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HOSPITAL MARKET ANALYSIS USING A COHORT OF PRIVATELY INSURED PATIENTS WITH TOTAL HIP AND KNEE REPLACEMENT PROCEDURES

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DEDICATION

To My Father and My Mother

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Background: Several recent studies have analyzed the contribution of hospital inpatient prices and utilization to variation in medical spending. However, it is still unknown how the drivers of spending for specific procedures differ within privately insured patients. Next, the market concentration of hospitals has been a matter of concern for several decades. However, researchers usually calculate Herfindahl-Hirschman index (HHI) as a measure of market concentration or power, but there is a drawback of using this measure. Hospitals sell differentiated products, and the HHI measure does not take this differentiation into account in its formulation (Gaynor and Town, 2011). Objective: First aim was to calculate and compare variation in hospital spending of a privately insured population with total hip or knee replacement procedures within and across Hospital Referral Regions (HRRs) in Colorado between 2009 and 2014; and assess the contribution of price and utilization to the variation in hospital spending. Second aim was to calculate and estimate the impact of different market competition indices, namely willingness to pay (WTP) and logit competition index (LOCI), on negotiated prices between private payer and hospitals for total hip and knee replacement procedures in Colorado between 2009 and 2014. Methods: This was a retrospective cohort

study that included private insurance payer claims for total hip or knee replacement procedures using Colorado All Payer Claims Database (CO APCD) data. The hospital inpatient spending index measure for each HRR was calculated. Next, the relative contributions of price and quantity to spending variation were analyzed within and between HRRs in Colorado. Later, beneficiary demand for hospitals for total hip and knee replacement procedures using a discrete choice model was estimated as a first step to attain market power measures of WTP and LOCI. After calculating WTP and LOCI measure, the impact of hospital market power on inpatient hospital prices reimbursed by PPO plans in Colorado was estimated. Results: For HMO and PPO spending, quantity differences across HRRs accounted for between 64 percent to 71 percent; and for POS spending, quantity differences across HRRs accounted for around 25 percent for both clinical cohorts of total hip or knee replacement procedures. The patient choice model showed that patients with an elective procedure prefer to have the procedure in a hospital nearby. The mean value of LOCI was 0.572 which indicates that the competition was low on average among hospitals in Colorado for total hip or knee replacement procedure market. Changes in WTP for total hip or knee replacement surgery markets were associated with a change of approximately 1% to 5% in negotiated hospital prices for PPO plan types in the period 2009–2014. Conclusion: Findings for overall service category spending (i.e. inpatient spending) cannot be generalized to different service lines within a specific service category (i.e. total hip or knee replacement procedures). Increased market power (i.e. low competition among hospitals) was associated with significant increases in the negotiated hospital prices for PPO plans, in the case of total hip or total knee replacement surgeries during 2009–2014 in Colorado.

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BACKGROUND

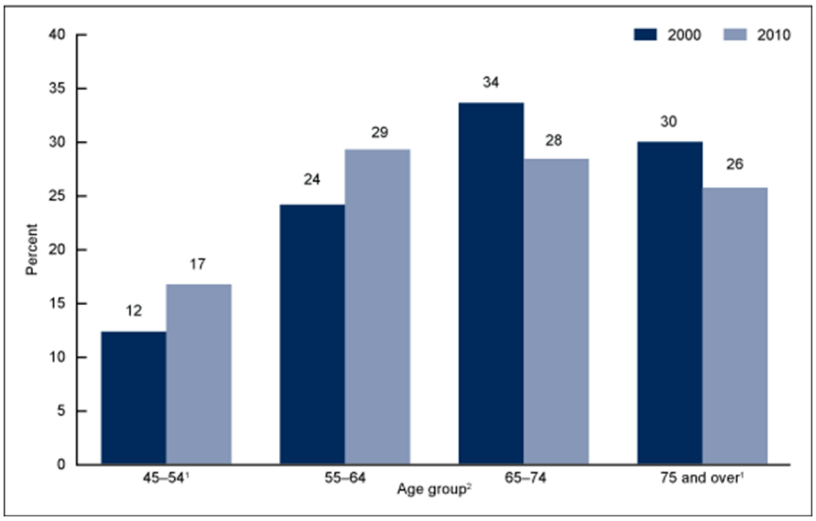
Introduction

This dissertation used data from Colorado All Payer Claims Database (CO APCD) to investigate two service lines performed by the hospital industry, namely total hip and knee replacement procedures, among the commercially insured 45-64 population. Total hip and knee replacements are the most common and costly inpatient surgical procedures performed on Medicare beneficiaries[1]. Moreover, there has been an increase in the demand of total hip and knee replacement procedures in the younger population. The recent report by the Centers for Disease Control and Prevention[2] (CDC) written by Wolford et. al (2015) revealed that the age distribution of patients aged 45 and over who received total hip replacements changed significantly between 2000 and 2010, with the percentage of total hip replacements increasing for younger age groups and decreasing for older age groups (Figure 1).

Another report from the CDC written by Williams et. al (2015) used National Hospital Discharge Survey (NHDS) data and presented trends in the rate of hospitalizations for total knee replacement procedures among inpatients aged 45 and over in United States between 2000 and 2010. Williams et. al (2015) categorized patients into two age groups (i.e. 45-64; 65 and over). Although they found that the incidence rate for both the younger and older age groups have increased significantly between 2000 and 2010 (Figure 2), the growth of incidence rate was higher (almost tripled) for the younger age category (45-64) compared to older age category (65 and over).

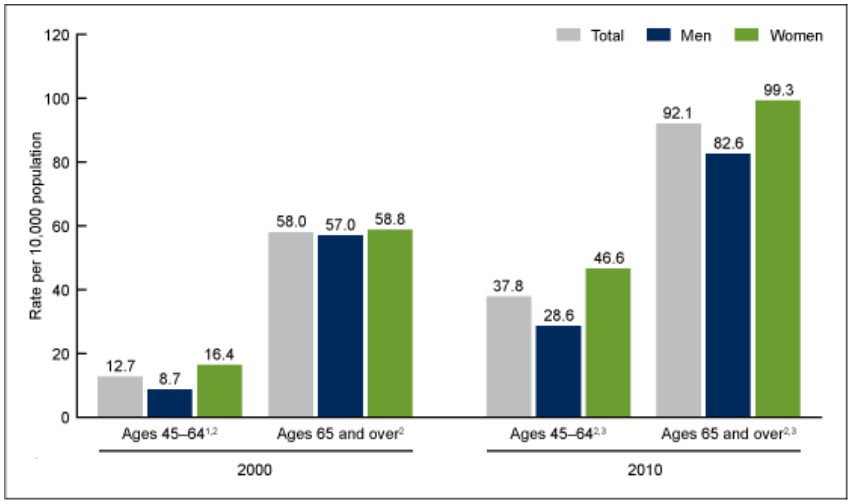
[1] This information was taken from CMS website: https://innovation.cms.gov/initiatives/cjr

Figure 1: Percent distribution of total hip replacements among inpatients aged 45 and over: United States, 2000 and 2010



[1]Significantly different from age groups 55–64 and 65–74 in both 2000 and 2010.
[2]Significant differences between 2000 and 2010 for each age group.
Source: National Center for Health Statistics (NCHS) Data Brief No. 186, February 2015

Figure 2: Rate of total knee replacements among inpatients aged 45 and over: United States, 2000 and 2010 (per 10,000 population)



[1]Significant difference in 2000 between men and women within age group ($p < 0.05$).
[2]Significant difference between 2000 and 2010 within sex and age group ($p < 0.05$).
[3]Significant difference in 2010 between men and women within age group ($p < 0.05$).
Source: National Center for Health Statistics (NCHS) Data Brief No. 210, September 2015

Total hip and knee replacement procedures are two of the costliest inpatient service lines in the United States. According to the CDC, the mean inflation adjusted cost per hospitalization was approximately $17,500 for hip replacement and approximately $16,500 for knee replacements in 2012[3]. When the cost was stratified by age; CDC found that the mean cost for the 45-64 (hip replacement=$17,364; knee replacement=$16,710) group was higher than the 65-74 (hip replacement=$17,322; knee replacement=$16,372)[4]. Lam et al. (2018) indicated that Medicare paid on average approximately $13,000 per hip/knee replacements in 2015; and Medicare payments varied from $9,000 to $17,500 by state. There is also evidence on payment rates from commercial insurance side: Blue Cross Blue Shield (BCBS, 2015) analyzed three years (2010-2013) of independent BCBS companies' claims data for typical hip and knee replacement procedures and reported mean payments of approximately $30,124 for a hip replacement (with a variation from $11,317 to $69,654) and $31,124 for a knee replacement (with a variation from $11,327 to $ $73,987).

In this dissertation, I focused on the variation in hospital spending, utilization and prices, as well as the effect of hospital market competition on prices using CO APCD data from privately insured patients aged 45 to 64 in this growing sub-sector of the hip and knee replacement market. While we know that hospital market power is associated with higher prices, utilization and spending overall for a basket of hospital goods, we know less about the

[3],[4] The mean costs were taken from Table 105. Cost of hospital discharges with common hospital operating room procedures in nonfederal community hospitals, by age and selected principal procedure: United States, selected years 2000-2012 accessed via https://www.cdc.gov/nchs/hus/contents2014.htm#105. In that table, charges (the amount billed by the hospital) were converted to costs using cost-charge ratios from the Centers for Medicare & Medicaid Services. Costs are for the entire hospitalization including the principal procedure. Costs were adjusted for inflation to 2012 dollars.

effects of competition on specific procedure or service-lines, such as total hip and knee replacements. In the first paper, I analyzed the variation in hospital spending, and the contribution of variation in price and utilization to variation in spending for total hip and knee replacement procedures within and between HRRs. In my second paper, I calculated market power indices developed by semi-structural approaches (i.e. Willingness to Pay (WTP) and Logit Competition Index (LOCI)) and used these indices to estimate the impact of hospital market power on prices of total hip and knee replacement procedures in the commercially insured population.

Several recent studies have analyzed the contribution of hospital inpatient prices and utilization to variation in medical spending (i.e. Dartmouth Atlas, 2014; Cooper et al., 2019; Franzini et al., 2014), and shown that the drivers of high spending differ across the Medicare and privately insured populations – that is, in the Medicare population, high utilization is associated with high spending areas while among the privately insured population high prices are associated with high spending. However, it is still unknown whether areas with high spending overall have high spending across different service lines, nor whether or how the drivers of spending for specific procedures also differ within privately insured patients. Given that, as mentioned before, the demand for total hip and knee replacement procedures has been increasing significantly in the younger population and given that current variation studies on hip and knee replacement procedures use Medicare data (Cram et al., 2015; Li et al., 2013; Miller et al., 2011; Thakore et al., 2015), the first paper of this dissertation extends the literature on variation analyses by focusing on a service line that has been understudied in the privately insured population. Specially, I looked at how – for a commercially insured, age

of 45-64 cohort – variation in prices, as well as variation in utilization, contributes to variation in overall spending in total hip and knee replacements across and within hospital markets.

The first paper also contributes to the variation literature because the measure of price I used is the price actually paid for each admission (i.e., the allowed amount), rather than constructed estimates based on charges that many studies (i.e. Baker et al., 2008; Chernew et a.,2010) focusing on a privately-insured population use, because, unlike publicly-known Medicare payments, the prices that hospitals negotiate with private insurers are generally unavailable to researchers. The dataset used in this dissertation provided actual paid amounts.

The market concentration of hospitals and insurers has been a matter of concern for several decades. Recently, Gaynor et al. (2015) reviewed studies of the competitive landscape of hospitals, health insurers, and physician services and found that hospital and health insurer markets have become more concentrated since the 1990s. In addition, reviews of studies of hospital markets (Gaynor et al., 2012; Gaynor et al., 2015) found that concentrated markets are associated with higher hospital prices, with price increases often exceeding 20 percent when mergers occur in such markets. However, as with the literature on variation in prices, utilization and spending, most of the competition literature (i.e. Burgess et al.,2005; Dranove et al., 2008; Melnick et al., 2011) also uses estimates of actual prices (usually based on charges) rather than actual data on negotiated prices. Even more, researchers usually calculate Herfindahl-Hirschman index (HHI) as a measure of market concentration or power, but there is a drawback of using this measure. Gaynor and Town

(2011) explained that the relationship between HHI and prices are hypothesized with Cournot behavior. On the other hand, models based on Cournot behavior assume quantity setting with homogeneous products; and such models are inconsistent with the hospital market context. Hospitals sell differentiated products, and the HHI measure does not take this differentiation into account in its formulation (Gaynor and Town, 2011). In the second paper, the dissertation aimed to add to hospital competition literature by (i) using actual procedure prices instead of charged-based price estimates, (ii) using market power indices developed by semi-structural approaches (i.e. Willingness to Pay (WTP), Logit Competition Index (LOCI)) and (iii) focusing on a set of commonly performed elective orthopedic procedures (since some hospitals may specialize in performing them that may grant them higher bargaining power) while analyzing the impact of hospital market power on prices of total hip and knee replacements in the privately insured population.

Literature Review

Hospital Market Areas

The definition of hospital markets has become increasingly important with the growth of multihospital systems and the increased interest of the Federal Trade Commission and the United States Department of Justice in examining competition in the health care sector (Morrisey et al., 1988). Most of the healthcare studies use geographic markets which usually depend on geo-political boundaries such as counties or Metropolitan Statistical Areas (MSAs). Comparability and practicality are the key advantages of geopolitical boundaries, but they have some drawbacks. For instance, some counties may be too small to capture all hospitals that constitute a market. Particularly, hospitals located near a county line may be

relevant competitors for hospitals in the neighboring county as well (Garnick et al., 1987). In the case of MSAs, since travel from home to work are used to compute MSAs, the data are targeting a labor market rather than a hospital market (Garnick et al., 1987). Many urban areas are spread out and cross several counties and include so many hospitals that the assumption that all hospitals in MSA are competitors is unrealistic (Garnick et al., 1987). According to Zwanziger et al. (1990), the use of geopolitical boundaries may also understate the level of competition; a competing hospital may be located just on the other side of a geopolitical boundary.

There are also market definitions that represent local health care markets for hospital care (i.e. Hospital Service Areas (HSAs)) or regional health care markets for tertiary medical care (i.e. Hospital Referral Regions (HRRs)). Especially, HRRs are commonly used in geographic variation literature. According to Zhang et al. (2012), there are advantages to look at such large areas; they may be large enough to capture relatively homogeneous patient pools. On the other hand, Zhang et al. (2012) also indicated that such an exclusive focus can mask substantial heterogeneity at the more local level.

Variation in Hospital Spending and Hospital Prices in the United States

Since Medicare pays standard fee schedule prices to professionals and Diagnosis Related Group (DRG) based payments to hospitals, the primary driver of the geographic variation in Medicare spending is the difference in the quantity of health care delivered in different regions (Gottlieb et al., 2010); particularly due to the utilization of post-acute care and inpatient services (Newhouse and Garber, 2013). According to Philipson et al. (2010), "economic theory suggests that private insurers have stronger incentives to restrain

utilization and costs, while public insurers have greater monopsony power to restrain price" (pg 325). Using samples of heart disease patients, Philipson et al. (2010) found that regional variation in utilization is greater for Medicare beneficiaries, while variation in spending appears to be greater for beneficiaries with private insurance.

Aside from spending, other recent studies confirmed that private insurers' hospital payment rates (i.e. price) for their private insurance plans are much higher than the rates paid by the public Medicare program. For instance, Cooper et al. (2019) used claims data from three large national insurers; and found that "Medicare payments are 53 percent of private rates for inpatient care, 55 percent for hip replacement, 56 percent for knee replacement" (pg.14) between 2007 and 2011. Ginsburg (2010) also found that San Francisco hospitals' private prices were 210 percent of public Medicare reimbursements compared with 147 percent in Miami. According to American Hospital Association (2014), Medicare paid 86 cents for each dollar a hospital spent on its patients, whereas private insurers paid $1.49 for each dollar hospitals spent on its patients in 2009.

Some studies also found that private insurance payment rates for hospital services revealed significant geographic variation. Recently, Cooper et al. (2019) found that commercial payment rates for hospital inpatient services vary greatly across hospital referral regions (HRRs). After adjusting for geographic differences in wage rates, the average payment rate for hospital inpatient services (which was risk-adjusted for DRG, age and gender) was more than four times as high in the highest priced HRR as in the lowest priced HRR (Cooper et al., 2019). White et al. (2014) used claims data from autoworkers to examine hospital prices in thirteen Midwestern markets; and found that the highest priced

hospitals in a market were typically paid 60 percent more for inpatient care than the lowest priced hospitals.

Also, there is some information on the projection of contribution of health care prices to healthcare cost growth. For instance, Keehan et al. (2017) expected that growth in medical prices will account for 46 percent of total growth in personal health care spending during the projection period of 2020-2025, up from a share of 25 percent in 2016 that was announced by CMS. Eventually, evidence from these studies as well as reports by the Dartmouth Atlas of Health and Health Care Cost Institute (HCCI) suggest that healthcare expenditures vary due to differences in prices as well as utilization.

Most of the studies on the privately insured population have been restricted to market level measures due to limited availability of data on prices negotiated between providers and insurers. For instance, the study by Melnick et al. (2011) did not have actual hospital prices paid by private health plans; and used a proxy for hospital prices where they regressed total hospital net revenue on a set of independent variables that included hospital volume and hospital case-mix. This makes the understanding of factors affecting hospital prices difficult; and it will be best course of action to use actual negotiated prices due to the complexity of insurer and hospital contracts.

Hospital Market Power in the United States

Gaynor and Town (2011) analyzed trends in US hospital concentration between 1988 and 2008; and showed that US hospital markets are highly concentrated and have become even more concentrated over time. Recently the study by Fulton (2017) also stated that about 90 percent of hospital markets were highly concentrated in 2016. The need to question the

reasons behind the highly concentrated hospital markets have emerged accordingly. Fuchs (1997) pointed to the rise of managed care as the principal factor for this high concentration. Dranove et al. (2002) examined data from 1981 to 1994 and found a correlation between metropolitan area HMO penetration in 1994 and the change in market structure. However, Town et al. (2007) examined the change in hospital market structure and the change in HMO penetration and found little correlation, suggesting no direct causal link. The results are mixed for the reasons behind the highly concentrated markets, but it is believed that high market concentration in hospital markets can have substantial impact on hospital prices and profits (Antwi et al. (2013); Capps et al., 2003; Town and Vistnes, 2001).

Hospital Market Power Indices

The factors influencing the hospital competition or market power are complex and varied; including issues related to the demand side, such as whether patients are willing to travel in order to receive a service; technical issues related to the costs of providing services, such as the existence of economies of scale and the degree of spare capacity that can be tolerated; and the ease by which information about services and quality may be accessed and interpreted by patients (Gaynor and Town, 2011). Above all, there are few distinguishing features to consider while modeling competition in hospital markets. First, commercial plans build their provider network through direct negotiation with hospitals and professionals and set the reimbursement rates for services (Gaynor and Town, 2011). Second, patients choose commercial private health plans mostly acquired through their employers before the need for a treatment which defines hospital markets as an option demand market (Dranove and Satterthwaite, 2000; Capps et al., 2003). Employers select the set of health plans they offer to

their workers based on expected costs, benefit structure and provider networks (Gaynor and Town, 2011). Finally, patients get sick and hospital care for privately insured patients is often accessed through their health insurer within in-network hospitals.

Hospital market power is usually quantified through the Herfindahl- Hirschman Index (HHI) for hospital markets. HHI is the sum of the squared market share of each hospital or hospital system in the market area multiplied by 10,000. Unconcentrated markets have HHI below 1500; moderately concentrated markets have HHI between 1500 and 2500; and highly concentrated markets have HHI above 2500[5].

The other market power measure is the Logit Competition Index (LOCI) developed by Antwi et al. (2013). LOCI is a competition index for differentiated product oligopoly markets (Antwi et al., 2013). Unlike the HHI, LOCI is grounded in economic theory like a fully specified structural model. LOCI measure depends on data on market shares and observable patient types. It is bounded between zero and one; a hospital with a monopoly for all patient types has a value of LOCI that approaches 0 in the limit, and a hospital in a competitive market for all patient types has a value of LOCI that approaches 1 in the limit (Antwi et al., 2013).

In another approach, Town and Vistnes (2001) and Capps et al. (2003) used Willingness-to-Pay (WTP) measure as a proxy for provider's market power in option demand markets. "In option demand markets, intermediaries sell choice sets to downstream

[5]These cut-off points can be accessed via https://www.ftc.gov/sites/default/files/attachments/merger-review/100819hmg.pdf

consumers. If the intermediary market is competitive, then the price paid by the end-user is determined by the bargaining position of the upstream suppliers: when the value to consumers of a choice set is greatly reduced when a given firm is removed, that firm commands a premium" (Capps et al., 2003, pg.760). This approach uses logit demand models to estimate consumer preferences over hospitals. Capps et al. (2003) used the demand coefficients to calculate the value in utils patients receive from having access to a network of hospitals.

The Effect of Hospital Market Power on Prices

Increase in managed care had a huge impact on market power (Konetzka et al., 2008). In the 1980s, selective contracting with hospitals resulting from managed care encouraged hospitals to compete by lowering prices to gain contracts (Konetzka et al., 2008). On the other hand, there has been a decrease in managed care bargaining power and increase in hospital prices due to greater hospital contracting leverage because of hospital market concentration and lower managed care contracting leverage resulting from managed care backlash (Konetzka et al., 2008). Overall, studies focusing on data from the managed care era suggested that greater hospital market competition resulted in lower prices, and higher concentration resulted in higher prices (Burgess et al., 2005; Cuellar and Gertler, 2005; Tenn, 2011). Baker et al. (2014) also found that hospitals vertically integrated with physician practices charged higher prices.

Reduced form specifications based on the Structure-Conduct-Performance (SCP) paradigm in the industrial organization literature form the basis of most of the analysis on the impact of hospital market power on prices (Gaynor et al., 2015). Basically, researchers

usually calculate HHI or some form of it and regress it on the price controlling for other confounding variables. Gaynor and Town (2011) provided the review of these reduced form papers published between 2000 and 2011. All but one of the papers found a positive relationship between hospital concentration and price among the papers reviewed in this study. Accordingly, using the inpatient data from California Office of Statewide Health Planning and Development (OSHPD) between 1994 and 1998, Burgess et al. (2005) calculated hospital level HHI and average net private revenue per discharge[6]; and found that HHI is positively correlated with price. Using inpatient data from California OSHPD and Florida State Center for Health Statistics between 1990 and 2003, Dranove et al. (2008) used hospital system HHI; and stated that the association between market concentration and price increased during the 1990s and leveled off during 2000s. Using the inpatient data from California OSHPD from 1999 and 2003, Melnick and Keeler (2007) used hospital system HHI and average net revenue per discharge[7]; and found that system HHI is positively associated with price growth. Moriya et al. (2010) estimated the relationship between hospital concentration (i.e. HHI calculated from the share of enrollment among insurers) and DRG[8] adjusted prices from MarketScan® insurance claims from 2001 to 2003; and argued that hospital concentration and price relationship is insignificant. In fact, Moriya et al. (2010) found that increases in insurance market concentration are significantly associated with decreases in hospital prices, whereas increases in hospital concentration are non-significantly

[6] Burgess et al. (2005) used net revenues per discharge for 10 common diagnosis related groups (DRGs)
[7] Melnick and Keeler (2007) also used patient level discharge data to calculate the average gross revenue per discharge within each of 10 common DRGs.
[8] Moriya et al. (2010) used DRGs to group services/procedures; and collapsed the 435 unique DRG codes in the data into 20 categories.

associated with increases in prices. Most recently, Scheffler and Arnold (2017) used prices of hospital admissions and analyzed how provider and insurer market concentration as measured by HHI interacted with prices. Scheffler and Arnold (2017) found evidence that insurers had the bargaining power to reduce provider prices in highly concentrated provider markets; hospital admission prices were 5 percent lower in markets with high provider concentration.

Capps et al. (2003) took semi-structural approach to estimate the relationship between bargaining leverage and price. Capps et al. (2003) calculated willingness-to-pay (WTP) for each hospital in San Diego; and regressed it against hospital profits using OSHPD discharge data for San Diego. WTP and hospital profits were highly correlated; a one-unit increase in WTP increased hospital profits by $2,233 (Capps et al., 2003). Lewis and Pflum (2015) built upon the Capps et al. (2003) framework; and estimated a hospital cost function and found that WTP is correlated with market power. Town and Vistnes (2001) used data on negotiated price between two MCOs and hospitals in Southern California to estimate the relationship between WTP and price. They found that hospitals with higher bargaining power negotiated higher prices.

Public Health Significance

Greaney (2017) claimed that provider market power has a significant impact on high health care costs in the United States. Although there has been antitrust litigation and regulatory interventions for decades, high health care costs still overshadow the benefits of market policies(Greaney, 2017). Greaney (2017) argued that “antitrust law has an important but constrained role to play and has proved to be especially inept in dealing with extant

market power" (pg.1564). According to Glied and Altman (2017), increasing concentration in the health care market is due to the decline of community hospitals and the evolution of health insurance products. Therefore, they argued that regulators might need to regulate some prices and establish competitive bidding across markets, instead of trying to increase competition within markets. Seeing that, economic analyses of healthcare markets help policy makers, hospitals and payers to gain valuable insights on the current trends and associations regarding healthcare market power and prices.

It has been widely supported total amounts paid to providers for various procedures should be provided publicly. Analysis that focus on variation in prices for different procedures may help to advocate the need for transparency on such measures. The extent of price variation in an elective procedure such as total hip and knee replacements may also bring into question the need for tiered-provider networks or reference pricing. Tiered-provider networks help the plans to deal with high-price hospitals in areas where patients have hospital choices (Mays et. al, 2003). This approach maintains a broad provider network while steering patients toward lower cost providers. The results of this dissertation may indicate whether hospital inpatient services for total hip and knee replacements can be tiered in a simple way based just on the index procedure price instead of episode pricing. Next, reference pricing, which allows the plan to set a maximum price it will pay for a specific procedure, is another approach that can be brought into attention according to the extent of variation in prices of one of the popular elective procedures in inpatient hospital setting (i.e. total hip and knee replacements).

Lastly, understanding the relationship between market competition and hospital prices would provide valuable information about important trends in the health care system in recent years. Moreover, it could help improve policy making going forward. For instance, if a study shows that increased market concentration is associated with significant increases in the negotiated hospital prices, there needs caution in implementing policies that could encourage further concentration in hospital markets.

Research Question, Specific Aims or Objectives

Research Question:

The research question of this dissertation is twofold. Aim 1 addresses the question: to what extent do prices and utilization contribute to the variation in hospital spending of total hip and knee replacement procedures in a privately insured population in Colorado?

Aim 2 addresses the question: what is the association, if any, between variation in market power indices developed by semi-structural approaches and negotiated prices of total hip and knee replacement procedures in a privately insured population in Colorado?

Aim 1 (First Journal Article): To calculate and compare variation in hospital spending of a privately insured population with total hip or knee replacement procedures within and across Hospital Referral Regions (HRRs) in Colorado between 2009 and 2014; and assess the contribution of price and utilization to the variation in hospital spending.

Aim 2 (Second Journal Article):

To calculate and estimate the impact of different market competition indices, namely willingness to pay (WTP) and logit competition index (LOCI), on negotiated prices between

a private insurance payer and hospitals for total hip and knee replacement procedures in Colorado between 2009 and 2014.

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FIRST JOURNAL ARTICLE

Title of Journal Article:

Variation in Inpatient Hospital Spending for Privately Insured Hip or Knee Replacement Procedures in Colorado

BACKGROUND

In 2009, former U.S. president Barack Obama held up Grand Junction in Colorado as a model healthcare market because of its low Medicare costs (The Denver Post, 2009). Yet those familiar with Grand Junction's healthcare environment have claimed for years that costs for the privately insured, as opposed to those in the federally funded programs such as Medicare, are high (Olinger, 2015). Differences in price, utilization and overall spending patterns between private payer and Medicare beneficiaries have been noted by recent studies (Philipson et. al, 2010; White, 2012; Dartmouth Atlas, 2014; Franzini et. al, 2014; Franzini et. al, 2015; Cooper et. al, 2019). Such discrepancies are of interest to policymakers and researchers because they imply opportunities for saving and waste reduction. The public nature of Medicare data means much is known about spending variation, but this is not true for private insurance data. This study contributes to this line of inquiry by studying regional price variation among private payer plans in Colorado.

Researchers have been able to rely on public Medicare data to identify places that appeared to be providing health care efficiently as well as regions of potential waste and fraud. There has been less opportunity to analyze private insurance claims data. One exception is the recent study on regional variation in healthcare prices by Cooper et al. (2019), which used the Health Care Cost Institute (HCCI) database that included health

insurance claims from 2007 to 2011 for individuals with coverage from three of the five largest insurance companies in the US: Aetna, Humana, and UnitedHealth. The study by Cooper et al. (2019) found regions where federally regulated Medicare expenditures were low but private hospital care costs were high. In the case of Colorado, Cooper et al. (2019) found that Grand Junction had the third-lowest costs per Medicare beneficiary for all inpatient events among 306 hospital referral regions (HRRs) nationwide, but at the same time, it had the ninth-highest average inpatient prices for private patients in 2011[9]. The study also looked at how widely the prices of private insurance payers for certain procedures varied among hospitals and market regions. Though Cooper et al. (2019) does not present the whole picture in Colorado, it stated that among the country's 25 most-populated hospital markets, Denver had the highest average cost for commercial inpatient visits, at $14,363. Its prices for hip replacements and coronary angioplasties were below the national average, while cesarean sections and colonoscopies were above (Cooper et al., 2019).

This study aims to extend the literature on variation analyses by focusing on a service line that has been mostly understudied in the younger, privately insured population (i.e. total hip or total knee replacement procedures). Though Cooper et al. (2019) included hip and knee replacement cohorts in their study; their analysis was limited to commercial payer claims in 2010 and 2011 and did not include claims from one of the key players in the health insurance industry (Blue Cross Blue Shield). The study by Cooper et al. (2019) did not also provide the full analysis in Colorado; they just focused on Denver for the price variation

[9] Both costs per Medicare beneficiary and inpatient prices for private patients were for all inpatient events; and they were controlled for DRGs.

analysis on hip and knee replacement procedures. This paper evaluates whether and to what extent the hospital inpatient prices for the same service line changed between different private insurance product types (i.e. HMO, PPO, POS), and between (and within) geographic markets in Colorado (i.e. HRRs).

METHODS

Study Design and Data

This is a retrospective cohort study that included private insurance payer claims for total hip or knee replacement procedures in Colorado between 2009 and 2014 to analyze the variation in hospital spending, prices and utilization between different private insurance product types and HRRs.

This study used Colorado All Payer Claims Database (CO APCD) data. The CO APCD is the state's most comprehensive source of health care insurance claims information representing 4.3 million unique covered lives in the state across 33 commercial health insurance plans, Medicare Advantage, and Health First Colorado (Colorado's Medicaid program), as of May 2018[10],[11]. The CO APCD was a recommendation of the Governor-appointed Blue Ribbon Commission on Health Reform (208 Commission) and was created by legislation passed in 2010[12]. The Center for Improving Value in Health Care (CIVHC) was named administrator of the CO APCD by the Executive Director of the CO Department of Health Care Policy and Financing (HCPF) the same year and the database was launched in

[10] This information was taken from https://www.apcdcouncil.org/state/colorado
[11] The CO APCD did not include self-insured plans; this limit private plans to fully insured.
[12] This information was taken from https://www.civhc.org/get-data/co-apcd-overview/

2012. The CO APCD data includes medical claims and beneficiary enrollment files, and it is de-identified at the beneficiary level. The CO APCD data do not include beneficiary identifiers such as social security numbers, names, dates of birth, or addresses. The study was exempted by the University of Texas Health Science Center at Houston Institutional Review Board since the CO APCD data is de-identified.

The CO APCD data include a unique hospital identifier, a unique patient identifier, the date services were provided, hospitals' charges, hospitals' negotiated transaction prices, and payments to hospitals made by patients in the form of co-insurance payments, co-payments, and the payments made before deductibles were met. As a result, the amounts paid to hospitals for all health care encounters were recorded in the data.

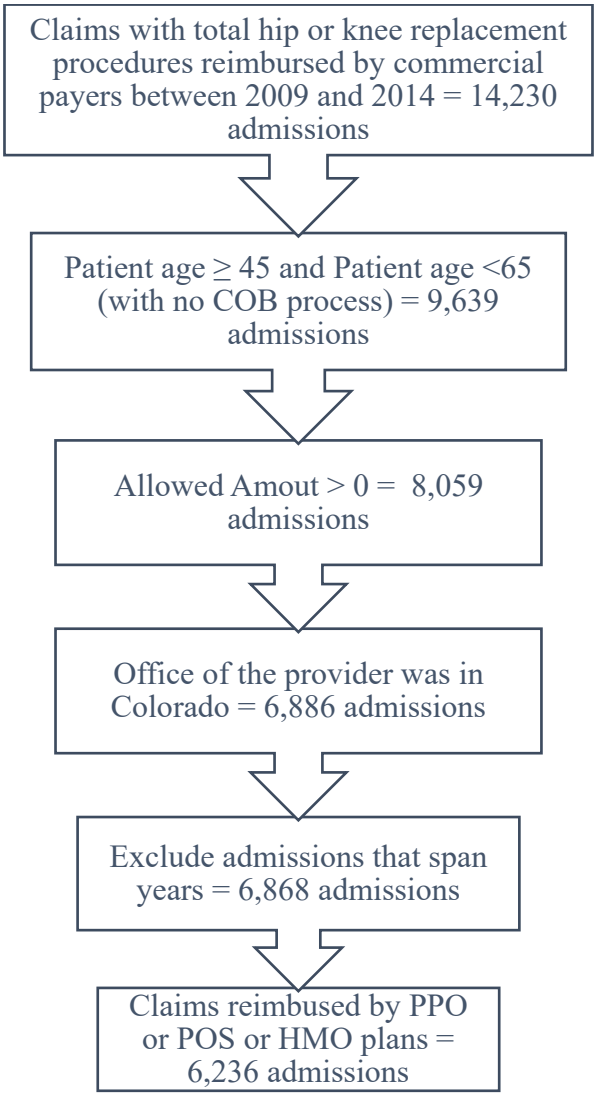
Study Population

This study included elective total hip or total knee replacement procedures performed in the hospital inpatient setting and reimbursed by Health Maintenance Organizations (HMO) plans, Preferred Provider Organizations (PPO/PPO+) plans or Point of Service (POS) plans in Colorado between 2009 and 2014. The study only included claims where commercial plans had the primary payment responsibility, and we excluded claims with the Coordination of Benefits (COB) process. The study focused on the patient population older than or equal to 45 years old and younger than 65 years old since older patients or atypically young patients[13]

[13] Median age for total hip or knee replacement procedures in CO APCD for HMO, PPO or POS patients was 59 years during the study period (before limiting the age of patients). Mean age was 58 years (with standard deviation of 7 years).

may raise costs (Cooper et. al, 2019). We also excluded claims with admissions that span years or claims with zero allowed amounts.

Figure 1: Steps of the derivation of study cohort



After applying the above inclusion/exclusion criteria, there were 6,236 admissions of total hip or knee replacement procedures reimbursed by HMO (n=3,207 admissions), PPO (n=1,998 admissions) or POS (n=1,031 admissions) plan types in Colorado from 2009 to 2014. After constructing sperate cohorts for total hip or total knee replacement procedures, to minimize the impact of unusually complicated cases or billing errors, we further excluded claims with a length of stay above the 99th percentile, as well as claims with negotiated prices below the 1st percentile or above the 99th percentile.

Eventually, the data contained 2,339 commercial payer inpatient hospital claims for the clinical cohort of *total hip replacement* procedures, and 3,601 commercial payer inpatient hospital claims for the clinical cohort of *total knee replacement* procedures (Total sample size was 5,940 admissions)[14]. Among the hip cohort, 1,265 claims were reimbursed by HMO plans, 702 claims were reimbursed by PPO plans, and 372 claims were reimbursed by POS plans. Among the knee cohort, 1,841 claims were reimbursed by HMO plans, 1,139 claims were reimbursed by PPO plans, and 621 claims were reimbursed by POS plans.

Geographic Unit

This study examined variation across and within HRRs, which represent regional health care markets, and are defined by determining where patients were referred for major

[14] Using data from Colorado Department of Regulatory Agencies, we found that there were approximately 17,000 admissions for total hip or knee replacement procedures (DRG 470) from 2009 to 2014. Almost half of these admissions were reimbursed by Medicare Advantage, so that there were approximately 8,500 admissions by other private insurance plans. Since approximately 40 percent of private insurance admissions were from self-insured patients, and CO APCD data do not include self-insured plans, it turns out that the estimated number of admissions for total hip or knee replacement procedures in Colorado from 2009 to 2014 is approximately 5,000 which is consistent with the sample size of our study (N=5,940 admissions).

cardiovascular surgical procedures and for neurosurgery[15]. HRRs are the most widely established geographic unit used in the literature on geographic variation (Skinner, Staiger, and Fisher 2010; Zuckerman et al. 2010; Newhouse and Garber 2013; Franzini et. al, 2014; Cooper et. al, 2019). There are 7 HRRs in Colorado: Boulder, Colorado Springs, Denver, Fort Collins, Grand Junction, Greeley, and Pueblo.

Data Analysis

The study constructed two narrowly defined clinical cohorts for commonly provided orthopedic inpatient procedures, namely total hip (ICD-9 81.51) and total knee replacement (ICD-9 81.54) procedures. We also performed a separate analysis for each insurance product type (i.e. HMO, PPO and POS) since financial data for these plans are not easily comparable. The objective of this study is to determine the extent to which variation in the price of care across HRRs and variation in the utilization of care provided across HRRs contribute to the variation in hospital inpatient spending for the privately insured total hip or knee replacement procedures in Colorado from 2009 to 2014.

i. Risk-Adjusted Hospital Inpatient Prices

Following the literature (White, 2012; Dartmouth Atlas, 2014; Franzini et. al, 2014; Franzini et. al, 2015; Cooper et. al, 2019), we defined hospital inpatient prices for total hip or knee replacement procedures as the allowed amount paid for the initial inpatient stay- facility payments only, which is the total amount that the health plan and beneficiary are liable to pay

[15] HRRs were created by researchers at the Dartmouth Institute for Health Care. This information was taken from http://www.dartmouthatlas.org/data/region/.

together[16]. This study excludes spending on physician services or other medical services since White et al. (2014) found that the price of the initial inpatient stay was the most important factor in total spending for hip or knee replacement episodes for a privately insured population. White et al. (2014) observed that 81 percent of the variation in hospital spending for hip and knee replacement episodes was due to the price of the initial hospital stay. Consequently, for each of the clinical cohorts in this study, the price of initial inpatient stay captured the combined price on all claims associated with services provided to the patient by hospitals from admission through discharge.

Analyzing variation in prices usually raises concerns about reflecting observed or unobserved differences between different providers, especially case mix (Cooper et al., 2019). In order to address such concerns, first, this study used risk-adjusted price measures for patient case-mix. Using the methodology discussed by Cooper et. al (2019), we adjusted prices for differences in patient characteristics. For each separate clinical cohort and for each insurance product type (i.e. HMO, PPO, POS), we regressed allowed amounts (i.e. price) paid by patient *i* with insurance product type *j* in clinical cohort *c* to hospital *h* ($p_{i,j,h,c}$) on hospital fixed effects ($\alpha_{h,j,c}$) and a vector of patient characteristics which included age[17] and gender of the patient ($X_{i,j,h,c}$). The regression took the form:

$$p_{i,j,h,c} = \alpha_{h,j,c} + X_{i,j,h,c}\beta_{c,j} + u_{i,j,h,c}$$

(Equation 1)

[16] Beneficiary liability amount includes any deductible, copay and coinsurance paid out-of-pocket by the patient.

[17] The Charlson Comorbidity Index did not vary much among plans, therefore the study adjusted for age and gender.

where $u_{i,j,h,c}$ is the stochastic error term. After recovering the vector of estimated hospital fixed effects and estimators for patient characteristics, we calculated hospital's price adjusted for its mix of patients at the sample means of the patient characteristics as:

$$\hat{p}_{h,c,j} = \hat{\alpha}_{h,c,j} + \bar{X}\hat{\beta}_{c,j}$$

(Equation 2)

ii. Hospital Inpatient Spending per Privately Insured Beneficiary

The study calculated average hospital inpatient spending per privately insured beneficiary for each clinical cohort by each insurance product type from 2009 to 2014 and looked at trends in spending levels over time. We calculated average hospital inpatient spending per privately insured beneficiary as the sum of the risk-adjusted hospital inpatient prices in each clinical cohort, *c*, in each HRR, *m,* for each insurance product type, *j*, per year, *y,* ($\sum p_{m,c,j,y}$) divided by the respective number of beneficiaries aged between 45 and 64 in that HRR, for each insurance product type, *j*, per year, *y,* ($n_{m,j,y}$). Like Cooper at. al (2019), we presented the rates as compound annualized growth rates. To calculate growth rates, we divided the spending levels in 2014 by the spending levels in 2009, raised the fraction to the power of 1 divided by 5 (since the growth period is 5 years), and subtracted 1 from the result.

$$Compound\ Annualized\ Growth\ Rate = \left(\frac{\sum p_{m,c,j,2014}}{n_{m,j,2014}} \Big/ \frac{\sum p_{m,c,j,2009}}{n_{m,j,2009}} \right)^{1/5} - 1$$

(Equation 3)

It is important to note that the spending measure we used in this study has a population-based denominator (i.e. the number of privately insured beneficiaries in each HRR in Colorado with plan type HMO/PPO/POS per year and aged between 45 and 64, and *not* the number of cases of hip or knee procedures). According to the report written by National Quality Forum (2017)[18], a cost measure with population-based denominator can be useful to complement episode-based measure for a complete view of utilization across the measurement years. Spending measures with population-based denominator support a measurement to identify areas of overuse or underuse. Being that. the spending measure with population-based denominator enabled the identification and calculation of the contribution of differences in price and quantity of care delivered to spending variation across and within HRRs in Colorado.

While calculating the hospital inpatient spending index for total hip and total knee replacement procedures, we pooled data from 2009 to 2014 and the risk-adjusted hospital inpatient prices were inflation adjusted to 2014 dollars using the Colorado All Items Consumer Price Index[19]. The study calculated the average hospital inpatient spending index for each clinical cohort, *c*, in each HRR, *m,* by each insurance product type, *j,* by comparing the average hospital inpatient spending per beneficiary for each clinical cohort in each HRR

[18]The report can be accessed via:
https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=14&cad=rja&uact=8&ved=2ahUKEwiznN6OsL3lAhUNSq0KHUsjChsQFjANegQIBhAC&url=http%3A%2F%2Fwww.qualityforum.org%2FProjects%2Fc-d%2FCost_and_Resource_Use_2016-2017%2FFinal_Report.aspx&usg=AOvVaw3AkPUFBEPae-Ruw8XYiVVW

[19]The CPI values was taken from:
https://data.bls.gov/pdq/SurveyOutputServlet?data_tool=dropmap&series_id=CUURS48BSA0,CUUSS48BSA0

m for the pooled data to the average hospital inpatient spending per beneficiary in Colorado for the pooled data. That is,

$$Hospital\ Inpatient\ Spending\ Index_{m,c,j} = \frac{\frac{\sum p_{m,c,j}}{n_{m,j}}}{\frac{\sum_m \sum p_{m,c,j}}{\sum_m n_{m,j}}}$$

(Equation 4)

In equation 4, the numerator is the average hospital inpatient spending per beneficiary in each HRR, *m*, for each clinical cohort, *c*, by each insurance product type, *j* for the pooled data. The denominator represents average hospital inpatient spending per beneficiary in the state of Colorado for each clinical cohort, *c*, by each insurance product type, *j*, for the pooled data where total hospital inpatient spending in each HRR, *m*, is summed across all HRRs and divided by the number of beneficiaries aged between 45 and 64 in each insurance product type, *j*, in the state of Colorado for. If the hospital inpatient spending index is larger than one, it signifies that the hospital inpatient spending per beneficiary for the specific clinical cohort (i.e., total hip replacement or total knee replacement) in HRR, *m*, is larger than the average in the base area (or the inpatient hospital spending per beneficiary in the state of Colorado); and if the index is less than one, it signifies that the hospital inpatient spending per beneficiary is less than the average in the base area.

iii. Decomposition of Variation in Hospital Inpatient Spending into Price and Quantity

Next, our study analyzed the relative contributions of price and quantity to spending variation for private insurance patients in CO APCD. Following McKellar et al. (2012) and

Cooper et al. (2019), we decomposed the variance of the natural logarithm of hospital inpatient spending into hospital inpatient price and quantity components as follow:

$$var\left(\ln\left(\frac{\sum p_{m,c,j}}{n_{m,j}}\right)\right)$$

$$= (\ln(\bar{p}_{m,c,j}))^2 \times var\left(\ln\left(\frac{q_{m,c,j}}{n_{m,j}}\right)\right) + \left(ln\left(\frac{q_{m,c,j}}{n_{m,j}}\right)\right)^2 \times var(\ln(\bar{p}_{m,c,j}))$$

$$+ higher\ order\ terms$$

(Equation 5)

where $\frac{\sum p_{m,c,j}}{n_{m,j}}$ is the average hospital inpatient spending per privately insured beneficiary (plan type, *j*, in each HRR, *m*, for each clinical cohort, *c,* for the pooled data); $\bar{p}_{m,c,j}$ is the average allowed amount per procedure in each clinical cohort, *c*, and HRR, *m*, for each plan type, *j*, for the pooled data; and $\left(\frac{q_{m,c,j}}{n_{m,j}}\right)$ is the number of procedures per privately insured beneficiary in each HRR, *m*, for each clinical cohort, *c,* and plan type, *j*, for the pooled data. The higher order terms include the covariance between quantity and price. Since the higher order terms can be negative, like McKellar et al. (2012), we presented the relative share of variance in hospital inpatient spending per beneficiary attributable to quantity as:

$$\frac{(\ln(\bar{p}_{m,c,j}))^2 \times var\left(\ln\left(\frac{q_{m,c,j}}{n_{m,j}}\right)\right)}{(\ln(\bar{p}_{m,c,j}))^2 \times var\left(\ln\left(\frac{q_{m,c,j}}{n_{m,j}}\right)\right) + \left(ln\left(\frac{q_{m,c,j}}{n_{m,j}}\right)\right)^2 \times var(\ln(\bar{p}_{m,c,j}))}$$

(Equation 6)

Consequently, the relative share of the variance in hospital spending per privately insured beneficiary attributable to hospital inpatient price across HRRs, m, and different plan type, j, in each clinical cohort, c, for the pooled data is represented by:

$$Share\ Attributable\ to\ Price = 1 - Share\ Attributable\ to\ Quantity$$

$$= 1 - \frac{(\ln(\bar{p}_{m,c,j}))^2 \times var\left(\ln\left(\frac{q_{m,c,j}}{n_{m,j}}\right)\right)}{(\ln(\bar{p}_{m,c,j}))^2 \times var\left(\ln\left(\frac{q_{m,c,j}}{n_{m,j}}\right)\right) + \left(ln\left(\frac{q_{m,c,j}}{n_{m,j}}\right)\right)^2 \times var(\ln(\bar{p}_{m,c,j}))}$$

(Equation 7)

RESULTS

Hospital Inpatient Spending per Privately Insured Beneficiary

This study examined the growth in hospital inpatient spending per beneficiary with different private insurance plan types for total hip and total knee replacement procedures in Colorado (Table 1). For total hip replacement procedures from 2009 to 2014, the average hospital inpatient spending per beneficiary for a privately insured patient with an HMO plan increased from $6.40 in 2009 to $38.87 in 2014; at an annualized growth rate of 43.45 percent. Whereas the average hospital inpatient spending per beneficiary for privately insured with a PPO plan increased at a lower annualized growth rate of 3.21 percent, from $24.93 to $29.20. In the case of a POS plan, the average hospital inpatient spending per beneficiary increased at an annualized growth rate of 20.75 percent during the same period, from $16.84 to $43.23. For total knee replacement procedures, from 2009 to 2014, the average hospital inpatient spending per beneficiary for privately insured with an HMO plan increased from $12.64 in 2009 to $50.73; at an annualized growth rate of 32.04 percent. Whereas the

Table 1: Hospital Inpatient Spending for Total Hip/Knee Replacement Procedures, COAPCD Data, 2009-2014

A. Total Hip Replacement

	Total Hospital Inpatient Spending ($) (b)			Average Hospital Inpatient Spending per Beneficiary ($) (=b/Table A.1)		
	HMO	PPO	POS	HMO	PPO	POS
2009	1,036,892	2,691,721	936,577	6.40	24.93	16.84
2010	1,259,846	2,892,196	2,019,042	7.74	24.77	32.83
2011	4,315,606	2,703,783	1,267,610	28.18	22.99	22.84
2012	7,494,045	3,730,590	1,369,922	39.91	29.16	25.96
2013	7,353,898	4,816,190	2,568,327	39.31	30.92	38.74
2014	8,864,280	5,828,245	2,787,038	38.87	29.20	43.23
Total	*30,324,567*	*22,662,725*	*10,948,516*	*53.60*	*57.63*	*62.97*
Annualized Growth Rate (%)	*53.57*	*16.71*	*24.37*	*43.45*	*3.21*	*20.75*

B. Total Knee Replacement

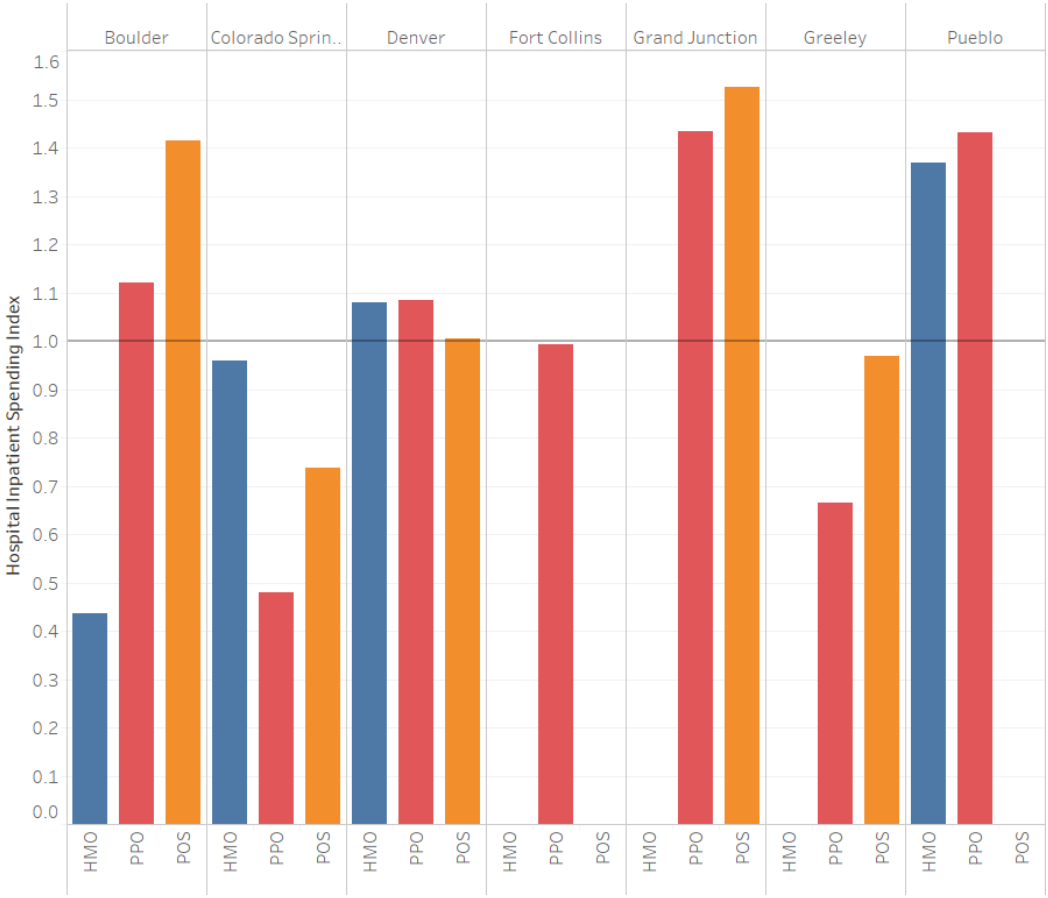
	Total Hospital Inpatient Spending ($) (b)			Average Hospital Inpatient Spending per Beneficiary ($) (=b/Table A.1)		
	HMO	PPO	POS	HMO	PPO	POS
2009	2,046,203	3,962,452	2,038,644	12.64	36.70	36.66
2010	2,171,090	5,490,726	2,827,230	13.34	47.02	45.97
2011	6,303,239	5,586,250	2,356,131	41.16	47.50	42.45
2012	11,816,395	6,586,923	2,464,770	62.92	51.48	46.70
2013	11,793,883	8,705,223	3,289,086	63.04	55.89	49.61
2014	11,569,144	9,850,115	4,634,667	50.73	49.35	71.88
Total	*45,699,953*	*40,181,690*	*17,610,528*	*80.78*	*102.19*	*101.29*
Annualized Growth Rate (%)	*41.41*	*19.98*	*17.85*	*32.04*	*6.10*	*14.41*

Note: Hospital inpatient spending values have been inflation adjusted to 2014 dollars using the BLS All Items Consumer Price Index; and age-gender adjusted.

average hospital inpatient spending per beneficiary for privately insured with a PPO plan increased at a lower annualized growth rate of 6.10 percent, from $36.70 to $49.35. In the case of a POS plan, the average hospital inpatient spending per beneficiary increased at an annualized growth rate of 14.41 percent during the same period, from $36.66 to $71.88. There was substantial variation in hospital inpatient spending per beneficiary compound annualized growth rates across private insurance plan types in the period 2009 to 2014 in Colorado for both clinical cohorts. Specifically, HMO plans had a significant annualized growth rate increase between 2009 to 2014 compared to PPO and POS plan types in both clinical cohorts. Whereas PPO plans had the lowest annualized growth rate compared to HMO and POS plans between 2009 to 2014 in both clinical cohorts.

Next, the study evaluated hospital inpatient spending index for each clinical cohort of total hip and total knee replacement procedures across HRRs in Colorado, by each private insurance plan type using the pooled data from 2009 to 2014 (Table A.2 in Appendix). We limited the analysis to HRRs that had at least 15 procedures within the study period. For total hip replacement procedures (Figure 2), Pueblo was the HRR with highest hospital inpatient spending index (hospital inpatient spending was 37 percent higher than the state average) and Boulder was the HRR with the lowest hospital inpatient spending (hospital inpatient spending was 56 percent lower than the state average) for the HMO plan type. In the case of the PPO plan type, Pueblo and Grand Junction were the HRRs with the highest hospital spending index (hospital inpatient spending was 43 percent higher than the state average in both HRRs) and Colorado Springs was the HRR with the lowest hospital inpatient spending index (hospital inpatient spending was 52 percent lower than the state average). Last but not

Figure 2: Hospital Inpatient Spending Index for Total Hip Replacement Procedure, by HRR, by Plan Type, Colorado, 2009-2014

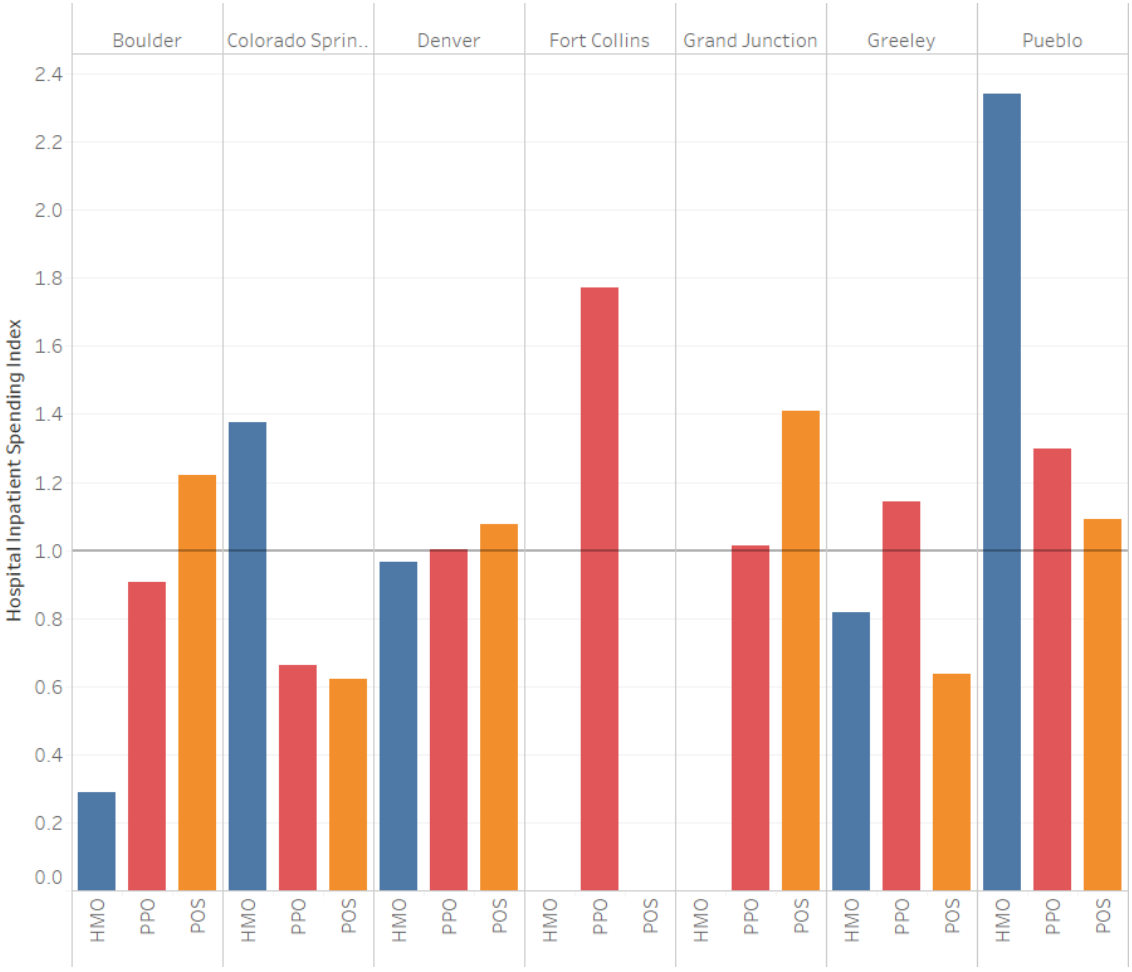


least, for POS plan type, Grand Junction was the HRR with the highest hospital spending index (hospital inpatient spending was 53 percent higher than the state average) and Colorado Springs was the HRR with the lowest hospital inpatient spending index (hospital inpatient spending was 26 percent lower than the state average). The Denver HRR had hospital inpatient spending closest to state of Colorado average for all three commercial plan types. Overall, Pueblo and Grand Junction were the HRRs with the highest hospital inpatient

commercial spending for total hip replacement procedures, whereas Colorado Springs and Boulder were the HRRs with lowest hospital inpatient commercial spending for total hip replacement procedures.

In the same way, we also evaluated the hospital inpatient price index for total knee replacement procedures (Figure 3), Pueblo was the HRR with highest hospital inpatient spending index (hospital inpatient spending was 134 percent higher than the state average) and Boulder was the HRR with the lowest hospital inpatient spending (hospital inpatient spending was 71 percent lower than the state average) for HMO plan type. In the case of PPO plan type, Fort Collins was the HRR with the highest hospital spending index (hospital inpatient spending was 77 percent higher than the state average) and Colorado Springs was the HRR with the lowest hospital inpatient spending index (hospital inpatient spending was 34 percent lower than the state average). Last but not least, for POS plan type, Grand Junction was the HRR with the highest hospital spending index (hospital inpatient spending was 41 percent higher than the state average) and Colorado Springs was the HRR with the lowest hospital inpatient spending index (hospital inpatient spending was 38 percent lower than the state average). Like in the case of total hip replacement procedures, Denver was the HRR with hospital inpatient spending closest to state average for all three commercial plan types. Overall, Pueblo, Fort Collins and Grand Junction were the HRRs with the highest hospital inpatient commercial spending for total knee replacement procedures, while Boulder and Colorado Springs were the HRRs with lowest hospital inpatient commercial spending for total knee replacement procedures.

Figure 3: Hospital Inpatient Spending Index for Total Knee Replacement Procedure, by HRR, by Plan Type, Colorado, 2009-2014



After analyzing hospital inpatient spending per beneficiary annualized growth rates across years; and comparing hospital inpatient spending per beneficiary for two clinical cohorts in relation to state averages across HRRs and private payer plan types, we evaluated variation in hospital inpatient negotiated prices for each clinical cohort across HRRs by private insurance plan types. All results are presented in Table 2. For total hip replacement procedure, the mean hospital inpatient transaction price paid by HMO plans was $23,972 in

Colorado, and the coefficient of variation across 7 HRRs in Colorado was 0.20. The mean hospital transaction price in the highest price HRR (Pueblo) was $36,070, almost one and a half times as much as the mean hospital inpatient transaction price in the lowest price HRR (Denver, $22,886). The coefficient of variation across hospital-level prices paid by HMO plan type within Pueblo was 0.19 for total hip replacement procedures (with standard deviation of $6,853). Next, the mean hospital inpatient transaction price paid by PPO plan type was $32,283 in Colorado, and the coefficient of variation across 7 HRRs in Colorado was 0.30 (with standard deviation of $9,746). The mean hospital transaction price in the highest price HRR (Greeley) was $53,442, almost twice as much as the mean hospital inpatient transaction price in the lowest price HRR (Grand Junction, $29,077). On the other hand, the coefficient of variation across hospital-level prices paid by PPO plan type within Greeley (where mean price paid by PPO plan type to hospitals were highest) was 0.15 (standard deviation $8,057), whereas the coefficient of variation was 0.41 in Grand Junction (where mean price paid by PPO plan type to hospitals were lowest) for total hip replacement procedures. Lastly, the mean hospital inpatient transaction price paid by POS plan type was $29,432 in Colorado, and the coefficient of variation across 7 HRRs in Colorado was 0.25 (with standard deviation of $8,542. The mean hospital transaction price in the highest price HRR (Greeley) was $45,853, almost twice as much as the mean hospital inpatient transaction price in the lowest price HRR (Denver, $27,105). On the other hand, the coefficient of variation across hospital-level prices paid by POS plan type within Grand Junction was 0.29 for total hip replacement procedures (with standard deviation of $9,267). Consequently, variation in hospital inpatient prices for total hip replacement procedures across 7 HRRs in

Colorado was the highest among PPO plan types. Also, for total hip replacement procedures, Pueblo was the HRR with highest variation in inpatient prices across hospitals paid by HMO plans; and Grand Junction was the HRR with highest variation in inpatient prices across hospitals paid by both PPO and POS plans between 2009 and 2014.

For total knee replacement procedure, the mean hospital inpatient transaction price paid by HMO plan type was $24,823 in Colorado, and the coefficient of variation across 7 HRRs in Colorado was 0.26 (with the standard deviation of $6,333). The mean hospital transaction price in the highest price HRR (Greeley) was $44,112, almost twice as much as the mean hospital inpatient transaction price in the lowest price HRR (Denver, $22,857). The coefficient of variation across hospital-level prices paid by HMO plan type within Pueblo was 0.29 for total knee replacement procedures (with standard deviation of $10,597). Next, the mean hospital inpatient transaction price paid by PPO plan type was $35,278 in Colorado, and the coefficient of variation across 7 HRRs in Colorado was 0.35 (with standard deviation of $12,294). The mean hospital transaction price in the highest price HRR (Fort Collins) was $56.127, almost twice as much as the mean hospital inpatient transaction price in the lowest price HRR (Pueblo, $30,236). On the other hand, the coefficient of variation across hospital-level prices paid by PPO plan type within Denver was 0.33 (with standard deviation $10,824) for total hip replacement procedures. Lastly, the mean hospital inpatient transaction price paid by POS plan type was $28,358 in Colorado, and the coefficient of variation across 7 HRRs in Colorado was 0.32 (with standard deviation of $9,134). The mean hospital transaction price in the highest price HRR (Greeley) was $39,843, almost one and a half times as much as the mean hospital inpatient transaction price in the lowest price HRR

(Pueblo, $24,565). Whereas the coefficient of variation across hospital-level prices paid by POS plan type within Pueblo was 0.45 for total knee replacement procedures (with standard deviation of $11,168). Consequently, variation in hospital inpatient prices for total knee replacement procedures across 7 HRRs in Colorado was the highest among PPO plan types. In addition, for total knee replacement procedures, Pueblo was the HRR with highest variation in inpatient prices across hospitals paid by both HMO and POS plan types; and Denver was the HRR with highest variation in inpatient prices across hospitals paid by PPO plan type between 2009 and 2014.

Table 3 also shows the extent of the variation in hospital inpatient negotiated prices within the state of Colorado for total hip or total knee replacement procedures across the years by three types of private insurance plans. The coefficient of variation in hospital inpatient prices for both clinical cohorts were lower for HMO plans compared to PPO and POS plans from 2009 to 2014. The coefficient of variation in hospital inpatient prices for both procedures were relatively higher for PPO plans compared to POS plans from 2009 to 2012, though POS plans had a higher variation in hospital inpatient prices for both procedures in 2014.

Lastly, the study evaluated the decomposition of spending into price and quantity using the pooled data from 2009 to 2014. All results were presented in Table 4. We analyzed the contribution of price[20] and quantity[21] to hospital inpatient spending for total hip or total

[20] Price is the average allowed amount per procedure in each clinical cohort, *c*, and HRR, *m*, for each plan type, *j*, for the pooled data.

[21] Quantity is the number of procedures per privately insured beneficiary in each HRR, *m*, for each clinical cohort, *c,* and plan type, *j*, for the pooled data.

Table 2: Variation in Hospital Inpatient Procedure Prices within and across HRRs in Colorado

A. Total Hip Replacement

	Number of Admissions			Mean Hospital Inpatient Price			Standard Deviation			Coefficient of Variation		
	HMO	PPO	POS	HMO	PPO	POS	HMO	PPO	POS	HMO	PPO	POS
Boulder	31	83	48	30,735	29,081	32,095	5,417	7,052	5,317	0.18	0.24	0.17
Colorado Springs	121	51	26	27,178	30,123	34,382	3,936	9,463	6,316	0.14	0.31	0.18
Denver	1071	419	253	22,886	31,856	27,105	3,366	7,298	7,601	0.15	0.23	0.28
Fort Collins	1	19	1	*	53,220	*	*	10,767	*	*	0.20	*
Grand Junction	-	77	24	*	29,077	31,956	*	11,920	9,267	*	0.41	0.29
Greeley	7	22	15	*	53,442	45,853	*	8,057	11,262	*	0.15	0.25
Pueblo	34	31	6	36,070	30,302	*	6,853	6,469	*	0.19	0.21	*
Colorado	*1265*	*702*	*373*	*23,972*	*32,283*	*29,432*	*4,778*	*9,746*	*8,542*	*0.20*	*0.30*	*0.29*

B. Total Knee Replacement

	Number of Admissions			Mean Hospital Inpatient Price			Standard Deviation			Coefficient of Variation		
	HMO	PPO	POS	HMO	PPO	POS	HMO	PPO	POS	HMO	PPO	POS
Boulder	31	114	69	30,514	30,314	30,917	6,403	7,855	5,601	0.21	0.26	0.18
Colorado Springs	245	110	47	29,053	34,032	25,711	4,860	10,804	8,646	0.17	0.32	0.34
Denver	1447	662	432	22,857	33,077	27,377	3,822	10,824	8,602	0.17	0.33	0.31
Fort Collins	4	57	5	*	56,127	*	2,766	6,807	*	*	0.12	*
Grand Junction	6	81	34	*	34,586	33,503	4,495	9,619	10,293	*	0.28	0.31
Greeley	21	65	17	45,112	54,964	39,843	5,118	7,563	14,105	0.11	0.14	0.35
Pueblo	87	50	17	36,326	30,236	24,565	10,597	8,729	11,168	0.29	0.29	0.45
Colorado	*1841*	*1139*	*621*	*24,823*	*35,278*	*28,358*	*6,333*	*12,294*	*9,134*	*0.26*	*0.35*	*0.32*

Note: Prices are averaged 2009-2014 using inflation adjusted prices in 2014; age and gender adjusted allowed amounts.

(*) = Number of procedures<15

Table 3: Variation in Hospital Inpatient Procedure Prices in Colorado, by Plan Type, by Year, 2009-2014, COAPCD Data

A. Total Hip Replacement

	Number of Admissions			Mean Hospital Inpatient Price			Standard Deviation			Coefficient of Variation		
	HMO	PPO	POS	HMO	PPO	POS	HMO	PPO	POS	HMO	PPO	POS
2009	37	78	32	28,024	34,509	29,268	10,506	10,511	8,193	0.37	0.30	0.28
2010	41	89	69	30,728	32,497	29,261	5,199	11,670	9,096	0.17	0.36	0.31
2011	175	84	43	24,661	32,188	29,479	4,906	9,220	6,892	0.20	0.29	0.23
2012	319	122	46	23,492	30,579	30,443	3,824	9,769	7,096	0.16	0.32	0.23
2013	315	148	89	23,346	32,542	28,858	3,851	9,577	9,345	0.16	0.29	0.32
2014	378	181	94	23,450	32,200	29,649	4,443	8,578	8,913	0.19	0.27	0.30

B. Total Knee Replacement

	Number of Admissions			Mean Hospital Inpatient Price			Standard Deviation			Coefficient of Variation		
	HMO	PPO	POS	HMO	PPO	POS	HMO	PPO	POS	HMO	PPO	POS
2009	79	111	77	25,901	35,698	26,476	7,232	12,077	8,293	0.28	0.34	0.31
2010	71	150	101	30,579	36,605	27,992	9,397	13,422	8,029	0.31	0.37	0.29
2011	253	169	91	24,914	33,055	25,892	6,221	12,175	8,761	0.25	0.37	0.34
2012	490	186	83	24,115	35,414	29,696	5,052	13,215	9,164	0.21	0.37	0.31
2013	489	241	118	24,118	36,121	27,874	5,572	12,384	8,703	0.23	0.34	0.31
2014	459	282	151	25,205	34,929	30,693	7,110	10,961	10,185	0.28	0.31	0.33

Note: Hospital inpatient prices were inflation adjusted to 2014 dollars using the BLS All Items Consumer Price Index; and age-gender adjusted.

knee replacement procedures within each HRRs in Colorado using Equation 5. Most of the variation in hospital inpatient spending for either total hip or knee replacement procedure on the privately insured by HMO plans within each HRR in Colorado was largely due to quantity differences across providers, one exception was Pueblo. More than 70 percent of the variation in hospital inpatient spending for either total hip or total knee replacement procedures were due to price differences across providers in Pueblo. Next, the contribution of price to the variation in hospital inpatient spending on the privately insured by PPO plans within each HRR in Colorado for either clinical cohort ranged from 16 percent to 94 percent. Although the contribution of quantity differences across providers to hospital inpatient spending for either clinical cohort were higher for most of the HRRs in Colorado among the PPO plan type, Colorado Springs and Grand Junction were two HRRs in Colorado that had high price effect in the variation of hospital inpatient spending for both procedures. Indeed, price differences across providers within Grand Junction accounted for 94 percent of variation in hospital inpatient spending for total hip replacement procedures reimbursed by PPO plans and 83 percent of variation in hospital inpatient spending for total knee replacement procedures reimbursed by PPO plans. Lastly, for the POS plan type, the study found that variation in hospital inpatient spending for either clinical cohort was driven almost exclusively by differences in the price of care delivered across providers in each HRR in Colorado, one exception was Boulder. Boulder was the only HRR where the variation in hospital inpatient spending for either total knee or total hip replacement procedures reimbursed by POS plans were attributable to changes in quantities across providers. Consequently, the study also evaluated the contribution of price and quantity to hospital

Table 4: Price and Quantity Decomposition of Hospital Inpatient Spending for HRRs in Colorado, by Plan Type

A. Total Hip Replacement

	Share Price			Share Quantity		
	HMO	PPO	POS	HMO	PPO	POS
Boulder	0.351	0.535	0.435	0.649	0.465	0.565
Colorado Springs	0.440	0.690	0.715	0.560	0.310	0.285
Denver	0.253	0.186	0.796	0.747	0.814	0.204
Fort Collins	*	0.479	*	*	0.521	*
Grand Junction	*	0.941	0.784	*	0.059	0.216
Greeley	*	0.363	0.909	*	0.637	0.091
Pueblo	0.720	0.160	*	0.280	0.840	*
Colorado	*0.286*	*0.359*	*0.747*	*0.714*	*0.641*	*0.253*

B. Total Knee Replacement

	Share Price			Share Quantity		
	HMO	PPO	POS	HMO	PPO	POS
Boulder	0.487	0.451	0.440	0.513	0.549	0.560
Colorado Springs	0.455	0.574	0.895	0.545	0.426	0.105
Denver	0.300	0.279	0.744	0.700	0.721	0.256
Fort Collins	*	0.154	*	*	0.846	*
Grand Junction	*	0.831	0.812	*	0.169	0.188
Greeley	0.018	0.279	0.877	0.982	0.721	0.123
Pueblo	0.775	0.144	0.963	0.225	0.856	0.037
Colorado	*0.343*	*0.351*	*0.735*	*0.657*	*0.649*	*0.265*

(*) = Number of procedures less than 15; excluded from the analysis.

Note: The data was pooled, and prices were averaged from 2009 to 2014 using inflation adjusted prices in 2014; age and gender adjusted allowed amounts.

inpatient spending across HRRs in Colorado for either total hip or total knee replacement procedures by different plan types. Accordingly, the hospital inpatient price differences across HRRs in Colorado accounted for 29 percent and 36 percent of the variation in hospital inpatient spending for total hip replacement procedures whereas 71 percent and 64 percent of variation was attributable to quantity differences across HRRs in Colorado for HMO and PPO plan types, respectively. Similarly, for total knee replacement procedures, hospital inpatient price differences across HRRs in Colorado accounted for 34 percent and 35 percent of the variation in hospital inpatient spending for total hip replacement procedures whereas 66 percent and 65 percent of variation was attributable to quantity differences across HRRs in Colorado for HMO and PPO plan types, respectively. In contrast, for POS plan type, the hospital inpatient price differences across HRRs in Colorado accounted for around 74 percent of the variation in hospital inpatient spending for either clinical cohort whereas around 26 percent of variation was attributable to quantity differences across HRRs in Colorado. These results suggested that variation in hospital inpatient spending on privately insured is a function of variation in both the market determined prices that providers and insurers negotiate and quantity of care delivered within and across HRRs, yet the relative impact of these two effects can be different between different private plan types.

DISCUSSION

The demand for total hip or knee replacement procedures has been increasing significantly in the younger population and given that current variation studies on hip and knee replacement procedures use Medicare data (Cram et al., 2015; Li et al., 2013; Miller et al., 2011; Thakore et al., 2015), this study extends the literature on variation analyses by focusing on a service line that has been understudied in the younger, privately insured population. Specially,

for each of the clinical cohorts of hip or knee replacement procedures in which the cohorts included privately insured patients above 45 and below 65 years old, this study looks at how the variation in hospital inpatient prices as well as variation in hospital inpatient admissions (i.e. quantity) contribute to variation in hospital inpatient spending in hip or knee replacements across and within hospital markets. In addition, this paper evaluates whether and to what extent the hospital inpatient spending, prices and quantities for the same service line change between different private insurance product types, within and across geographic markets, and over time.

With this intention, first, we analyzed the growth of inpatient hospital spending. Specifically, for each of the clinical cohorts of total hip or total knee replacement procedures in which the cohorts included privately insured patients above 45 and below 65 years old, this study looked at the growth in hospital inpatient spending per beneficiary in each clinical cohort by different private insurance plan types in the period from 2009 to 2014. Of note, there was substantial variation in the growth rates for hospital inpatient spending for both clinical cohorts across different private insurance plan types in Colorado. Hospital inpatient spending per HMO beneficiary increased 43 percent and 32 percent for total hip and total knee replacement procedures, respectively. Also, hospital inpatient spending per POS beneficiary increased 21 percent and 14 percent for total hip and total knee replacement procedures, respectively. Whereas hospital inpatient spending per PPO beneficiary increased 3 percent and 6 percent for total hip and total knee replacement procedures, respectively. This variation in inpatient hospital spending for total hip or total knee replacement procedures across different private insurance plan types could suggest that PPO plans are more successful than HMO and POS plans at constraining hospital inpatient spending growth for total hip or total knee replacement procedures in Colorado between 2009 and 2014, though the annualized growth rate of enrollment

were higher for PPO plan type compared to HMO and POS plan types for above 45 below 65 age group cohort during the study period[22]. Cooper et. al (2019) analyzed the growth in health spending on people with employer-sponsored private health insurance between 2007 and 2014 and documented the variation in growth rates across years in US. Though the results are not specific for a service line and did not compare growth rates by different private insurance plan types, Cooper et. al (2019) found substantial variation in the growth rates for private health spending across years in US. This study adds to the recent literature by looking at the picture from another segment of the market in which total hip or knee replacement procedure claims from health plans for individual, small group, and large group fully-insured lives were used; and it shows that there was a variation in the growth rates for private health spending across years by different private insurance plan types in Colorado.

After observing the growth of hospital inpatient spending over time by different private insurance plan types for the clinical cohort of interest, we pooled data from 2009 to 2014 to evaluate the average hospital inpatient spending for each clinical cohort of total hip and total knee replacement procedures across HRRs in Colorado by different private insurance plan types. The hospital inpatient spending index measure we calculated for each HRR shows the variation in average hospital inpatient spending in each HRR compared to state averages for the privately insured population who underwent total hip or total knee replacement procedures. HRRs in Colorado showed similar HRR-level trends in hospital inpatient spending for both clinical cohorts among HMO and POS plans, but not for PPO plan types. For instance, for both clinical cohorts of total hip and total knee replacement procedures, Pueblo was the HRR with highest average hospital inpatient spending for the HMO plan type; and Grand Junction was the HRR

[22] This may be likely because the CO APCD continued to acquire data from payers in each year.

with highest average hospital inpatient spending for POS plan type. On the other hand, HRR-level regional variation showed differences between different commercial plan types, especially regional variation trends were different between HMO plan type vs PPO (or POS) plan types for both clinical cohorts. Though not much is known about regional variation in spending between different private insurance plan types, there are few studies that used private insurance claims data and observed cross-sectional variation in health spending on people with employer-sponsored insurance (Chernew et. al, 2010; Cooper et. al, 2019; McKellar et. al; 2014).

Later, given the importance of prices for the privately insured (Cooper et. al; 2019; Government Accountability Office, 2014; Selden et. al, 2015; White et. al, 2013; White et. al, 2019), we described the variation in hospital prices for both clinical cohorts of total hip and total knee replacement procedures across and within HRRs in Colorado by different private insurance plan types. To the best of our knowledge, no papers have assessed variation in hospital inpatient prices or spending between different private insurance plan types for total hip or total knee replacement procedures, and thus this is a contribution of this study. It is therefore also assuring that the price variation we found between plan types are broadly in-line with what we would expect: On average, hospitals were paid $23,972 by HMO plan types, $32,283 by PPO plan types and $29,432 by POS plan types for total hip replacement procedures in Colorado between 2009 and 2014. Similarly, on average, hospitals were paid $24,823 by HMO plan types, $35,278 by PPO plan types and $28,358 by POS plan types for total knee replacement procedures in Colorado between 2009 and 2014. According to Colorado Hospital Price Report which is a joint project of the Colorado Hospital Association and the Colorado Department of Regulatory Agencies, Division of Insurance stated that average reimbursement rate for major joint replacement or reattachment of lower extremity without major complications (DRG 470) was

$26,377 in 2014. This report combined the reimbursement amounts by different private insurance plan types and used DRG-level pricing.

Further, it is important to note that Medicare reimbursed these same hospitals in Colorado $11,697 on average for DRG 470 in 2014[23]. The significant difference between private and public (Medicare) payment rates is also broadly consistent with the recent literature that focuses on difference between private and public (Medicare and Medicaid) payment rates for inpatient hospital stays (Selden et al ,2015; Selden et. al, 2018; Sen et. al, 2019; White and Whaley, 2019). Variation in hospital inpatient prices for total hip replacement procedures across 7 HRRs in Colorado was the highest among PPO plan type (CoV=0.30) compared to HMO (CoV=0.20) and POS (CoV=0.29) plan types. Also, for total hip replacement procedures, Pueblo was the HRR with highest variation in inpatient prices across hospitals paid by HMO plans (CoV=0.19); and Grand Junction was the HRR with highest variation in inpatient prices across hospitals paid by both PPO (CoV=0.41) and POS (CoV=0.29) plans between 2009 and 2014. Next, for total knee replacement procedures, variation in hospital inpatient prices across 7 HRRs in Colorado was the highest among PPO plan type (CoV=0.35) compared to HMO (CoV=0.26) and POS (CoV=0.32) plan types. In addition, for total knee replacement procedures, Pueblo was the HRR with highest variation in inpatient prices across hospitals paid by both HMO (CoV=0.29) and POS (CoV=0.45) plan types; and Denver was the HRR with highest variation in inpatient prices across hospitals paid by PPO plan type (CoV=0.33) between 2009 and 2014. The only recent study that we can compare our results for variation in hospital prices for total hip or total knee replacement procedures in Colorado was conducted by Cooper et. al (2019). Cooper et. al (2019)

[23] This number was derived using Medicare Provider Charge Inpatient data for 2014: https://data.cms.gov/Medicare-Inpatient/Inpatient-Prospective-Payment-System-IPPS-Provider/9zmi-76w9

used data from 2008 to 2011 and found that coefficient of variation in hospital prices for Denver was 0.256 for hip replacement procedures and 0.382 for knee replacement procedures. Though Cooper et. al (2019) did not identify variation in price for different private insurance plan types, our results are broadly consistent with what they found. We also observed that variation in hospital prices for both clinical cohorts decreased for PPO plan types and increased for HMO and POS plan types from 2012 to 2014 in Colorado (Table 3). We found annualized growth in total hospital inpatient spending for both clinical cohorts were relatively low for PPO plan types during the study period of 2009 to 2014. The downward trend in variation in hospital prices for PPO plan (aside from structural changes such as higher deductibles) may seem like encouraging evidence for the slowdown in spending growth for PPO plan type compared to HMO and POS plan types. On the other hand, it is also important to recognize that the factors associated with high (low) levels of spending may not be the same factors that are associated with a high (low) rate of spending growth (Chernew et al, 2010). Therefore, this may be a topic for further research.

Lastly, several recent studies analyzed the contribution of hospital inpatient prices and quantity to the variation in medical spending (i.e. Philipson et. al, 2010; McKellar et. al, 2012; White, 2012; Dartmouth Atlas, 2014; Franzini et. al, 2014; Franzini et. al, 2015; Cooper et. al, 2019) and showed that the drivers of high spending differ across the Medicare and privately insured populations. However, these studies did not address different service lines (except Cooper et. al, 2019); or, whether or how the drivers of spending for specific procedures also differ within different plan types of privately insured patients. We found that variation in hospital inpatient spending on privately insured is a function of variation in both the market determined prices that providers and insurers negotiate and quantity of care delivered within and across

HRRs, yet the relative impact of price and quantity effects can be different between different private insurance plan types. Overall, both clinical cohorts have similar levels of price and quantity variation across HRRs. We showed that for HMO and PPO spending, quantity differences across HRRs accounted for between 64 percent to 71 percent for both clinical cohorts; and for POS spending, quantity differences across HRRs accounted for around 25 percent for both clinical cohorts. Therefore, for HMO and PPO spending, price differences across HRRs accounted for between 29 percent to 36 percent for both clinical cohorts; and for POS spending, price differences across HRRs accounted for around 75 percent for both clinical cohorts. Our results are broadly consistent with what Cooper et. al (2019) found for price and quantity decomposition of spending for the top 25 DRGs in their data. For DRG 470, Cooper et. al (2019) found that 38 percent of variation in spending was due to differences in prices across HRRs in US; and around 65 percent of variation in spending was due to differences in quantities across HRRs in US. Though Cooper et. al (2019) conducted the decomposition analysis at the national level and combined all private insurance plan types, state level results we found for Colorado HMO and PPO plans seem to be in line with them. When looking at the results within each HRRs (across providers) in Colorado, we observed that Pueblo (for HMO plan type) and Grand Junction (for PPO plan type) were two HRRs in which the variation in private spending across providers for both clinical cohorts was driven largely by differences in hospitals' prices in contrary to other HRRs where variation in spending for both clinical cohorts on the HMO and PPO plan type population is driven significantly by differences in the quantity of care across providers. In fact, Pueblo and Grand junction were the HRRs with significant price variation compared to other HRRs in Colorado for both HMO and POS plan types from 2009 to 2014, therefore, perhaps unsurprisingly, this suggests the significant price contribution to hospital

inpatient spending within these HRRs. In addition, it is important to note that recent studies that evaluated the contribution of price and quantity to spending found that private insurance inpatient spending variation is almost exclusively due to price variation. For instance, using Truven MarketScan® data from 2007 to 2009, McKellar et. al (2012) found that 82 percent of variation in inpatient spending was due to differences in prices. Next, using Blue Cross Blue Shield of Texas claims data for Texas in 2011, Franzini at. al (2014) found that 85.9 percent of variation in inpatient spending was attributable to differences in adjusted price. On the other hand, recent existing study by Cooper et. al (2019) most closely related to our study also showed that, for total hip and total knee replacement procedures, inpatient spending variation was driven mostly by differences in quantities at the national level. Seeing that, these results suggest that findings for overall service category spending (i.e. inpatient spending) cannot be generalized to different service lines within a specific service category (i.e. total hip or knee replacement procedures).

Interpretation of the study results must be informed by the limitations of the study. Firstly, the study sample size was low. From 2009 to 2014, there were 2,339 private insurance admissions for total hip replacement procedures, and 3,601 private insurance admissions for total knee replacement procedures in COAPCD data. Based on discussions with COAPCD data administrator, we were informed that self-insured claims are not included in the COAPCD data; and our informed but not well-documented understanding is that data from 2009 to 2011 were less reliable than data from 2012 onward. Self-insured claims represent a large proportion of processed claims in Colorado (the percentage of self-insured was 40% in 2014[24]) and the absence of such data in the COAPCD is an obstacle to fully understand Colorado's healthcare landscape.

[24] This information was taken from Health Insurance Cost Report by Colorado Department of Regulatory Services

On the other hand, using data from Colorado Department of Regulatory Agencies[25], We found that there were approximately 17,000 admissions for total hip or knee replacement procedures (DRG 470) from 2009 to 2014. Almost half of these admissions were reimbursed by Medicare Advantage, so that there were approximately 8,500 admissions by other private insurance plans. Since approximately 40 percent of private insurance admissions were from self-insured patients, it turns out that the estimated number of admissions for total hip or knee replacement procedures in Colorado from 2009 to 2014 is approximately 5,000 which is consistent with the sample size of our study (N=5,940 admissions). Secondly, administrative claims data are not collected for research purposes and measurement error may have been introduced by coding that was in error or driven by reimbursement needs more than research needs. It is also important to note that this study was conducted using private insurance payer claims of patients with total hip or total knee replacement procedures in Colorado. Though the study focused on a specific clinical cohort to decrease the confounding effect of regional differences on health status, these results may not be fully generalized to Medicare, Medicaid, and uninsured populations; and it may not be fully generalized to other states or other clinical conditions.

[25] The data can be accessed from: http://doraapps.state.co.us/insurance/drg/Default.aspx

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APPENDIX A

SUPPLEMENTARY MATERIAL FOR FIRST ARTICLE

Table A.1: Annual Commercial Payer Beneficiaries aged between 45 and 64 in COAPCD data, by Plan Type, 2009-2014

	HMO	PPO	POS
2009	161,919	107,970	55,615
2010	162,731	116,785	61,499
2011	153,144	117,603	55,504
2012	187,796	127,948	52,780
2013	187,093	155,754	66,304
2014	228,072	199,587	64,476
Total	*565,725*	*393,219*	*173,871*
Annualized Growth Rate (%)	*7.09*	*13.08*	*3.00*

Table A.2: Calculation of Hospital Inpatient Spending Index from COAPCD Data, by HRR, by Plan

A. Total Hip Replacement

	Distinct Beneficiaries			Total Hospital Inpatient Spending ($)			Hospital Inpatient Spending per Beneficiary ($)			Hospital Inpatient Spending Index		
	HMO	PPO	POS	HMO	PPO	POS	HMO	PPO	POS	HMO	PPO	POS
Boulder	40,783	37,355	17,284	952,795	2,413,683	1,540,539	23.36	64.61	89.13	0.44	1.12	1.42
Colorado Springs	64,017	55,458	19,237	3,288,567	1,536,270	893,925	51.37	27.70	46.47	0.96	0.48	0.74
Denver	423,399	213,628	108,438	24,510,750	13,347,585	6,857,484	57.89	62.48	63.24	1.08	1.08	1.00
Fort Collins	5,168	17,675	6,633	28,059	1,011,183	35,446	5.43	57.21	5.34	N/A	0.99	N/A
Grand Junction	1,313	27,098	7,980	0	2,238,913	766,951	0.00	82.62	96.11	N/A	1.43	1.53
Greeley	14,341	30,623	10,521	318,001	1,175,717	641,941	22.17	38.39	61.02	0.41	0.67	0.97
Pueblo	16,704	11,382	3,778	1,226,396	939,373	212,231	73.42	82.53	56.18	1.37	1.43	N/A
Colorado	565,725	393,219	173,871	30,324,567	22,662,725	10,948,517	53.60	57.63	62.97	1.00	1.00	1.00

B. Total Knee Replacement

	Distinct Beneficiaries			Total Hospital Inpatient Spending ($)			Hospital Inpatient Spending per Beneficiary ($)			Hospital Inpatient Spending Index		
	HMO	PPO	POS	HMO	PPO	POS	HMO	PPO	POS	HMO	PPO	POS
Boulder	40,783	37,355	17,284	945,932	3,455,791	2,133,258	23.19	92.51	123.42	0.29	0.91	1.22
Colorado Springs	64,017	55,458	19,237	7,117,912	3,743,547	1,208,429	111.19	67.50	62.82	1.38	0.66	0.62
Denver	423,399	213,628	108,438	33,074,589	21,897,188	11,826,790	78.12	102.50	109.06	0.97	1.00	1.08
Fort Collins	5,168	17,675	6,633	186,718	3,199,231	208,006	36.13	181.00	31.36	N/A	1.77	N/A
Grand Junction	1,313	27,098	7,980	267,113	2,801,441	1,139,109	203.44	103.38	142.75	N/A	1.01	1.41
Greeley	14,341	30,623	10,521	947,348	3,572,671	677,337	66.06	116.67	64.38	0.82	1.14	0.64
Pueblo	16,704	11,382	3,778	3,160,342	1,511,821	417,600	189.20	132.83	110.53	2.34	1.30	1.09
Colorado	565,725	393,219	173,871	45,699,953	40,181,690	17,610,528	80.78	102.19	101.29	1.00	1.00	1.00

Notes:

All data from 2009 to 2015 was pooled.

Hospital inpatient spending values have been inflation adjusted to 2014 dollars using the BLS All Items Consumer Price Index; and age-gender adjusted.

Gray shaded area shows the HRR-payer type pair that had less than 15 procedures during 2009-2014 study period (N/A for spending index).

SECOND JOURNAL ARTICLE

Title of Journal Article:

The Impact of Hospital Market Power on Inpatient Hospital Prices of Total Hip or Total Knee Replacement Procedures in Colorado

BACKGROUND

The market concentration of hospitals and insurers has been a matter of concern for several decades. Recently, Gaynor et al. (2015) reviewed studies of the competitive landscape of hospitals, health insurers, and physician services and found that hospital and health insurer markets have become more concentrated since the 1990s. Although provider concentration could produce beneficial efficiencies, the evidence does not point in that direction. For example, reviews of studies of hospital markets (Gaynor et al., 2012; Gaynor et al., 2015) found that concentrated markets are associated with higher hospital prices, with price increases often exceeding 20 percent when mergers occur in such markets. However, most of the competition literature relies on estimates of actual prices (usually based on charges) rather than actual data on negotiated prices. Even more, researchers usually use the Herfindahl-Hirschman index (HHI) as the measure of market power, which as Gaynor and Town (2011) explain, is flawed insofar that the relationship between HHI and prices are hypothesized with Cournot behavior. Models based on Cournot behavior assume quantity setting with homogeneous products; and such models are inconsistent with the hospital market context. Hospitals sell differentiated products, and the HHI measure does not take this differentiation into account in its formulation (Gaynor and Town, 2011).

Hospital charges are list prices and it is not difficult to obtain the charges data. Bargaining between hospitals and insurers determine actual transaction prices and obtaining these prices were not easy in the past. Therefore, most market power studies (i.e. Burgess et al., 2005; Dafny, 2009; Krishnan, 2001; Melnick and Keeler, 2007; Sacher and Vita, 2001; Spang et al., 2001) used a measure of average payment per some unit of quantity which may suffer from some problems. As also stated by Moriya et al. (2010), "first, they do not necessarily capture discounts from charges obtained by insurers. Second, since they are averages, they obscure differences in pricing across services or patients. Last, quantity is difficult to measure in health care. Some measures are per day, some per admission and some per patient or beneficiary. In all these cases the denominator measures only some aspect of quantity. Consequently, prices are potentially measured with considerable error" (pg. 462).

Alternatives to the HHI have been proposed in the health economics literature: Town and Vistnes (2001), Gaynor and Vogt (2003), and Capps, Dranove, and Satterthwaite (2003) introduced structural approaches to measuring market power that circumvent the assumption of Cournot behavior. For example, Capps et al. (2003) proposed a willingness to pay (WTP) framework, which assumes that while negotiating with hospitals, insurers consider how much value each hospital brings to consumers when it is added to the network. WTP is derived from a model of patient choice of provider that considers the locations of all providers and patients, service offerings, and other provider and patient characteristics (Capps et al., 2003). The idea behind the WTP model is that prices resulting from bargaining should reflect the hospital's added value to the insurer network (Capps et al., 2003). Therefore, a higher WTP translates into a higher profit margin (Capps et al., 2003).

Another market power measure is the Logit Competition Index (LOCI) developed by Antwi et al. (2013). LOCI is grounded in economic theory like a fully specified structural model. The LOCI measure assumes a differentiated competition model between hospitals under logit demand with insurers as price takers, which leads to an inverse relationship between the price-cost margin and LOCI (Antwi et al., 2013). Also, the LOCI measure does not require market definition (Akosa Antwi et. al, 2013), which can be a major advantage given the difficulties with determining the relevant geographical region and the fact that the geographical market definition is often disputed in merger assessment cases (Berden et al., 2019).

This study aims to add to hospital competition literature by estimating the impact of market power on hospital prices (i) using actual procedure prices instead of charged-based price estimates, (ii) using market power indices developed by semi-structural approaches (i.e. WTP, and LOCI) and (iii) focusing on a set of commonly performed elective orthopedic procedures (since some hospitals may specialize in performing them may have greater bargaining power if patients place greater value on the successful treatment) of total hip or knee replacements for the PPO insured population in Colorado.

METHODS

Study Design and Data

This is a retrospective cohort study that used private payer claims to analyze the impact of hospital market power on prices of total hip or knee replacement procedures. Our study design requires two steps: first, we must calculate our two competition indices (WTP and LOCI) using structural models of patients' demand for hospitals and then, second, we

regress actual hospital prices on these competition indices, while controlling for hospital and patient characteristics.

The main data we used was the 2009-2014 Colorado All Payer Claims Database (CO APCD). The CO APCD is the Colorado's most comprehensive source of health care insurance claims information representing 4.3 million unique covered lives in the state across 33 commercial health insurance plans, Medicare Advantage, and Health First Colorado (Colorado's Medicaid program), as of May 2018[26]. The CO APCD was created by legislation passed in 2010[27]. The Center for Improving Value in Health Care (CIVHC) was named administrator of the CO APCD by the Executive Director of the CO Department of Health Care Policy and Financing (HCPF) the same year and the database was launched in 2012. The CO APCD data includes medical claims and beneficiary enrollment files; and it is de-identified at the beneficiary level. The CO APCD data do not include beneficiary identifiers such as social security numbers, names, dates of birth, or addresses. The study was exempted by the University of Texas Health Science Center at Houston Institutional Review Board since the CO APCD data is de-identified.

Among other variables, the CO APCD data include a unique hospital identifier, a unique patient identifier, the date services were provided, hospitals' charges, hospitals' negotiated transaction prices, and payments to hospitals made by patients in the form of co-insurance payments, co-payments, and the payments made before deductibles were met. Allowed amounts paid to hospitals for all health care encounters were recorded in the data.

[26] This information was taken from https://www.apcdcouncil.org/state/colorado
[27] This information was taken from https://www.civhc.org/get-data/co-apcd-overview/

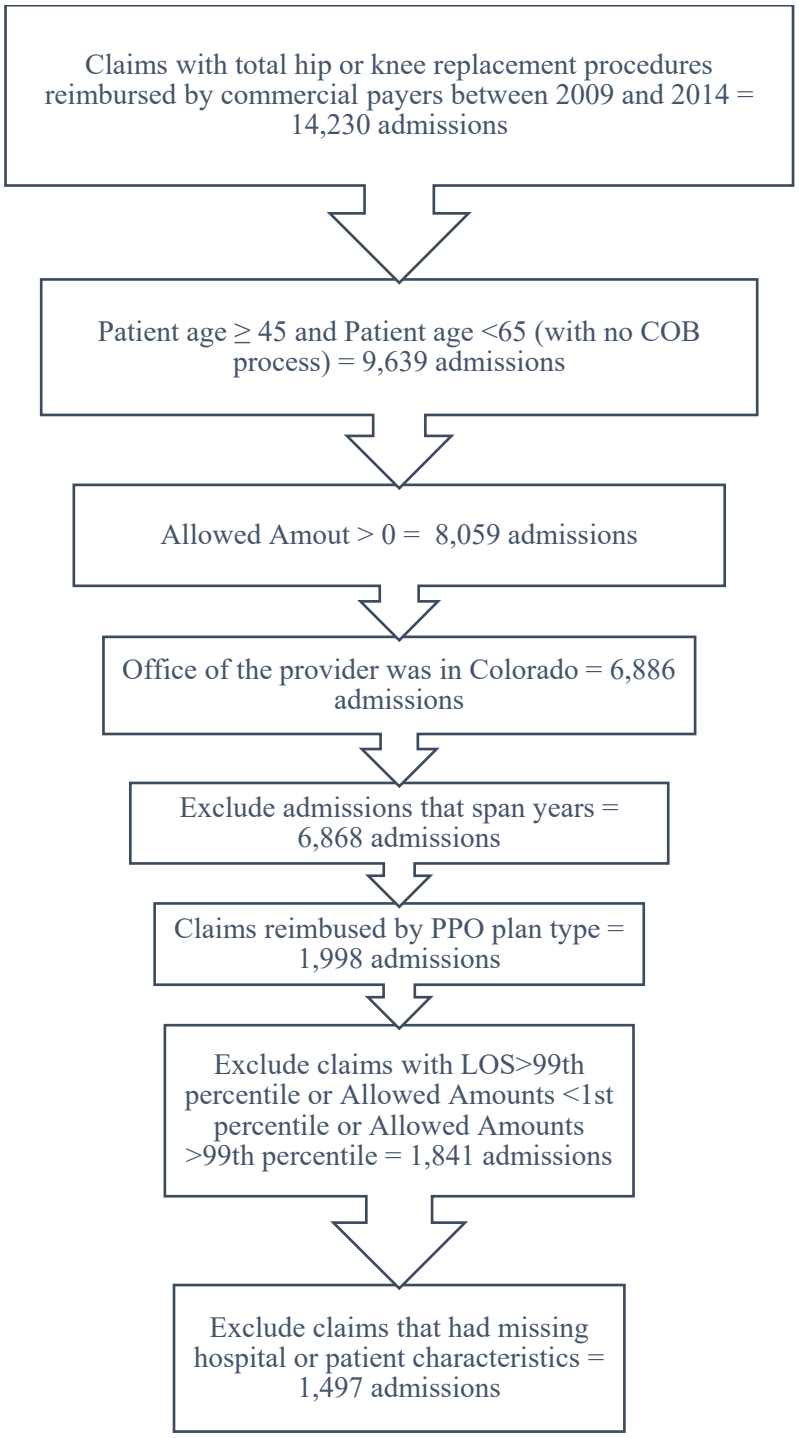
In addition to the CO APCD, this study used three other datasets. First, we used hospital cost reports from the Centers of Medicare and Medicaid Services (CMS), which contain provider information such as facility characteristics. We also used Hospital Compare data from CMS to get the hip/knee replacement complication rates for each hospital. Finally, we downloaded the 2010-2014 American Community Survey (ACS) data to obtain the median household income data, matched to patients by zip code

Study Population

Figure 1 describes how the study cohort was derived. First, we extracted hospital inpatient admissions of total hip or total knee replacement procedures (ICD-9 81.51 and ICD-9 81.54, respectively) performed in Colorado and reimbursed by private health insurance payers from 2009 to 2014. We included all patients who were 45 years and older, and younger than 65 years old. We included only claims where commercial plans had the primary payment responsibility, and excluded claims with Coordination of Benefits (COB) process. We also excluded claims with admissions that span years or claims from providers which operated outside the state or claims with zero allowed amounts. Eventually, there were 1,998 claims reimbursed by PPO plan type.

Claims reimbursed by Health Maintenance Organization (HMO) or Point of Service (POS) plans were excluded. It is not recommended to include HMO or POS beneficiaries in the hospital market power studies with choice model since HMOs usually face a narrower choice model, and HMO or POS plans may provide incentives to physicians to steer patients to low-cost hospitals within the choice set (Capps et. al, 2003).

Figure 1: Steps of the derivation of study cohort



We constructed separate clinical cohorts for total hip or knee replacement procedures for PPO plan types. There were 761 admissions for total hip replacement procedures and 1,237 admissions for total knee replacement procedures. In order to minimize the impact of unusually complicated cases or billing errors, we further excluded claims with length of stay above the 99th percentile, as well as claims with negotiated prices below the 1st percentile or above the 99th percentile (157 claims were excluded).

After applying above inclusion and exclusion criteria, the dataset contained 1,841 admissions with either total hip replacement (N= 702 admissions) or total knee replacement (N= 1,139 admissions) procedures reimbursed by PPO plans from 2009 to 2014 in Colorado. We had to exclude additional claims that had missing hospital or patient characteristics information; the final data contained 1,497 admissions (568 admissions with total hip replacement procedures and 929 admissions with total knee replacement procedures) from 46 hospitals.

Table 1 lists the hospitals in Colorado and some of their characteristics. The average number of PPO patients visiting a hospital for total hip or total knee replacement procedures was 33 (with standard deviation of 39 patients), with the minimum of 1 patient and the maximum of 194 patients. There were 46 hospitals that performed total hip or total knee replacement procedures to PPO patient population during the study period; 52% of them (n=24) were teaching hospitals and 76% of them were not-for-profit hospitals (n=35). The average number of beds in a hospital was 160 (with standard deviation of 132). The average

score of complication rate for hip/knee replacement patients is 2.6 (with standard deviation of 0.47), with the minimum of 1.9 and the maximum of 3.9.

Like Ho (2006) and Ho and Lee (2013; 2017), we categorized beneficiaries into age and gender groups (i.e. 45-54 male/female and 55-64 male/female). We calculated the Grouped Charlson Comorbidity Index (GRPCI) using the Stata "Charlson" package, which calculates the Charlson index of comorbidity from data containing ICD-9-CM, ICD-10 or Enhanced ICD-9-CM comorbidity diagnoses codes. The Charlson score reflects the cumulative increase in likelihood of one-year mortality due to the severity of the effect of comorbidities such as heart disease, AIDS, or cancer. If the Charlson score is equal to zero, the GRPCI is assigned zero; if the Charlson score is equal to one, the GRPCI is assigned one; and lastly if the Charlson score is greater or equal to two, the GRPCI is assigned two. Patients characteristics also include distance between the patient and the provider which was calculated using the 'ZIPCITYDISTANCE' function tool in SAS®. This function returns distance in miles between two zip code locations.

Descriptive statistics for PPO patients with total hip or total knee replacement procedures in the CO APCD data are listed in Table 2. Taking the hip cohort first, Table 2 shows approximately 13% of the patient population were males aged 45-54, 12% were females aged 45-54, 33% were males aged 55-64, and 42% were females aged 55-64. Their median household income was approximately $65,000, and the majority (approximately 90%) of patients had a Charlson comorbidity index of zero. Lastly, the average distance traveled to admitted hospital was approximately 21 miles (with standard deviation of 27 miles). Within the cohort of total knee replacement procedures, approximately 9% of the

Table 1: Colorado hospitals that performed total hip or knee replacement procedures for PPO enrollees in COAPCD data between 2009 and 2014 (N=46)

HRR City	Hospital	Patients in Sample	Teaching Hospital	Control	Average Number of Beds	Score of complication rate for hip/knee replacement patients
Boulder	Avista Adventist Hospital	32	No	NP	114	2.8
Boulder	Boulder Community Health	82	No	NP	136	3
Boulder	Good Samaritan Medical Center	7	No	NP	214	2.9
Boulder	Longmont United Hospital	30	No	NP	125	2.2
Colorado Springs	Penrose-St. Francis Health Services	104	Yes	NP	399	2.4
Colorado Springs	Pikes Peak Regional Hospital	4	Yes	FP	15	2.3
Colorado Springs	St. Thomas More Hospital	12	No	NP	45	N/A
Colorado Springs	UCHealth Memorial Hospital	95	Yes	NP	506	1.9
Denver	Aspen Valley Hospital District	1	No	NP	25	2.3
Denver	Castle Rock Adventist Hospital	4	No	NP	50	3.4
Denver	Denver Health	1	Yes	NP	332	N/A
Denver	Littleton Adventist Hospital	25	No	NP	186	3.2
Denver	Lutheran Medical Center	44	No	NP	271	3.2
Denver	Medical Center of Aurora	23	Yes	FP	276	3.8
Denver	North Suburban Medical Center	6	Yes	FP	120	3.1
Denver	OrthoColorado Hospital	105	No	FP	48	2.3
Denver	Parker Adventist Hospital	10	No	NP	153	2.5
Denver	Platte Valley Medical Center	3	No	NP	89	2.5
Denver	Porter Adventist Hospital	194	Yes	NP	183	2.1

Denver	Presbyterian-St. Luke's Medical Center	41	No	FP	352	2.5
Denver	Rose Medical Center	99	Yes	FP	226	2.6
Denver	Saint Joseph Hospital	23	Yes	FP	344	2.6
Denver	Sky Ridge Medical Center	72	Yes	FP	227	2.5
Denver	St. Anthony Hospital	24	Yes	NP	172	2.4
Denver	St. Anthony North Health Campus	47	Yes	NP	93	2.9
Denver	St. Anthony Summit Medical Center	5	No	NP	34	2.9
Denver	Swedish Medical Center	27	Yes	FP	332	2.5
Denver	UCHealth University of Colorado Hospital	8	Yes	NP	505	2.8
Denver	Vail Valley Medical Center	18	No	NP	58	2.2
Denver	Yampa Valley Medical Center	25	Yes	NP	39	2.5
Fort Collins	UCHealth Poudre Valley Hospital	72	Yes	NP	197	2
Grand Junction	Community Hospital	11	No	NP	44	2.5
Grand Junction	Delta County Memorial Hospital	16	No	NP	49	2.4
Grand Junction	Family Health West Colorado Canyons Hospital	1	No	NP	16	N/A
Grand Junction	Gunnison Valley Hospital	3	No	NP	20	3.1
Grand Junction	Montrose Memorial Hospital	29	No	NP	52	2
Grand Junction	St. Mary's Medical Center	38	Yes	FP	277	1.9
Grand Junction	Valley View Hospital	29	No	NP	49	2.9
Greeley	East Morgan County Hospital	1	Yes	NP	25	N/A
Greeley	McKee Medical Center	14	Yes	NP	115	2.3
Greeley	North Colorado Medical Center	54	Yes	NP	267	3
Greeley	Sterling Regional MedCenter	1	Yes	NP	30	2.5
Greeley	UCHealth Medical Center of the Rockies	8	Yes	FP	147	2.1
Greeley	Wray Community District Hospital	5	No	NP	16	2.9
Pueblo	Parkview Medical Center	28	Yes	NP	265	3.9
Pueblo	St. Mary-Corwin Medical Center	16	Yes	NP	134	2.1

Table 2: Descriptive Statistics for Patient Variables, CO APCD, PPO enrollees, 2009-2014

A. Total Hip Replacement

Patient Characteristics	2009 (N=56)	2010 (N=76)	2011 (N=69)	2012 (N=93)	2013 (N=109)	2014 (N=165)	*Total (N=568)*
Age Gender Categories (%)							
45-54 Male	14.29	21.05	5.80	16.13	11.01	10.30	*12.68*
45-54 Female	7.14	14.47	15.94	10.75	12.84	12.12	*12.32*
55-64 Male	35.71	30.26	36.23	34.41	33.94	30.91	*33.10*
55-64 Female	42.86	34.21	42.03	38.71	42.20	46.67	*41.90*
Median Household Income ($)	62,693	63,445	69,330	68,239	62,440	65,221	*64,993*
Grouped Charlson Comorbidity Index (%)							
Score 0	87.50	86.54	86.96	89.25	88.07	92.73	*89.26*
Score 1	8.93	6.58	11.59	6.45	6.42	3.64	*6.51*
Score 2	3.57	6.58	1.45	4.30	5.50	3.64	*4.23*
Distance to Admitted Hospital (miles)							
Mean	30.18	19.88	17.71	22.76	18.60	20.70	*21.10*
Standard Deviation	38.92	27.58	22.37	27.36	23.08	26.17	*27.21*

B. Total Knee Replacement

Patient Characteristics	2009 (N=83)	2010 (N=121)	2011 (N=132)	2012 (N=149)	2013 (N=180)	2014 (N=264)	*Total (N=929)*

Age Gender Categories (%)							
45-54 Male	14.46	10.74	8.33	11.41	9.44	6.82	*9.47*
45-54 Female	14.46	12.40	16.67	13.42	19.44	15.15	*15.50*
55-64 Male	39.76	38.02	26.52	35.57	32.78	32.95	*33.69*
55-64 Female	31.33	38.84	48.48	39.60	38.33	45.08	*41.33*
Median Household Income ($)	57,215	60,815	60,982	60,815	63,038	64,643	*61,000*
Grouped Charlson Comorbidity Index (%)							
Score 0	87.95	85.12	82.58	87.25	88.33	89.02	87.08
Score 1	4.82	9.92	12.88	8.05	7.78	5.3	7.86
Score 2	7.23	4.96	4.55	4.7	3.89	5.68	5.06
Distance to Admitted Hospital (miles)							
Mean	16.02	23.90	13.13	20.24	20.95	22.61	*20.14*
Standard Deviation	23.43	35.65	20.15	29.88	29.34	31.90	*29.65*

patient population were males aged 45-54, 16% were females aged 45-54, 34% were males aged 55-64, and 41% were females aged 55-64. Their median household income was $61,000, and the majority (approximately 87%) of patients had a Charlson comorbidity index of zero. Lastly, the average distance traveled was approximately 20 miles (with standard deviation of 30 miles).

Geographic Unit & Patient Choice Sets

The market definition we used for this study was the Hospital Referral Region (HRR), which represents regional health care markets and was created by researchers at the Dartmouth Institute for Health Care. Dartmouth defines these geographic regions by determining where most patients were referred for major cardiovascular surgical procedures and for neurosurgery. HRRs are widely used for health care policy and research because they correspond to local travel patterns which often cross county lines. There are also recent studies of hip or knee replacement surgery that used HRR as market definition (Cooper et. al (2019); Cram et. al (2012); Hussey et. al (2015); Ward and Dasgupta (2020); Weeks et. al (2017); Wynn-Jones et. al (2019)). There are 7 HRRs in Colorado: Boulder, Colorado Springs, Denver, Fort Collins, Grand Junction, Greeley, and Pueblo.

This study makes some assumptions to specify the choice set of each patient. Following Capps et. al (2003) and Ho and Lee (2017), we assumed that the choice set of each beneficiary includes all the hospitals in his/her HRR and the nearby HRR(s) within 73.5 miles (90^{th} percentile of the distance between the patient and the admitted hospital) away from the centroid of the HRR the enrollee resides. Table 3 shows the HRRs included in the

Table 3: The choice set of the total hip or total knee replacement procedure patient population in each HRR in Colorado.

Member HRR City		Provider HRR City							
		Boulder	Colorado Springs	Denver	Fort Collins	Grand Junction	Greeley	Pueblo	Total
Boulder	Number of Patients	115	0	18	3	0	1	0	137
	Percent of Patients (%)	83.94	0	13.14	2.19	0	0.73	0	100
	Distance between HRRs (miles)	0	97	28	46	255	54	141	-
Colorado Springs	Number of Patients	3	140	85	3	5	0	48	284
	Percent of Patients (%)	1.06	49.3	29.93	1.06	1.76	0	16.9	100
	Distance between HRRs	97	0	71	133	287	132	45	-
Denver	Number of Patients	65	2	692	1	8	4	2	774
	Percent of Patients (%)	8.4	0.26	89.41	0.13	1.03	0.52	0.26	100
	Distance between HRRs	28	69	0	66	243	57	114	-

Fort Collins	Number of Patients	3	0	6	31	0	2	0	42
	Percent of Patients (%)	7.14	0	14.29	73.81	0	4.76	0	100
	Distance between HRRs	46	133	66	0	303	31	177	-
Grand Junction	Number of Patients	2	0	29	0	127	0	0	158
	Percent of Patients (%)	1.27	0	18.35	0	80.38	0	0	100
	Distance between HRRs	255	287	243	303	0	302	285	-
Greeley	Number of Patients	4	0	10	37	0	76	0	127
	Percent of Patients (%)	3.16	0	7.87	29.13	0	59.84	0	100
	Distance between HRRs	54	132	57	31	302	0	168	-
Pueblo	Number of Patients	2	10	10	0	0	0	30	60
	Percent of Patients (%)	3.33	30.00	16.67	0	0	0	50.00	100
	Distance between HRRs	141	45	114	177	285	168	0	-

choice set of the patients residing in each HRR in Colorado. Gray shaded boxes in Table 3 indicates the HRRs in the choice set for beneficiaries living in a specific HRR. For instance, the choice set of beneficiaries living in Boulder, Fort Collins or Greeley included hospitals in Boulder, Denver, Fort Collins and Greeley. Similarly, the choice set of beneficiaries living in Colorado Springs included hospitals in Colorado Springs, Denver and Pueblo. Next, the choice set of beneficiaries living in Denver included hospitals in Boulder, Colorado Springs, Denver, Fort Collins and Greeley. The choice set of beneficiaries living in Grand Junction included hospitals only in Grand Junction. Lastly, the choice set of beneficiaries living in Pueblo included hospitals in Colorado Springs and Pueblo.

Data Analysis

As mentioned above, our analysis requires two steps: first, we must calculate our two market power measures (WTP and LOCI) using structural models of patients' demand for hospitals over their choice sets and then, second, we regress actual hospital prices on these market power measures, while controlling for hospital and patient characteristics.

i. Willingness-to-Pay (WTP)

To attain the first market power measure of interest, WTP, we defined beneficiary demand for hospitals based on Ho and Lee (2013). We estimated beneficiary demand for hospitals for total hip and knee replacement procedures using a discrete choice model that allows preferences to vary by patient and hospital characteristics. The demand model predicts hospitals' patient flows (Ho and Lee, 2013).

Suppose beneficiary *k* in age-gender category *κ(k)* who lives in market *m* becomes ill, then the utility from visiting hospital j for the admission of total hip or total knee replacement procedure, l, in a given year, *t,* is defined as:

$$u^{D}_{k,j,l,m,t} = \delta_{j,t} + z_{j,t}v_{k,l,t}\beta^{z} + d_{j,k,t}\beta^{d}_{m} + \varepsilon^{D}_{k,j,l,m,t}$$

(Equation 1)

where $\delta_{j,t}$ are hospital fixed effects, $z_{j,t}$ are observed hospital characteristics (teaching status and number of beds), $v_{k,l,t}$ are observed beneficiary characteristics (median income, Charlson Comorbidity Index, a dummy for total knee or total hip replacement procedure), $d_{j,k,t}$ is the distance between the hospital *j* and the patient *k*'s zip code and $\varepsilon^{D}_{k,j,l,m,t}$ is an idiosyncratic error term assumed to be i.i.d. Type 1 extreme value. As stated by Town and Vistnes (2001), this Type I extreme value assumption is "the standard logit assumption that imposes an independence of irrelevant alternatives substitution pattern on an individual patient's choice of hospital" (pg. 739). Since the study focuses only on patient cohorts with total hip or knee replacement procedures, l is the procedure code for total hip or total knee replacement procedures (ICD-9 81.51 and ICD-9 81.54, respectively). Because this is a fixed-effects logistic regression, independent variables that do not vary within group (i.e. beneficiary characteristics) will get dropped while estimating the equation. Therefore, we included interactions of observed beneficiary characteristics and hospital characteristics to explain variability in the utility from visiting a specific hospital within each beneficiary group. In other words, as stated by Capps et. al (2003), the interaction of patient and hospital characteristics permits flexible substitution patterns across hospitals.

Consequently, the utility that patients receive depends on the characteristics of the hospital, characteristics of the patients, the travel distance to the hospital, and idiosyncratic error term. The CO APCD data include only patients who are ill enough to go to a hospital for a diagnosis, therefore there is no outside option. Next, this study is interested in calculating a market power of each hospital for total hip or knee replacement procedures over all PPO plans. We estimated the multinomial logit model of hospital choice using maximum likelihood techniques. This model relied on the claims and enrollment files from the CO APCD, hospital characteristics data from CMS cost reports, and household income data from the ACS data.

Using the estimated parameters from the discrete choice model in equation (1), we predicted the probability that beneficiary k in age-gender category *κ(k)* who lives in HRR market *m* chooses hospital j for the admission of total hip or total knee replacement procedure, l, in year, *t,*:

$$s_{k,j,m,t|l}(H) = \frac{\exp\left(\hat{\delta}_{j,t} + z_{j,t} v_{k,l,t} \hat{\beta}^z + d_{j,k,t} \hat{\beta}^d_m\right)}{\sum_{h \in H_{k,m}} \exp\left(\hat{\delta}_{h,t} + z_h v_{k,l,t} \hat{\beta}^z + d_{h,k,t} \hat{\beta}^d_m\right)}$$

(Equation 2)

If $H_{k,m}$ is the set of hospitals in the choice set of beneficiary *k* in market *m*, then $s_{k,j,m|l}(H)$ is hospital *j*'s expected market share for beneficiary k in age-gender category *κ(k)* for the admission of total hip or total knee replacement procedure, *l,* in year, *t*.

Next, we followed Ho and Lee (2013), Ho and Lee (2017) and the option demand model proposed by Capps et al. (2003) to predict the WTP measure. Given the assumption on

the distribution of $\varepsilon^{D}_{k,j,l,m}$ and the estimated utility specification in equation (1), we computed the expected utility of the beneficiary *k* in age-gender category *κ(k)* from the choice set of hospitals. This is the utility *before* the patient needs the total hip or knee replacement procedure, that is, "when one knows his or her health state, but has not begun the process of choosing among available hospitals" (Capps et al., 2003; pg.741):

$$EU_{k,l,m,t}(H_{k,m}) = Emax_{h\in H_{k,m}}(\hat{u}^{D}_{k,h,l,m,t})$$

$$= ln(\sum_{h\in H_{k,m}} \exp\,(\hat{\delta}_{h,t} + z_{h,t}v_{k,l,t}\hat{\beta}^{z} + d_{h,k,t}\hat{\beta}^{d}_{m}))$$

(Equation 3)

Then, the change in expected utility from including hospital *j* in the choice set of hospitals $H_{k,m}$ or the contribution of hospital *j* to the expected utility of the beneficiary *k* in age-gender category *κ(k)* is given by:

$$\Delta EU_{k,j,l,m,t}\,(H_{k,m}) = EU_{k,l,m,t}(H_{k,m}) - EU_{k,l,m,t}(H_{k,m}\backslash j)$$

$$= ln\left\{\left[\sum_{g\in H_{k,m}\backslash j} \frac{\exp(\hat{\delta}_{g,t}+z_{g,t}v_{k,l,t}\hat{\beta}^{z}+d_{g,k,t}\hat{\beta}^{d}_{m})}{\sum_{h\in H_{k,m}}\exp\,(\hat{\delta}_{h}+z_{h}v_{k,l}\hat{\beta}^{z}+d_{h,k}\hat{\beta}^{d}_{m})}\right]^{-1}\right\}$$

$$= ln\left[\frac{1}{1-s_{k,j,m,t|l}(H_{k,m})}\right]$$

(Equation 4)

Next, the study computed the gain in expected benefit each beneficiary *k* in age-gender category *κ(k)* expects to get from visiting hospital *j* (prior having the total hip or total knee replacement procedure) in year, *t*, using the equation proposed by Ho and Lee (2013):

$$\Delta WTP_{k,j,l,m,t}(H_{k,m}) = \gamma^{a}_{\kappa(k),t} \sum_{l} \gamma_{\kappa(k),l,t} \Delta EU_{k,j,l,m,t}$$

(Equation 5)

where $\gamma^{a}_{\kappa(k),t}$ is the probability of admission to a hospital for each age-gender category *κ(k)*[28]in year, *t*, and $\gamma_{\kappa(k),l,t}$ is the probability of an individual in age–gender category *κ(k)* of being admitted for total hip or total knee replacement procedure in year, *t*. Taking the weighted average and summing over all beneficiaries in age-gender category *κ(k)* in market *m* gives the overall WTP for hospital *j* for the admission of total hip or total knee replacement procedure, *l*, in year, *t*; and it is also a measure of market power of hospital *j* in the option demand markets for total hip or total knee replacement procedures, in year, *t*:

$$\Delta WTP_{j,l,m,t} = \sum_{k \in \kappa(),m} \frac{N_{\kappa,m,t}}{N_{m,t}} \Delta WTP_{k,j,l,m,t}(H_{k,m})$$

(Equation 6)

where $N_{\kappa,m,t}$ is the commercially insured population of market *m* in age–gender category *κ(k)* in year *t,* and $N_{m,t}$ is the commercially insured population in market *m* in year *t*. It is important to note that the change in beneficiaries' WTP to include hospital *j* is measured in utils, not dollars. Nonetheless, this specification still helps us understand relative differences of hospitals market power.

[28] Following Ho and Lee (2013), this probability is calculated by dividing the total number of admissions from PPO enrolled insurers, by age-gender category, to the total privately insured PPO population in Colorado (using CO APCD data).

ii. Logit Competition Index (LOCI)

The other hospital market power measure of interest is the logit competition index (LOCI) developed by Akosa Antwi et al. (2013). We calculated LOCI using predicted market shares (Equation 2 that is calculated after estimating the multinomial logit hospital choice model) and observable patient types. LOCI is bounded between zero and one. Antwi et al. (2013) states that "a firm with a monopoly for all consumer types has a value of LOCI that approaches 0 in the limit; whereas a firm in a competitive market for all consumer types has a value of LOCI that approaches 1 in the limit" (pd. 3). The LOCI measure takes the following form:

$$\Lambda_{j,l,t} = \sum_{k \in \kappa(k)} \frac{N_{k,l,t} \bar{q}_{k,l,t} s_{k,j,l,t}}{\sum_{k \in \kappa(k)} N_{k,l,t} \bar{q}_{k,l,t} s_{k,j,l,t}} \left(1 - s_{k,j,l,t}\right)$$

(Equation 7)

where hospitals are indexed by *j*, year is indexed by *t* and beneficiary type is indexed by *k*. $N_{k,l,t}$ captures the number of patients with total hip or total knee replacement procedures, *l,* in patient type *k* in year *t*, $\bar{q}_{k,l,t}$ is the average number of total hip or total knee replacement, *l,* of admissions by patient type *k* in year *t*, and $s_{k,j,l,t}$ the predicted probability that patient type *k* in age-gender category *κ(k)* chooses hospital j for the admission of total hip or total knee replacement procedure, l, in year *t.* As stated by Antwi et al. (2013), the first part of the equation is the proportion of hospital *j*'s demand that comes from beneficiary of type *k*; this term captures how important hospital j is to patient type *k* in age-gender category *κ(k)*. The second part of the equation, which is $(1-s_{k,j,l,t})$, is the proportion of patient type *k* who did not

choose hospital *j*. This term captures hospital j's weakness or its substitutability for patient type *k* (Antwi et al., 2013).

iii. Estimation Models

The second objective of this study is to estimate the impact of hospital market power on inpatient hospital prices for total hip or total knee replacement procedures reimbursed by PPO plans in Colorado. Following Town and Vistnes (2001) and Capps, Dranove, and Satterthwaite (2003), we used a semi-structural approach to estimate the relationship between hospital market power and price. Like these papers, we regressed the logarithm of allowed amounts[29] (i.e. prices) on our calculated market power measures, however the regression equation differs by market power measure. In addition, like Town and Vistnes (2001), our calculations of hospital market power measures (i.e. WTP and LOCI) were based on the entire network of hospitals. However, as they do, we then excluded hospitals with less than 10 procedures within the study period when estimating the impact of hospital market power on inpatient hospital prices of total hip or total knee replacement procedures in Colorado (see Table 1 – excluded hospitals are highlighted in gray).

When using the WTP market power measure, we write the regression equation as:

$$\log(P_{j,l,m}) = \alpha_1 \Delta WTP_{j,l,m} + \alpha_2 FP_{j,m} + \alpha_3 Score_{j,m} + \alpha_4 LOS_{j,l,m} + \alpha_5 ICD_{j,l,m} + HRR_{j,m} + u_{j,l,m}$$

(Equation 8)

[29] Age and gender adjusted allowed amounts were inflation adjusted to 2014 dollars using the Colorado All Items Consumer Price Index.

where $P_{j,l,m}$ is age and gender adjusted allowed amounts for hospital j performing procedure l (i.e. either total hip replacement or total knee replacement procedures) in market m. We also inflation adjusted these prices to 2014 dollars. $FP_{j,m}$ is a dummy variable for ownership status of hospital j in HRR m, $Score_{j,m}$ is the score of the complication rate for total hip or knee replacement procedures for each hospital j, $LOS_{j,l,m}$ indicates average length of stay in days for procedure l in hospital j in HRR m, $ICD_{j,l,m}$ is a dummy variable to signify whether the procedure is a total knee or total hip replacement. The equation also includes HRR fixed effects $HRR_{j,m}$; they control for the average differences across HRRs due to any observable or unobservable predictors, and they reduce the threat of possible omitted variable bias.

We included ownership status, scores of hip and knee complication rate and LOS because these variables capture features of the hospital or episode that potentially affect the marginal cost of the procedure and thus the price. It has been recognized that not-for-profit hospitals may have different incentives to profit-maximize, and these potential differences could affect prices (Town and Vistnes, 2001). Hospitals also differ with respect to quality, and our study used Medicare Hospital Compare data to include the scores of hip and knee complication rate measure for each hospital. We ran the regression on the total hip and knee replacement samples together but included a dummy for total hip or knee replacement procedure since the level of prices are different between them.

While estimating the impact of LOCI on the inpatient hospital prices for total hip or total knee replacement procedures, the study used the price equation derived from the structural model of profit maximization proposed by Antwi et. al (2013):

$$p_j = Marginal\ Cost + \frac{1}{\alpha}\frac{1}{LOCI_j}$$

(Equation 9)

which, according to Antwi et. al (2013), implies that the inverse of LOCI is the price-cost markup up to scale $(1/\alpha)$. The study first calculated LOCI values, then estimated Equation 9 by ordinary least squares (OLS). Since the study data did not include marginal cost data, the study included controls for marginal cost measure. Additionally, like Antwi et. al (2013), the study assumes constant returns to scale since Gaynor and Vogt (2003) found that parameter for scale economies are not statistically significant in their pricing equation. Therefore, the study used cost shifters such as ownership type (i.e. for-profit), scores of hip and knee complication rate measure as a quality indicator, and length of stay to control for cost differences across hospitals. The resulting equation of estimation is:

$$p_{j,l} = \delta + \beta_1 \frac{\partial C}{\partial D}\left(O_j, S_j, LOS_{J,l}\right) + \beta_2 \frac{1}{\Lambda_j} + knee_l + \varepsilon_{lj}$$

(Equation 10)

where *j* is the index for hospitals, $\partial C/\partial D$ is a function of ownership type (O_j), scores of hip and knee complication rate measure (S_j) and length of stay ($LOS_{j,l}$), β_2 is the estimate of $1/\alpha$ in Equation 9. Equation 10 looks like regression specification of the SCP approach since $P_{j,l}$ (the age and gender adjusted allowed amounts that were inflation adjusted to 2014 dollars) for the procedure *l* (i.e. total hip or total knee replacement procedures) in hospital *j* is the dependent variable and market power measure is the key independent variable. On the other

hand, there is a key difference that the competition index LOCI in Equation 10 was derived from a model of differentiated product oligopoly (Antwi et. al, 2013).

RESULTS

Table 4 shows parameter estimates from the multinomial logit hospital choice model with hospital fixed effects (the table does not include estimated coefficients of hospital fixed effects due to space constraints). Like other recent studies that included hospital choice models such as Town and Vistnes (2001), Ho (2006), Ho and Lee (2013) and Ho and Lee (2017), the coefficient on distance was negative and varied across HRRs. The effects of hospital characteristics such as teaching hospitals and number of beds were absorbed in the hospital fixed effects; however, the interactions show that total knee replacement patients attached less weight to teaching hospitals compared to total hip replacement patients (although this parameter was statistically significant only for 2009, 2010 and 2011). Interactions between patient median household income and hospital characteristics of teaching status were mostly negative or insignificant, whereas the interactions between patient median household income and hospital characteristics of number of beds were either positive or insignificant. This may imply that higher-income individuals preferred non-teaching hospitals with high bed capacity (although the coefficient were statistically insignificant for some years). The interaction terms between hospital characteristics and patient comorbidity index were all insignificant. The fit of the model is reasonable since the study used only total hip or total knee replacement procedures for the patient choice model; the adjusted R^2 ranged from 0.49 (in 2014 analysis) to 0.59 (in 2009 analysis).

Table 4: Parameter estimates from multinomial logit hospital choice model with hospital fixed effects, Colorado, 2009-2014

		2009	2010	2011	2012	2013	2014
Interaction Terms	Variable	Parameter	Parameter	Parameter	Parameter	Parameter	Parameter
Interactions: Teaching Status	Income ($000)	-0.03128 ** (0.01462)	0.00274 (0.01014)	-0.02071** (0.01054)	0.30163 (0.41096)	0.00894 (0.00866)	-0.01929*** (0.00671)
	Grouped CCI	1.069029 (0.69353)	0.26566 (0.38056)	0.17868 (0.42933)	0.55443 (0.40573)	-0.17882 (0.31260)	0.23592 (0.31834)
	Total Knee Replacement	-1.10891** (0.53760)	-0.63859* (0.40863)	-0.99151* (0.53286)	0.55443 (0.40574)	-0.14235 (0.33382)	-0.22873 (0.28504)
Interactions: Number of Beds	Income ($000)	0.00022*** (0.00007)	0.00000 (0.00004)	0.00012*** (.00004)	0.00003 (0.00004)	0.00001 (0.00004)	0.00005* (0.00003)
	Grouped CCI	0.0005202 (0.00298)	0.00080 (.00149)	0.00395 (0.00213)	0.00184 (0.00161)	0.00112 (0.00147)	0.0008 (0.00125)
	Total Knee Replacement	-0.00923*** (0.00285)	.00047 (.00170)	0.00395* (0.00226)	-0.00304** (0.00160)	0.00072 (0.00151)	0.00118 (0.00120)
Distance Interactions:	HRR 101	-0.25892*** (0.06286)	-0.07645*** (0.01294)	-0.19821*** (0.04340)	-0.26559*** (0.04950)	-0.15359*** (0.02069)	-0.20094*** (0.02720)

HRR 102	-0.12777*** (0.02319)	-0.08182*** (0.01361)	-0.11185*** (0.02679)	-0.10285*** (0.01499)	-0.11022*** (0.02080)	-0.04577*** (0.00752)
HRR 103	-0.09164*** (0.01421)	-0.08927*** (0.00974)	-0.13131*** (0.01736)	-0.08604*** (0.01057)	-0.08933*** (0.00913)	-0.042744*** (0.00529)
HRR 104	-0.13886*** (0.04495)	-0.08544*** (0.01401)	-0.11797*** (0.02627)	-0.09243*** (0.02117)	-0.07242 (0.01080)	-0.0565*** (0.01395)
HRR 105	-0.08343*** (0.02483)	-0.13278*** (0.06343)	-0.09093*** (0.02890)	-0.06457*** (0.01490)	-0.07399*** (0.05514)	-0.19780* (0.13424)
HRR 106	-0.08209*** (0.01674)	-0.12255*** (0.02333)	-0.12379*** (0.02495)	-0.08138*** (0.01418)	-0.08289*** (0.01280)	-0.13102*** (0.03231)
HRR 107	-0.17428*** (0.04190)	-0.09477*** (0.02609)	-0.28329*** (0.22747)	-0.23361*** (0.05843)	-0.06553*** (0.01980)	-0.03451*** (0.00977)
Number of Observations	5,887	9,284	9,109	10,942	13,833	20,714
Hospital Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted-R2	0.5937	0.5062	0.5622	0.5574	0.4925	0.4910

Notes: Standard errors in parentheses. *p<0.10 **p<0.05 ***p<0.01

Estimating the choice model was the first step in calculating the WTP measure. Parameter estimates from the choice model were then used to calculate changes in expected utility from having each hospital potentially included in hip and knee patients' choice sets. Changes in expected utility were then used to calculate the WTP for each clinical cohort for each hospital in Colorado for each year between 2009 and 2014.

Table 5 reports the WTP for each hospital for total hip or total knee replacement procedures for PPO enrollees in Colorado from 2009 to 2014. The mean value of WTP for the entire sample (210 hospital-year pairs) was 0.0056 (standard deviation was 0.0077). The average WTP for hospitals for total hip or total knee replacement procedures increased over time (from 0.0033 in 2009 to 0.0085 in 2014), and it varied from the minimum of 0.0002 to the maximum of 0.0833.

As seen in Table 5, hospitals that were part of healthcare systems exercised the highest market power. For instance, both Penrose-St. Francis Health and Porter Adventist are part of Centura Health which is Colorado's largest health care network. Also, Rose Medical Center is part of HCA Healthcare which is Denver's largest health care system, and Yampa Valley Medical Center is part of UCHealth health care system.

Next, Table 6 reports the results of the regression of hospital prices on WTP. Robust standard errors are in parentheses. There were 274 observations of year-hospital-procedure type (i.e. total hip/total knee replacement procedures) combinations after excluding the hospitals that had total number of procedures less than or equal to 10 during the 2009-2014 study period. The estimated coefficient on the WTP measure is positive and significant at the 5% significance level, which is consistent with previous literature. The rest of the coefficient

Table 5: Willingness-To-Pay (WTP) for total hip or total knee replacement procedures, by hospital, by year

HRR City	Hospital	WTP (in utils) 2009	2010	2011	2012	2013	2014
Boulder	Avista Adventist Hospital	0.0011	0.0023	0.0037	0.0028	0.0039	0.0064
Boulder	Boulder Community Health	0.0028	0.0036	0.0065	0.0166	0.0185	0.0288
Boulder	Good Samaritan Medical Center	N/A	0.0006	N/A	N/A	0.0031	0.0006
Boulder	Longmont United Hospital	0.0026	0.0019	0.0039	0.0088	0.0063	0.0013
Colorado Springs	Penrose-St. Francis Health Services	0.0052	0.0135	0.0070	0.0092	0.0221	0.0207
Colorado Springs	Pikes Peak Regional Hospital	N/A	0.0005	N/A	0.0016	N/A	N/A
Colorado Springs	St. Thomas More Hospital	0.0025	0.0006	0.0038	0.0025	N/A	0.0014
Colorado Springs	UCHealth Memorial Hospital	0.0045	0.0085	0.0152	0.0165	0.0120	0.0136
Denver	Aspen Valley Hospital District	N/A	N/A	N/A	N/A	0.0014	N/A
Denver	Castle Rock Adventist Hospital	N/A	N/A	N/A	N/A	0.0006	0.0017
Denver	Denver Health	N/A	0.0005	N/A	N/A	N/A	N/A
Denver	Littleton Adventist Hospital	N/A	0.0011	0.0019	0.0011	0.0024	0.0082
Denver	Lutheran Medical Center	0.0088	0.0069	0.0032	0.0033	0.0025	0.0012
Denver	Medical Center of Aurora	0.0013	0.0015	0.0038	0.0006	0.0037	0.0023
Denver	North Suburban Medical Center	N/A	0.0005	0.0012	0.0013	0.0006	N/A
Denver	OrthoColorado Hospital	N/A	0.0026	0.0059	0.0112	0.0169	0.0298
Denver	Parker Adventist Hospital	0.0005	0.0018	0.0006	0.0005	0.0006	0.0017
Denver	Platte Valley Medical Center	0.0010	0.0006	N/A	N/A	N/A	N/A
Denver	Porter Adventist Hospital	0.0035	0.0046	0.0118	0.0118	0.0180	0.0833
Denver	Presbyterian-St. Luke's Medical Center	0.0015	0.0034	0.0047	0.0055	0.0070	0.0023
Denver	Rose Medical Center	0.0029	0.0036	0.0169	0.0141	0.0130	0.0123
Denver	Saint Joseph Hospital	N/A	N/A	0.0006	0.0023	0.0037	0.0070
Denver	Sky Ridge Medical Center	0.0013	0.0043	0.0043	0.0084	0.0145	0.0104
Denver	St. Anthony Hospital	0.0030	0.0030	0.0024	N/A	0.0012	0.0034

Denver	St. Anthony North Health Campus	0.0021	0.0049	0.0029	0.0020	0.0062	0.0093
Denver	St. Anthony Summit Medical Center	N/A	N/A	0.0013	0.0007	0.0006	0.0011
Denver	Swedish Medical Center	0.0004	0.0031	0.0031	0.0028	0.0037	0.0023
Denver	UCHealth University of Colorado Hospital	0.0009	N/A	N/A	N/A	N/A	0.0035
Denver	Vail Valley Medical Center	0.0062	0.0082	N/A	0.0006	0.0007	0.0024
Denver	Yampa Valley Medical Center	0.0048	0.0206	0.0052	0.0120	0.0017	0.0038
Fort Collins	UCHealth Poudre Valley Hospital	0.0078	0.0097	0.0076	0.0138	0.0211	0.0076
Grand Junction	Community Hospital	0.0016	N/A	0.0014	0.0032	0.0016	0.0007
Grand Junction	Delta County Memorial Hospital	0.0022	0.0007	0.0031	0.0010	0.0017	0.0023
Grand Junction	Family Health West Colorado Canyons Hospital	N/A	N/A	N/A	0.0005	N/A	N/A
Grand Junction	Gunnison Valley Hospital	N/A	0.0040	N/A	N/A	N/A	0.0016
Grand Junction	Montrose Memorial Hospital	0.0078	0.0044	0.0076	0.0050	0.0009	0.0149
Grand Junction	St. Mary's Medical Center	0.0077	0.0128	0.0052	0.0019	0.0125	0.0054
Grand Junction	Valley View Hospital	0.0117	0.0002	0.0108	0.0202	N/A	0.0097
Greeley	East Morgan County Hospital	N/A	N/A	N/A	N/A	N/A	0.0013
Greeley	McKee Medical Center	0.0010	0.0037	0.0014	0.0015	0.0006	0.0006
Greeley	North Colorado Medical Center	0.0044	0.0108	0.0069	0.0171	0.0064	0.0036
Greeley	Sterling Regional MedCenter	N/A	N/A	N/A	N/A	0.0010	N/A
Greeley	UCHealth Medical Center of the Rockies	0.0005	N/A	0.0014	N/A	0.0012	0.0021
Greeley	Wray Community District Hospital	0.0006	0.0010	0.0010	0.0022	0.0005	N/A
Pueblo	Parkview Medical Center	0.0016	N/A	0.0019	0.0082	0.0096	0.0078
Pueblo	St. Mary-Corwin Medical Center	0.0016	0.0021	0.0015	0.0017	N/A	0.0052
	N	*32*	*35*	*34*	*35*	*36*	*38*
	Mean	*0.0033*	*0.0043*	*0.0047*	*0.0061*	*0.0062*	*0.0085*
	Standard Deviation	*0.0029*	*0.0046*	*0.0040*	*0.0059*	*0.0067*	*0.0144*
	Minimum	*0.0004*	*0.0002*	*0.0006*	*0.0005*	*0.0005*	*0.0006*
	Maximum	*0.0117*	*0.0206*	*0.0169*	*0.0202*	*0.0221*	*0.0833*

Note: N/A indicates that there was no admission of total hip or knee replacement procedures in that year for that hospital.

Table 6: Pooled OLS parameter estimates of hospital inpatient pricing of total hip or total knee replacement procedures reimbursed by PPO plans in CO APCD.

Variable	Parameter
WTP	3.5958 ** (1.6440)
For-Profit	-0.1993*** (0.0.0289)
Score of Complication Rate for Hip and Knee Replacement Procedures	-0.0309 (0.0225)
Length of Stay	0.0037 (0.0176)
Total Knee Replacement	0.0037 (0.0195)
HRR 102	-0.0523*** (0.0339)
HRR 103	0.1074*** (0.0304)
HRR 104	0.4282*** (0.0342)
HRR 105	0.1168*** (0.0398)
HRR 106	0.4046*** (0.0280)
HRR 107	-0.1140** (0.0517)
Constant	10.4012*** (0.0821)
Dependent Variable	Log (Allowed Amounts)
Number of Observations	274
F(11, 262)	87.75
R2	0.4769

Notes: Robust standard errors in parentheses.
*p<0.10 **p<0.05 ***p<0.01

estimates of the model are in-line with our prior expectations. First, we see significant

estimates of the model are in-line with our prior expectations. First, we see significant differences between for-profit and non-profit hospitals' pricing behaviors. Inpatient hospital prices reimbursed by PPO plans for total hip or knee replacement procedures were 22% lower for for-profit hospitals than non-profit hospitals in Colorado. Next, the estimated coefficient on the score of the complication rate after hip or knee replacement procedures was negative and statistically insignificant. The coefficients on the length of stay and the dummy for procedure type (total hip/total knee replacement) were positive and statistically insignificant.

Table 7 illustrates the relationship we found between market power and prices for total hip or total knee replacement procedures reimbursed by PPO plan types in Colorado during the study period of 2009 to 2014. For each HRR where the enrollee lived, we calculated the difference in WTPs for all combinations of hospital pairs in the choice set. For instance, if the enrollee lived in Boulder, his or her choice set included all hospitals in Boulder, plus some hospitals in Denver, Fort Collins and Greeley, and we identified all combinations of hospital pairs within the choice set and calculated the difference in WTPs between all these combinations of hospital pairs. Table 7 reports the average of this difference in WTP for each enrollee HRR for each year. We also show the price effect of that average WTP difference, which was calculated using the coefficient estimate of WTP from the price regressions (see Table 6):

$$Price\ Effect = (\exp(Average\ Difference\ in\ WTP * Cooefficient\ Estimate\ of\ WTP) - 1) * 100$$

(Equation 11)

As seen in Table 7, the average WTP difference increased over time and was highest in 2014. For example, the average WTP difference between hospitals in the choice sets of patients living in the Denver HRR in 2014 was 0.0122. Transforming the coefficient via the Equation 11 above, we see that WTP difference was associated with a 4.47% difference in negotiated hospital inpatient prices (i.e. allowed amounts), *ceteris paribus*. Thus, given the mean allowed amount for total hip replacement procedures for hospitals in the choice sets of patients living in Denver was approximately $32,377 for PPO plans in 2014, a 4.47% difference in price due to WTP change would correspond to approximately $1,447 change in negotiated prices, holding all other hospital characteristics constant. As well, given the mean allowed amount for total knee replacement procedures for hospitals in the choice sets of patients living in Denver was approximately $34,250 for PPO plans in 2014, a 4.47% difference in price due to WTP change would correspond to approximately $1,531 change in negotiated prices, holding all other hospital characteristics constant. Alternatively, the average WTP difference between hospitals in the choice sets of patients living in the Grand Junction HRR in 2014 was 0.0066. Transforming the coefficient via the Equation 11 above, we see that WTP difference was associated with a 2.39% difference in negotiated hospital inpatient prices (i.e. allowed amounts). Thus, given the mean allowed amount for total hip replacement procedures for hospitals in the choice sets of patients living in Grand Junction was approximately $37,424 for PPO plans in 2014, a 2.39% difference in price due to WTP change would correspond to approximately $894 change in negotiated prices, holding all other hospital characteristics constant. As well, given the mean allowed amount for total knee replacement procedures for hospitals in the choice sets of patients living in Grand Junction

Table 7: The price effect of change in WTP for total hip and knee replacement procedures, by year, Colorado

	2009		2010		2011	
Enrollee HRR	Average difference in WTP between all combinations of hospital pairs in the choice set (utils)	Price Effect (%)	Average difference in WTP between all combinations of hospital pairs in the choice set (utils)	Price Effect (%)	Average difference in WTP between all combinations of hospital pairs in the choice set (utils)	Price Effect (%)
Boulder	0.0025	0.92	0.0042	1.53	0.0038	1.39
Colorado Springs	0.0024	0.87	0.0048	1.72	0.0046	1.66
Denver	0.0025	0.92	0.0046	1.68	0.0043	1.55
Fort Collins	0.0025	0.92	0.0042	1.53	0.0038	1.39
Grand Junction	0.0052	1.88	0.0058	2.11	0.0046	1.68
Greeley	0.0025	0.92	0.0042	1.53	0.0038	1.39
Pueblo	0.002	0.73	0.0068	2.47	0.0065	2.36
Weighted Average	*0.0025*	*0.9*	*0.0045*	*1.63*	*0.0041*	*1.49*
	2012		2013		2014	
Enrollee HRR	Average difference in WTP between all combinations of hospital pairs in the choice set (utils)	Price Effect (%)	Average difference in WTP between all combinations of hospital pairs in the choice set (utils)	Price Effect (%)	Average difference in WTP between all combinations of hospital pairs in the choice set (utils)	Price Effect (%)
Boulder	0.0064	2.32	0.0065	2.37	0.0121	4.43
Colorado Springs	0.0056	2.04	0.0073	2.65	0.0132	4.85
Denver	0.0065	2.34	0.0073	2.65	0.0122	4.47
Fort Collins	0.0064	2.32	0.0065	2.37	0.0121	4.43
Grand Junction	0.0075	2.72	0.0058	2.11	0.0066	2.39
Greeley	0.0064	2.32	0.0065	2.37	0.0121	4.43
Pueblo	0.0068	2.48	0.0084	3.06	0.0094	3.44
Weighted Average	*0.0063*	*2.29*	*0.0069*	*2.51*	*0.0122*	*4.48*

was approximately $34,711 for PPO plans in 2014, a 2.39% difference in price due to WTP change would correspond to approximately $830 change in negotiated prices, holding all other hospital characteristics constant.

Table 8 reports the LOCI for each hospital for total hip or total knee replacement procedures for PPO enrollees in CO APCD data from 2009 to 2014. The mean value of LOCI for the entire sample was 0.572 (with standard deviation of 0.149), and it varied from the minimum of 0.003 to the maximum of 0.954. This mean value of LOCI is an indicator that hospitals in Colorado were not very competitive on average in total hip or total knee replacement procedures market during the 2009-2014 study period. In fact, according to this measure, on average almost half of the hospitals in Colorado had exercised high market power in total hip or total knee replacement procedures market during the 2009-2014 study period.

According to Table 8, UCHealth Memorial Hospital in Colorado Springs (LOCI in 2009=0.133), Yampa Valley Medical Center in Denver (LOCI in 2011=0.003), Valley View Hospital in Grand Junction (LOCI in 2011=0.030 and LOCI in 2012=0.009), St. Mary's Medical Center in Grand Junction (LOCI in 2013=0.276), and Boulder Community Hospital (LOCI in 2014=0.417) were the hospitals with the highest market power.

The estimation results of the regression of the allowed amounts (i.e. inpatient hospital prices) on inverse LOCI and marginal cost controls were summarized in Table 9. The coefficient on inverse LOCI is 1,490.74 and statistically significant at the 5% significance level. In the pricing specification proposed by Akosa Antwi et. al (2009), LOCI measure enters the Equation 9 in inverse form, therefore a positive coefficient on LOCI indicates that

Table 8: Logit Competition Index (LOCI) for total hip or total knee replacement procedures, by hospital, by year

HRR City	Hospital	LOCI					
		2009	2010	2011	2012	2013	2014
Boulder	Avista Adventist Hospital	0.540	0.595	0.612	0.493	0.651	0.486
Boulder	Boulder Community Health	0.300	0.576	0.537	0.569	0.666	0.417
Boulder	Good Samaritan Medical Center	N/A	0.516	N/A	N/A	0.639	N/A
Boulder	Longmont United Hospital	0.647	0.553	0.324	0.502	0.518	0.456
Colorado Springs	Penrose-St. Francis Health Services	0.303	0.595	0.612	0.643	0.542	0.491
Colorado Springs	Pikes Peak Regional Hospital	N/A	0.576	N/A	0.720	N/A	N/A
Colorado Springs	St. Thomas More Hospital	0.424	0.636	0.616	0.685	N/A	0.685
Colorado Springs	UCHealth Memorial Hospital	0.133	0.597	0.554	0.681	0.568	0.557
Denver	Castle Rock Adventist Hospital	N/A	N/A	N/A	N/A	0.612	0.627
Denver	Littleton Adventist Hospital	N/A	0.604	0.622	0.614	0.633	0.633
Denver	Lutheran Medical Center	0.502	0.602	0.629	0.679	0.621	0.550
Denver	Medical Center of Aurora	0.651	0.610	0.554	0.601	0.616	0.628
Denver	North Suburban Medical Center	N/A	0.875	0.619	0.574	0.642	N/A
Denver	OrthoColorado Hospital	N/A	0.629	0.590	0.640	0.632	0.616
Denver	Parker Adventist Hospital	0.559	0.604	0.899	0.458	0.584	0.886
Denver	Platte Valley Medical Center	0.602	0.489	N/A	N/A	N/A	N/A
Denver	Porter Adventist Hospital	0.619	0.725	0.584	0.624	0.638	0.640
Denver	Presbyterian-St. Luke's Medical Center	0.598	0.629	0.741	0.590	0.603	0.637
Denver	Rose Medical Center	0.603	0.548	0.598	0.610	0.636	0.689
Denver	Saint Joseph Hospital	N/A	N/A	0.954	0.584	0.652	0.613
Denver	Sky Ridge Medical Center	0.612	0.583	0.742	0.631	0.643	0.633
Denver	St. Anthony Hospital	0.470	0.686	0.607	N/A	0.614	0.614

Denver	St. Anthony North Health Campus	0.614	0.759	0.611	0.611	0.631	0.614
Denver	St. Anthony Summit Medical Center	N/A	N/A	0.893	0.676	0.524	0.642
Denver	Swedish Medical Center	0.887	0.705	0.762	0.637	0.656	0.634
Denver	UCHealth University of Colorado Hospital	0.542	N/A	N/A	N/A	N/A	0.626
Denver	Vail Valley Medical Center	0.248	0.212	N/A	0.640	0.783	0.647
Denver	Yampa Valley Medical Center	0.581	0.003	0.280	0.648	0.520	0.550
Fort Collins	UCHealth Poudre Valley Hospital	0.530	0.596	0.670	0.523	0.693	0.588
Grand Junction	Community Hospital	0.640	N/A	0.484	0.523	0.714	0.778
Grand Junction	Delta County Memorial Hospital	0.482	0.628	0.453	0.588	0.531	0.502
Grand Junction	Family Health West Colorado Canyons Hospital	N/A	N/A	N/A	0.710	N/A	N/A
Grand Junction	Montrose Memorial Hospital	0.611	0.294	0.513	0.431	0.339	0.436
Grand Junction	St. Mary's Medical Center	0.557	0.673	0.474	0.782	0.276	0.538
Grand Junction	Valley View Hospital	0.514	0.940	0.030	0.009	N/A	0.501
Greeley	McKee Medical Center	0.857	0.659	0.502	0.628	0.704	0.496
Greeley	North Colorado Medical Center	0.642	0.557	0.626	0.450	0.689	0.697
Greeley	Sterling Regional MedCenter	N/A	N/A	N/A	N/A	0.738	N/A
Greeley	UCHealth Medical Center of the Rockies	0.830	N/A	0.522	N/A	0.816	0.601
Greeley	Wray Community District Hospital	0.943	0.494	0.312	0.026	0.925	N/A
Pueblo	Parkview Medical Center	0.341	N/A	0.131	0.342	0.596	0.564
Pueblo	St. Mary-Corwin Medical Center	0.212	0.849	0.793	0.575	N/A	0.524
	N	32	33	34	35	35	35
	Mean	0.550	0.594	0.572	0.563	0.624	0.594
	Standard Deviation	0.187	0.174	0.197	0.163	0.115	0.095
	Minimum	0.133	0.003	0.030	0.009	0.276	0.417
	Maximum	0.943	0.940	0.954	0.782	0.925	0.886

higher values of LOCI are associated with lower prices, as expected. The estimation results also show that prices of total hip or total knee replacement procedures at for-profit hospitals are on average $5.771.80 lower than non-profit hospitals. The estimate of the score of complication rate coefficient has correct sign, but it is statistically insignificant. As the LOS increases by one day, negotiated prices of total hip or total knee replacement procedures decreases by approximately $1,250 on average, and this coefficient estimate is statistically significant at 10% significance level. Lastly, the results show that the prices of total knee replacement procedures were on average $647 higher than total hip replacement procedures for PPO plan type.

As also stated by Antwi et. al (2013), the parameter estimate for inverse LOCI measure is not directly interpretable in terms of the effect of competition on prices. Antwi et. al (2013) proposed to calculate the impact of discrete changes in LOCI measure on price. Antwi et. al (2013) did these calculations for a hypothetical hospital with the same market share in all market segments doubling its market share. Like their study, we calculated changes in price at the various base market shares as well. Antwi et. al (2013) expressed the approximate price change as a result of change in base market share as a function of LOCI-Overlap:

$$\Delta\ Allowed\ Amount\ (i.e. price) \approx \frac{1}{\alpha}\frac{\Lambda_{12}}{\Lambda_2}$$

(Equation 12)

where $1/\alpha$ is the parameter estimate for inverse LOCI coefficient which is derived from the estimation results of the regression of the allowed amounts on inverse LOCI and marginal cost controls, Λ_2 is the LOCI measure with new market share, and Λ_{12} is the LOCI-Overlap.

Table 9: Pooled OLS parameter estimates of hospital inpatient pricing of total hip or total knee replacement procedures reimbursed by PPO plans in CO APCD.

Variable	Parameter
Inverse LOCI	1,490.74 ** (754.00)
For-Profit	-5,771.80** (1003.98)
Score of Complication Rate for Hip and Knee Replacement Procedures	-330.50 (1076.21)
Length of Stay	-1,248.67* (752.77)
Total Knee Replacement	647.07 (973.28)
Intercept	33,312.04*** (3,625.94)
Dependent Variable	Allowed Amount
Number of Observations	274

Notes: Standard errors in parentheses. *p<0.10 **p<0.05 ***p<0.01

Antwi et. al (2013) defines LOCI-Overlap as a measure of how responsive hospital's demand with new market share is to price at the base market share. Loci-Overlap can be calculated using the equation below:

$$\Lambda_{12} = \frac{\sum N_t \Pr(t \to 2) \Pr(t \to 1)}{\sum N_t \Pr(t \to 1) (1 - \Pr(t \to 1))}$$

(Equation 13)

where $\Pr(t \to 1)$ is the base market share, $\Pr(t \to 2)$ is the new market share and N_t is the number of patients in each patient category. We found that when a hospital doubled its market share from 20% to 40%, the approximate price increase was $621. The average price is approximately $33,887 for total hip or total knee replacement procedures during the study period, so this corresponds to a 1.83% increase in price when market share doubled from 20% to 40%. When a hospital doubled its market share from 25% to 50%, the approximate price increase was $993 (2.93% increase in price), and when a hospital doubled its market share from 33% to 67%, the approximate price increase was $2,225 (6.56% increase in price). The increases in price were increasing in the base market share.

DISCUSSION

A key finding from our study is that distance is very important in hospital choice models. As in other studies with patient choice model (Dranove et al., 1993; Kessler and McClellan, 2000; Capps et al., 2001; Town and Vistnes, 2001; Capps et al., 2003; Gaynor and Vogt, 2003; Tay, 2003; Ho, 2006; Ho and Lee, 2013; Ho and Lee, 2017), the negative and significant estimated coefficient in our patient choice models implies that distance plays a significant role, and patients have strong preferences for hospitals with closer proximity. However, patient choice studies in the current literature are not for specific procedures. Our paper thus contributes to the literature by presenting results that patients with an elective procedure also prefer to have the procedure in a hospital nearby; and the substitutability among hospitals in the choice set depends mostly on distance compared to teaching status or the number of beds the hospital has.

Next, our WTP measure – which estimate the value of including a specific hospital in patients' choice – shows that market power of hospitals can change over time. To our knowledge, there were no other studies that estimated WTP over time. Additionally, although there are studies that used WTP as part of their analyses, not all of them reported the summary statistics for this measure. Ho and Lee (2013) was the only study that provided some summary statistics on WTP measure which was in utils, but their study was not specific for a procedure. Their study defined six diagnosis categories (i.e. cardiac, cancer, neurological, labor, digestive diseases and other categories other than newborn babies) using ICD-9-CM codes while calculating the WTP (i.e. market power) for each hospital. Ho and Lee (2013) used 2004 claims information for enrollees covered by the California Public Employees' Retirement System (CalPERS), and they found that average WTP for hospitals in California was 0.109 (with standard deviation of 0.208). We found that average WTP for hospitals in Colorado for total hip or total knee replacement procedures was 0.0056 (standard deviation was 0.0077). Even though it is not easy to compare these two averages, it is expected that the WTP measure in utils for a specific procedure will be lower than their broader WTP measure.

The interpretation of LOCI is easier since this measure is bounded between 0 and 1, where zero is pure monopoly and one is perfect competition (Antwi et. al, 2013). We found that the mean value of LOCI for the entire sample was 0.572 which indicates that the competition was low on average among hospitals in Colorado for total hip or knee replacement procedure market between 2009 to 2014. When we look at the distribution of LOCI for hospitals in Colorado for total hip or knee replacement procedures, approximately

25% of hospitals had values of LOCI of 0.523 or below; and 50% of hospitals had values of LOCI of 0.603. These values imply that half of the hospitals in Colorado had high market power (and there was low competition) in total hip or total knee replacement procedures market during 2009-2014 study period.

When we estimated the association of price with a change in WTP measure, our estimates indicate that market power as measured by WTP has a significant positive effect on prices of total hip or total knee replacement procedures. The average price impact was positive for the most attractive hospitals. Our results confirm those found by Town and Vistnes (2001); they found that hospitals with higher bargaining power (as measured by WTP) negotiate higher prices using 1990-1993 data from two large network-model HMOs in Southern California and the Office of Statewide Health Planning and Development (OSHPD) for California. Although Town and Vistnes (2001) used negotiated hospital prices, they focused on HMO plans and their results were not procedure specific. We extended the literature on the effect of WTP on negotiated prices by finding that changes in hospital market power for total hip or knee replacement surgery markets were associated with a change of approximately 1% to 5% in negotiated hospital prices for PPO plan types in the period 2009–2014.

Similarly, our estimates indicate that market power as measured by inverse LOCI has a statistically significant and a positive effect on prices of total hip or total knee replacement procedures, as in Antwi et. al (2013). Antwi et. al (2013) used discharge data from 1992-1998 from patients whose payments came from HMO, PPO, other private, self-pay and Blue Cross Blue Shield; and included diagnosis related groups (DRGs) with a frequency of at least

1,000. Most importantly, Antwi et. al (2013) did not use negotiated prices (they used hospital charges) while conducting their analyses. In contrast, our analyses were specific to negotiated prices by PPO plans in total hip or knee replacement surgery market in Colorado from 2009 to 2014, and our results imply that while some changes in market shares of hospitals lead to limited price increases (less than 5%), some changes may have a much larger price effect (as in the case of doubling market share from 33% to 67%. Akosa Antwi et. al (2013) depicted this market share change from 33% to 67% as a merger between equal sized firms that decreases the number of firms from 3 to 2) despite the existence of many other nearby hospitals. From a policy perspective, this suggests that while many hospital mergers may raise no significant antitrust concerns, certain hospital mergers have the potential to cause real competitive harm.

Competition is a key mechanism to contain health care costs and improve the quality of care. It is therefore alarming when concentration is increasing (or competition is low) throughout the hospital markets. According to a recent analysis, about 90 percent of hospital markets were highly concentrated in US in 2016 (Fulton, 2017). Focusing on a specific procedure, we found that 50 percent of hospitals in Colorado for total hip or knee replacement surgery markets were facing less competition. This suggests that how a hospital, even if its overall market share is low or exercising a low market power, can gain leverage by specializing in specific service lines that are important to consumers.

Yet, like Town and Vistnes (2001) and Capps, Dranove and Satterthwaite (2001), we found that hospital markets were still localized, and that hospitals face limited competition despite nearby alternatives. In other words, there is some differentiation among hospitals to

allow for some exercise of market power. “This also suggests that hospital competition may be quite localized, with defined markets much smaller than the county or metropolitan area suggested in much of the previous literature” (Town and Vistnes, 2001; pg. 735).

Eventually, understanding the relationship between market competition and hospital prices would provide valuable information about important trends in the health care system in recent years. Moreover, it could help improve policy making going forward. For instance, our study shows that increased market concentration was associated with significant increases in the negotiated hospital prices for PPO plans, in the case of total hip or total knee replacement procedures during 2009–2014 in Colorado. Therefore, there needs to be caution in implementing policies that could encourage further concentration in hospital markets for total hip or replacement surgeries in Colorado.

Interpretation of the study results must be informed by the limitations of the study. Firstly, the study sample size was low. From 2009 to 2014, there were 1,497 admissions reimbursed by PPO plans (568 admissions with total hip replacement procedures and 929 admissions with total knee replacement procedures) in COAPCD data during the 2009-2014 study period. Based on discussions with COAPCD data administrator, we were informed that self-insured claims are not included in the COAPCD data; and our informed but not well-documented understanding is that data from 2009 to 2011 were less reliable than data from 2012 onward. Self-insured claims represent a large proportion of processed claims in Colorado (the percentage of self-insured was 40% in 2014[30]) and the absence of such data in

[30] This information was taken from Health Insurance Cost Report by Colorado Department of Regulatory Services.

the COAPCD is a challenge to fully understand Colorado's healthcare landscape. Next, although we used proxies for marginal cost measures in our pricing equations, we lack precise cost information for total hip or knee replacement procedures for each hospital in Colorado. Further validation should be performed with actual cost data. Lastly, administrative claims data are not collected for research purposes and measurement error may have been introduced by coding that was in error or driven by reimbursement needs more than research needs. It is also important to note that this study was conducted using private insurance payer claims of patients with total hip or total knee replacement procedures in Colorado. Though the study focused on a specific clinical cohort to decrease the confounding effect of regional differences on health status, these results may not be fully generalized to Medicare, Medicaid, and uninsured populations; and it may not be fully generalized to other states or other clinical conditions.

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APPENDIX B

Supplemental Material for Second Journal Article

Regression output with year dummies:

Variable	Parameter
WTP	3.3222 *
	(1.8107)
For-Profit	-0.1967***
	(0.0.0289)
Score of Complication Rate for hip and knee replacement procedures	-0.0303
	(0.0227)
Length of Stay	0.0027
	(0.0176)
Total Knee Replacement	0.0032
	(0.0197)
HRR 102	-0.0494
	(0.0333)
HRR 103	0.1077***
	(0.0304)
HRR 104	0.4328***
	(0.0329)
HRR 105	0.1182***
	(0.0398)
HRR 106	0.4053***
	(0.0295)
HRR 107	-0.1133***
	(0.0491)
Year 2010	-0.0136
	(0.0410)
Year 2011	-0.0485
	(0.0367)
Year 2012	-0.0179
	(0.0361)
Year 2013	-0.0078
	(0.0423)
Year 2014	0.0010
	(0.0391)
Constant	10.4175***
	(0.0824)
Number of Observations	274
F(16, 257)	66.98
R2	0.4834

Notes: Robust standard errors in parantheses. *p<0.10 **p<0.05 ***p<0.01

APPENDIX C

Sensitivity Analysis for Second Journal Article

We conducted the same research with all private payer plan types (i.e. HMO, PPO and POS).

Pooled OLS parameter estimates of hospital inpatient pricing of total hip or total knee replacement procedures reimbursed by PPO, HMO and POS plans in CO APCD.

Variable	Parameter
WTP	1.3280*** (0.3610)
For-Profit	-0.2031*** (0.0360)
Score of Complication Rate for hip and knee replacement procedures	-0.0894*** (0.03299)
Length of Stay	0.0189 (0.0206)
Total Knee Replacement	0.0059 (0.0284)
PPO	0.1155*** (0.0353)
HMO	0.0770** (0.0384)
HRR 102	-0.0875 (0.0604)
HRR 103	0.0604 (0.0304)
HRR 104	0.4282*** (0.0342)
HRR 105	0.1168*** (0.0398)
HRR 106	0.4046*** (0.0280)
HRR 107	-0.1140** (0.0517)
Constant	10.4012*** (0.0821)

Notes: Robust standard errors in parentheses. *p<0.10 **p<0.05 ***p<0.01
Reference Category for Insurance Type is POS.

The price effect of change in WTP for total hip and knee replacement procedures, by year, Colorado

	2009		2010		2011	
Member HRR	Average difference in WTP between all combinations of hospital pairs in the choice set (utils)	Price Effect (%)	Average difference in WTP between all combinations of hospital pairs in the choice set (utils)	Price Effect (%)	Average difference in WTP between all combinations of hospital pairs in the choice set (utils)	Price Effect (%)
Boulder	0.0052	0.69	0.0072	0.96	0.0118	1.58
Colorado Springs	0.0055	0.73	0.0084	1.12	0.0149	2
Denver	0.0051	0.68	0.0078	1.04	0.0134	1.8
Fort Collins	0.0052	0.69	0.0072	0.96	0.0118	1.58
Grand Junction	0.0073	0.98	0.015	2	0.0218	2.93
Greeley	0.0052	0.69	0.0072	0.96	0.0118	1.58
Pueblo	0.0024	0.32	0.0106	1.42	0.021	2.82
Weighted Average	*0.0052*	0.69	*0.0076*	1.01	*0.0128*	1.72
	2012		2013		2014	
Member HRR	Average difference in WTP between all combinations of hospital pairs in the choice set (utils)	Price Effect (%)	Average difference in WTP between all combinations of hospital pairs in the choice set (utils)	Price Effect (%)	Average difference in WTP between all combinations of hospital pairs in the choice set (utils)	Price Effect (%)
Boulder	0.0304	4.11	0.0296	4	0.041	5.59
Colorado Springs	0.0316	4.28	0.035	4.75	0.0453	6.19
Denver	0.0299	4.05	0.0319	4.32	0.0413	5.63
Fort Collins	0.0304	4.11	0.0296	4	0.041	5.59
Grand Junction	0.0218	2.93	0.0059	0.78	0.0104	1.39
Greeley	0.0304	4.11	0.0296	4	0.041	5.59
Pueblo	0.0273	3.68	0.0457	6.24	0.0326	4.42
Weighted Average	*0.0304*	4.11	*0.0308*	4.17	*0.0415*	5.65

Pooled OLS parameter estimates of hospital inpatient pricing of total hip or total knee replacement procedures reimbursed by PPO, HMO and POS plans in CO APCD.

Variable	Parameter
Inverse LOCI	1,952.53 ** (840.23)
For-Profit	-7,903.60*** (728.29)
Score of Complication Rate for Hip and Knee Replacement Procedures	-2,615.02*** (790.31)
Length of Stay	-42.58 (651.73)
Total Knee Replacement	179.57 (690.90)
PPO	2,259.61** (918.15)
HMO	583.62 (929.58)
Intercept	33,312.04*** (3,625.94)
Dependent Variable	Allowed Amount
Number of Observations	717

Notes: Standard errors in parentheses. *p<0.10 **p<0.05 ***p<0.01
Reference Category for Insurance Type is POS.

Approximate change in price as market share changes (calculation was done using the coefficient estimate of inverse LOCI):

We found that when a hospital doubled its market share from 20% to 40%, the approximate price increase was $813.55. When a hospital doubled its market share from 25% to 50%, the approximate price increase was $1,301.69, and when a hospital doubled its market share from 33% to 67%, the approximate price increase was $2,914.22.

CONCLUSION

First, this dissertation extends the literature on variation analyses by focusing on a service line that has been understudied in the younger, privately insured population. Specially, for each of the clinical cohorts of hip or knee replacement procedures in which the cohorts included privately insured patients above 45 and below 65 years old, this dissertation looks at how the variation in hospital inpatient prices as well as variation in hospital inpatient admissions (i.e. quantity) contribute to variation in hospital inpatient spending in hip or knee replacements across and within hospital markets in Colorado. In addition, this dissertation evaluates whether and to what extent the hospital inpatient spending and prices per admission for the same service line change between different private insurance product types, within and across geographic markets in Colorado. There is a significant difference between private and public (Medicare) payment rates in Colorado for total hip or knee replacement procedures. Variation in hospital inpatient prices for total hip or knee replacement procedures across 7 HRRs in Colorado was the highest among PPO plan type compared to HMO and POS plan types. Also, variation in hospital inpatient spending on privately insured is a function of variation in both the market determined prices that providers and insurers negotiate and quantity of care delivered within and across HRRs, yet the relative impact of price and quantity effects can be different between different private insurance plan types (i.e. HMO, PPO, POS). For total hip and total knee replacement procedures, inpatient spending variation was driven mostly by differences in quantities in Colorado. Therefore, this result suggests that findings for overall service category spending (i.e. inpatient spending variation

was driven mostly by differences in prices) cannot be generalized to different service lines within a specific service category (i.e. total hip or knee replacement procedures).

Next, this dissertation extends the hospital competition literature by estimating the impact of market power on hospital prices (i) using actual procedure prices instead of charged-based price estimates, (ii) using market power indices developed by semi-structural approaches (i.e. WTP, and LOCI) and (iii) focusing on a set of commonly performed elective orthopedic procedures -since some hospitals may specialize in performing them may have greater bargaining power if patients place greater value on the successful treatment- for the PPO insured population in Colorado. LOCI measure indicates that the competition was low on average among hospitals in Colorado for total hip or knee replacement procedure market between 2009 to 2014. Market power as measured by both WTP and inverse LOCI has a significant positive effect on prices of total hip or total knee replacement procedures. This dissertation shows that increased market power (i.e. low competition among hospitals) was associated with significant increases in the negotiated hospital prices for PPO plans, in the case of total hip or total knee replacement procedures during 2009–2014 in Colorado. Eventually, according to a recent analysis, about 90 percent of hospital markets were highly concentrated in US in 2016 (Fulton, 2017). Focusing on a specific procedure, this dissertation found that approximately 50 percent of hospitals in Colorado for total hip or knee replacement surgery markets were facing less competition. This suggests that how a hospital, even if its overall market share is low or exercising a low market power, can gain leverage by specializing in specific service lines that are important to beneficiary population.