	1.3214	1.2904-1.3531	<0.001
Hypertension, uncomplicated and complicated	0.9088	0.8943-0.9235	<0.001
Hypothyroidism	0.9373	0.9205-0.9544	<0.001
Liver disease	1.2315	1.1847-1.2800	<0.001
Lymphoma	1.4278	1.3516-1.5082	<0.001
Fluid and eletrolyte disorders	1.3285	1.3084-1.3489	<0.001
Metastatic cancer	2.019	1.9564-2.0837	<0.001
Other neurological disorders	1.0427	1.0203-1.0656	<0.001
Obesity	0.9318	0.9158-0.9482	<0.001
Paralysis	1.1928	1.1573-1.2295	<0.001
Peripheral vascular disorders	1.3386	1.3094-1.3684	<0.001
Pulmonary circulation disorders	1.2201	1.1784-1.2631	<0.001
Renal failure	1.4547	1.4304-1.4795	<0.001
Solid tumor without metastasis	1.6028	1.5509-1.6564	<0.001
Peptic ulcer disease excluding bleeding	1.2625	1.0260-1.5533	0.028
Valvular disease	1.0128	0.9877-1.0384	0.32
Weight loss	1.4084	1.3684-1.4496	<0.001

4. DISCUSSION

4.1. Current findings

In this study, we explored two dimensions of hospital readmission: In Aim 1, we examined the pattern of non-index hospital readmissions; and in Aim 2, we examined the relationship between comorbid SMI diagnosis and 30-day readmissions.

In Aim 1, We found that 30-day readmission rates were were 21.78%, 18.85% and 13.87% over the five years for CHF, AMI and pneumonia, respectively, and the readmission rates decreased by. This result is consistent with previous literatures (CHF readmission rate: 18.95%-24.56%; AMI readmission rate: 14.7%-19.94%; pneumonia readmission rate: 13.79%-18.22%) [40-43].

We found that all cause non-index readmission rate was 25.1% for all three cohorts over the five years which is consistent with prior studies, ranging between 18% and 29% [3, 10, 16]. And in examining different-hospital readmissions, we found significant differences in 30-day different-hospital readmissions between Medicare and non-Medicare patients: CHF (21.14% versus 32.15%, $p < 0.001$), AMI (29.34% versus 40.16%, $p < 0.001$), and pneumonia (21.16% versus 25.82%, $p < 0.001$). For all other readmission intervals, non-Medicare patients were also more likely to go to different hospitals for subsequent readmission. With this statistically significant finding (p-value < 0.001), we reject our initial hypothesis that both Medicare and non-Medicare patients are equally likely to be readmitted to non-index hospitals. This novel finding may suggest that non-Medicare patients, regardless of CHF, AMI and pneumonia, who experience readmission in non-index hospitals in a significant rate may necessitate additional care to improve overall hospital service quality. A consistent decreasing trend of non-index readmission rate with length of readmission interval was observed among non-Medicare patients for all of CHF, AMI and pneumonia cohorts, which may suggest the early readmission interval is critical.

We identified several significant predictors for CHF, AMI and pneumonia patients' 30-day non-index hospital readmission. For all three conditions, male was positively associated with the prediction of non-index hospital readmission. Admission through the emergency department was associated with lower odds of changing hospital during readmission for AMI cohort, whereas it was insignificant for CHF and pneumonia. On the other hand, going for readmission for same primary diagnosis as at index admission reduced risk of changing hospital during the readmission for CHF and pneumonia cohort, but not for AMI cohort. Charlson comorbid index had a negative association with CHF and AMI non-index hospital readmission, but not with pneumonia cohort. The index hospital owned by investor may significantly increase the risk of discharged patients changing hospital in their readmissions for all of three conditions. The result also shows a larger index hospital can decrease the odds of changing hospital during readmission. For CHF cohort, the index discharge happened in 2013 and 2014 had a higher odds of changing hospital, which indicates there was some effect of the penalty policy implemented in October 2012 influenced the strategy of hospital regarding CHF patients. However, this phenomenon was not observed in AMI and pneumonia cohort.

The higher 30-day non-index rehospitalization rate that we observed for non-Medicare patients as compared to Medicare patients has important policy implications for measuring, reporting, and the 30-day readmission rate. Also, we recommend attention to non-Medicare beneficiary care quality to improve the overall service quality of the hospitals, which has not received significant attention in the ongoing state-of-of-the-art research. Our predictive models identified the impacts of patients' socio-demographic and clinical factors on the non-index hospital readmission among Medicare and non-Medicare group. Therefore, we suggest the policy maker consider more thoroughly as making flexible strategies to improve care quality for different conditions.

In Aim 2, we found that a comorbid SMI diagnosis was associated with increased odds of 30-day rehospitalization among both medical and surgical inpatients, even after we controlled demographic, clinical and hospital charactersitics. The findings support most of previous studies [5, 22, 38, 44] for medical cohort, but conflict with previous literatures which claimed that there was no significant association between comorbid SMI and rehospitalization for surgical inpatients [28, 45]. The high odds of 30-day rehospitalization among medical and surgical patients can be explained by a poor quality health care due to limited access to transitional support postdischarge, community-based care options, and integrated health and behavioral health care [46, 47]. Our study suggests patients with comorbid SMI should be considered at high risk for readmission for both medical and surgical groups. Targeting interventions to these patients may be effective in preventing avoidable readmissions.

4.2 Limitations

Our studies were not without limitations. For Aim 1, which used California Patient Discharge Data, although the sample was large, it cannot be generalized to patients and hospitals nationally. We used same study period for different readmission interval, we cannot track the 45-day and 60-day readmissions whose index admissions happened in February 2010 and October 2014, which may lead to underestimate of readmission rate for 45, 60-day readmission. For Aim 2, which used National Readmission Database, we did not include patients who could use hospital service outside, and therefore, the number of rehospitalizations might be undercounted. There might be some unobserved confounders. Although we found a significant effect of comorbid SMI, we were unable to adjust for severity of SMI.

4.3 Future work

Given our findings, this area of research warrants further investigation. For Aim 1, we need to delve into our findings in multivariate analysis to full understand the deep reason behind the results. our predictive models for predicting non-index hospital readmission still had relatively low AUC index for CHF (0.618), AMI (0.626) and pneumonia (0.630). We need to modify our predictive models and improve the performance of predicting non-index hospital readmissions. So far we still have little understanding of consequence of non-index hospital readmission quantitatively, it is also necessary for us to determine the mortality or cost for non-index hospital in a quantitative level. For Aim 2, we need to find out the reasons of confliction between our findings and pervious findings on surgical patients' readmission. We only considered 30-day readmissions in this study, the readmissions on more readmission intervals would need to be examined. In addition, the impact of comorbid SMI diagnosis on readission cost also worth to be explored.

4.4 Conclusion

This study's findings report for the first time that non-Medicare patients have higher odds to be readmitted in a different hospital compared to Medicare patients. We also found both medical and surgical inpatients with a comorbid SMI diagnosis are associated with higher odds of readmission than those without a comorbid SMI diagnosis. The finding suggested greater attention is required to improve hospital care quality for non-Medicare patients and patients with comorbid SMI diagnosis.

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