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ABSTRACT

We estimate price regressions for surgical procedures used to treat colon cancer, a leading cause of cancer mortality. Using a claims database for self-insured employers, we focus on transaction prices, rather than more commonly available billing data that do not reflect actual payments made. Although the responsiveness of prices to hospital performance depends on the impact of quality on the slope of the quantity-demand of the payers, which are not known a priory, it is often assumed that higher performing hospitals are able to command higher prices. To test this hypothesis we construct performance rankings, based on hospital excess-mortality and incorporate them into our price models. We are interested in the type information available to large payers who negotiate prices on behalf of their members. To get a cancer-specific index we emulate the widely-reported risk-adjustment methodology used in the federal Hospital Compare reporting system for ranking cardiac performance. The effects were consistently negative in all models (adverse quality reduces price), though not significant. However, we observe a rational pricing structure whereby higher treatment complexity is reflected in higher price differentials, controlling for patient characteristics and market structure.

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1 Introduction

There is a growing recognition among policy makers that in order to make informed decisions, consumers of health care services need to possess information on both prices and quality. Similarly insurers and large group purchasers require information on quality and performance in order to negotiate prices with providers in their networks. Interest in this issue has prompted CMS to develop the Hospital Compare web site. As of April 2005 this site provided consumers with quality indicators for major medical conditions, in approximately 4,700 acute care community hospitals. The featured medical conditions were heart attacks (acute myocardial infarction), heart failure, and pneumonia; quality indicators were based on process of care measures associated with each of these conditions[1]. Due to the difficulty in interpreting over 30 disparate process measures and a greater emphasis on outcome-based measures in policy discourse, CMS began to report post-discharge hospital mortality rates for these conditions beginning in 2008. In 2009 CMS also began to report Medicare allowed charges for related procedures. However, these charges reflect mostly fixed rates paid to hospitals for treating Medicare beneficiaries, and apply to broad diagnostic categories used in the Medicare payment formula; they do not necessarily reflect actual hospital prices in the private segment of the market.

While these reporting systems represent progress, consumer confusion over ‘fair’ pricing continues to be widespread, particularly in private markets for hospital services

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[1] Process measures ranged from smoking cessation counseling for pneumonia or contraindicated aspirin for AMI to surgical safety. The complete list is available at www.hospitalcompare.hhs.gov. Process measures associated with hospitalizations due to childhood asthma were also added in subsequent years.

(Reinhardt, 2006; RWJF, 2013). Anecdotal press accounts often tell of individual consumers able to negotiate price discounts from hospitals using information gleaned from Hospital Compare and similar state based reporting systems, while consumer-oriented internet sites and blogs appear to reflect frustration over the lack of information regarding costly procedures left out of the published lists[2]. Most recently, a broader release of the CMS charge data has garnered substantial media attention, but its applicability to privately insured segment of the market remains contestable (Meier et al., 2013). A related issue of interest is the association between hospital performance measures and prices. While price transparency is intended to inject price competition overall (Ginsburg, 2007; GAO, 2011), it has been suggested that higher performing hospitals may be able to command higher prices if prices are negotiated with well-informed insurers (Cutler and Dafny, 2011).

In this study we focus on the example of colorectal cancer, and the inpatient surgical procedure associated with it, colon resection. We have two objectives. First, we examine the distribution of prices in the private segment of the market. Second, we assess the association between hospital performance and prices using a mortality-based outcome measure similar to that found in hospital report cards such as Hospital Compare. Note

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[2] Related to the procedure of main interest in this study, colon resection (also referred to as colectomy), an anxious patient asks, without getting a definitive reply: "…Please can someone give me a ballpark figure on how much the surgery to remove a tumor in the lower part of the colon would run? I need to know because I want to raise money because we currently don't have health coverage….", www.healthboards.com (accessed 4/30/11).

that we rely on transaction prices, namely actual payments made to hospitals by third party payers[3] (Capps and Dranove, 2004; Dor, Grossman and Koroukian, 2004).

The paper proceeds as follows. Section 2 provides background and context on colorectal cancer and related procedures. Section 3 describes data sources and estimating sample. Section 4 lays out the conceptual framework, including specification of our price models, definition of our mortality-based hospital performance measure, and simple theoretical motivation. The results are discussed in section 5, followed by conclusions in section 6. In the Appendix, construction of the hospital performance measures is explained in greater detail.

2 Colorectal Cancer

In the U. S., colorectal cancer accounts for approximately 147,000 cases and almost 50,000 deaths annually, making it the second leading cause of death among all cancers, following lung cancer. Treatment usually involves surgical removal of the affected portion of the colon (resection), with the type and extent of resection dependent on the location of the tumor. Other than the importance of colon cancer nationally, we chose to focus our analysis on colon cancer for two reasons. First, this surgery is performed on an inpatient basis only; in contrast to surgeries for other common cancers

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[3] For the most part, prices are negotiated between hospitals and managed care organizations, PPOs and other group purchasers, rather than between hospitals and individuals (Capps and Dranove, 2004; Dor, Grossman, and Koroukian, 2004). Consumer-directed health plans (CDHP) are an exception, currently accounting for only 13% of privately insured individuals nationally, but are negligible in the earlier period spanning our data.. Although states may offer CDHPs through their state health insurance exchanges, it remains to be seen if enrollments in such plans will grow or decline with the implementation of health reform (Claxton et al., 2010).

such as breast cancer for which surgeries may be performed on an outpatient basis as well. Second, in the case of colorectal cancer, there is no discretionary choice of therapy so all patients receive surgery treatment, unlike the example of prostate cancer where surgery and radiation are equally viable alternatives (Jacobson et al., 2010). Consequently, the price of colorectal surgery is more clearly defined and identifiable in insurance claims databases. Variants of the procedure include total surgery, in which the entire colon is removed, partial surgery, in which an incision is made to remove part of the colon, and less invasive laparoscopic surgery. Surgeries are performed on an emergency basis only when intestinal obstruction or perforation occurs (Diggs et al., 2007).

3 Data and Sample

3.1 Data sources

The main database used is the MarketScan Commercial Claims and Encounters file (CCE) which assembles complete insurance claims for approximately 100 large employers who self insure. We extracted claims for hospitalizations for employees and dependents with a diagnosis of colorectal cancer who underwent surgical treatment, namely colon resection. Unlike hospital discharge data which provide charges, claims databases reflect actual payments made to hospitals, namely transaction prices (see Dor, Grossman, Koroukian, 2004, and Dor, Koroukian, Grossman 2004). Other variables include the type of benefit plan administered by the employer, and comorbidities associated with the patient's main diagnosis, descriptors of the type and complexity of the surgery, and demographic characteristics. Due to strict confidentiality requirement in the data, the identity of employer is not known. However, for purposes of this study, hospital ids were made available so that hospital characteristics could be linked, provided that the identity of individual hospitals remained confidential. Hospital characteristics were taken from the American Hospital Association (AHA) Annual Survey and the Area Resource File (ARF) provided an additional variable on HMO penetration in the market area. The AHA survey provided a crosswalk to Hospital Referral Areas (HRRs). All of the source files were pooled for the years 2002-2007[4]. We kept only hospitals that performed more than 20 colorectal cancer surgeries per year. The final sample consisted of 5,293 cases of commercially insured individuals with matching hospital ids. Of these, 4,187 underwent partial colon resection, and 1,106 had total resection. The number of hospitals performing colon resections in the combined data ranged from 715 in 2002 to 998 in 2005.

Finally, hospital-level 30-day mortality rates for colorectal cancer admissions were calculated from the Medicare Provider Analysis and Review (MEDPAR) files for all hospitals matching hospitals in our data, for the years 2000-2007. These mortality rates were transformed into standardized performance measures, which are described in detail in our Methods Section. Summary statistics for the final analysis file are provided in Table 1.

3.2 Colorectal surgery prices by procedure variant

The distribution of transaction prices by the variant of colorectal surgery and hospital type are shown in Figure 1. The mean for all the procedures combined was

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[4] We obtained the additional years of MEDPAR to allow for inclusion of three-year moving averages of mortality ratios

$21,990 (2007 dollars). Four surgical variants are considered, namely partial resection, total resection, emergency cases and laparoscopy cases (colostomy, a follow up procedure to construct a colon bypass is rarely performed at the same admission). There were no statistically significant differences between partial and total resections[5]. Interestingly, laparoscopy which involves a more novel technology but is minimally invasive, was priced at $19,183.55 (grand mean), 14.3% below the $22,382.66 price for open surgery (grand mean), except when performed in for-profit hospitals. As expected, surgeries performed on an emergency basis were priced well above non-emergency surgeries, ($30,141.13 and $20,739.38 respectively). Similar differences were found in all hospital categories.

We further compare prices between hospital types within the ownership, teaching, and system affiliation categories. Tests indicated that generally, prices in public, for-profit, and non-profit hospitals were statistically different at the 99% significance level. However, prices in teaching and non-teaching hospitals, and system-affiliated and independent hospitals were not significantly different for any of the variants of the surgical procedure.

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[5] Colostomy is a surgical opening that connects the colon to the surface of the abdomen, providing a new pathway for waste materials. It is often done as a follow up to colon surgery, when medical risk necessitates. However, in or data it was rarely performed within the initial hospital stay for the main surgery. Colostomy added substantially to the price, up from $20,276 to $29,585 in the case of total resection, and from $19,946 to $29,892 for partial, a difference of 45.9% or 49.9% respectively. For a more detailed description of the underlying procedures see Diggs et al., 2007.

4 Analytical and Conceptual Framework

4.1 Simple theoretical insights

Although it may be natural to assume that higher quality is associated with higher prices, this may not necessarily be the case. To see this generally, let the hospital maximize[6]:

$$\pi = PX(P, Q) - C[X(P, Q), Q], \qquad (1)$$

where P is price, X is output, Q is quality, and C is total cost. Price is the choice variable of interest, while Q is exogenous. The first-order condition for price is

$$\pi_P = X(P, Q) + PX_P(P, Q) - C_X[X(P, Q), Q]X_P(P, Q) = 0. \qquad (2)$$

The notation $X_P(P, Q)$ is used to denote that X_P depends on P and Q.

Now consider the effect of an increase in Q on P. From the total differential of π_P and the implicit function theorem

$$\frac{dP}{dQ} = -\frac{\pi_{PQ}}{\pi_{PP}}$$

Since π_{PP} is negative by the second-order condition for profit maximization, we have $sign(dP/dQ) = sign(\pi_{PQ})$. Solving π_{PQ} and rearranging we get,

$$\pi_{PQ} = X_Q + (P - C_X)X_{PQ} - X_P C_{XX} X_Q - X_P C_{XQ} \qquad (3)$$

The sign of the first term on the right-hand side of equation (3) is positive while the signs of the last three terms are ambiguous. However, by imposing a few reasonable assumptions on the hospital's structure, it can be shown that *sign(dP/dQ)* depends on how quality affects the slope of the demand curve. For instance, if $C_{XX} \geq 0$ and if $C_{XQ} \geq 0$,

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[6] Dor and Farley (1996) use a similar framework to analyze the impacts of changes on regulated prices (e.g., the Medicare prospective payment system) on quality. They allow X and Q to enter the cost function multiplicatively, and find similar ambiguities.

then $\pi_{PQ} > 0$ (hence dP/dQ is positive) as long as $X_{PQ} = 0$ or $X_{PQ} > 0$. In the first case ($X_{PQ} = 0$), quality has no effect on the slope of the demand curve. The second case ($X_{PQ} > 0$) corresponds to the case where a quality improvement causes the slope of the (quantity) demand curve to be steeper[7] [8].

4.2 Empirical Estimation

4.2.a Price regressions

We model transaction prices for colon cancer surgeries adjusting for the underlying clinical traits of the procedure, patient traits, hospital and insurer characteristics, and local area market structure. The variable of greatest interest to us is the hospital performance measure. We explore two alternative specifications of this variable, the standardized mortality ratio (SMR) and the risk adjusted standardized mortality ratio (RSMR). Detailed construction of these two variables is provided in the next subsection.

We model the transaction price using a generalized linear model (GLM) with a log link and normal family (McCullagh and Nelder, 1989). It has been common practice to model the logarithm of prices, $E(ln(y|x)) = x\beta$ but models that specify $E(y|x)= \exp(x\beta)$ are preferred for a number of reasons (Manning, 1998; Manning and Mullahy, 2001). This allows us to report back-transformed coefficients without further adjustment, additionally allowing us to express the results in terms of relative price differences (see

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[7] Equivalently, an increase in price makes the (quantity) demand *less* sensitive to quality.

[8] It can easily be shown that the familiar price rule for the firm can be derived from eq. [1]. $P = (\varepsilon/(\varepsilon - 1))C_x$ where ε is the price elasticity of demand. Here, the optimal price would not change if C_X (the marginal cost of quantity) and ε are constant (do not depend on X or Q).

below). Model selection criteria showed that the normal family was preferred to other suitable candidates, e.g., Poisson and Gamma. Prices were adjusted for medical inflation using the hospital component of CPI, and are expressed in 2007 levels.

Construction of several variables included in the regression model requires further explanation. Indicators of type and severity of surgery are as previously described. Additionally, to adjust for patients' overall severity of illness and preexisting conditions in both our mortality and price models, we used the list of comorbid conditions as developed by Elixhauser et al. (1998), to define a scale of 0, 1, 2, 3+ conditions.[9] We also control for whether the patient received colostomy procedure during the surgery. Separately, we accounted for the presence of metastatic cancer (ICD-9 codes 196.0-199.1)[10].

Hospital characteristics were previously described. In addition, we control for the type of benefit plan available to the employee from the self-insured employer. Preferred provider organizations (PPOs) were the dominant form of benefit plans in our data, accounting for about 63% of all patient encounters. They formed the reference category; they were followed by other forms of fee-based plans, predominantly comprehensive fee-for-service (there was a small number of cases with consumer-

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[9] The Elixhauser index is based on a more comprehensive set of comorbid conditions than the Charlson index, which is also widely used in the epidemiologic literature. We identified these conditions through ICD-9 diagnosis codes documented in the inpatient datasets. In exploratory side regressions, we observed no marked difference between models incorporating binary indicators of the most prevalent conditions and the summary measure reported here.

[10] Cancer registry data incorporate the more detailed classification based on cancer staging, conventionally ranked on a 1-4 scale. These data however, are available for a limited number of states, and could not be matched to our data. Using claims data it was also possible to construct the binary measure of metastases, indicating cancer spread (Cooper et al., 1999; Merkow et al., 2013).

directed health plans; these were included in the fee-based category). The next most common type of benefit plan was fee-based plans, followed by point-of-service (POS) plans. POS plans combine features of PPOs and traditional health maintenance organizations (HMOs) whereby members are covered under capitation arrangements, but are given the option of going to providers outside the network. Traditional HMOs, i.e. closed panel HMO-type plans, formed the final and least common category; in our data this category included a small number of cases in Exclusive Provider Organizations (EPOs). EPOs are groups of medical care providers who have entered into written agreements with the employer under capitation arrangements similar to HMOs.[11]

In addition to the hospital characteristics previously described, we also included an HRR-level hospital market structure variable, namely the Herfindahl-Hirschman index (HHI) which measures market concentration in the area, defined as the sum of hospital squared market shares. We explored two ways of defining HHI. First, we counted each hospital as a separate entity. Second, in market areas with more than one hospital belonging to a particular multi-hospital system, we summed the share of hospitals within the system thereby counting them as one unit. All market shares were based on medical and surgical admissions. As expected the system based index yielded greater market concentration (Table 1). Since both HHI variables yielded similar results, we opted to include the coefficients for the more commonly used hospital-based HHI in Tables 1 and

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[11] Of the 791 of surgeries classified as fee-based in our sample only 22 were covered by consumer directed health plans (CDHP). All other surgeries in this category were coded as comprehensive fee-for-service (FFS). There was no statistical difference between prices in these plans. Of the 505 surgeries covered by HMOs, only 29 were coded as EPOs in our data.

2[12]. County-level HMO penetration rates, aggregated to metropolitan areas were obtained from the Health Resources and Services Administration's (HRSA) Area Resource File (ARF). The HMO penetration rates reported in ARF were calculated by dividing HMO enrollment data from the InterStudy County Surveyor Database by the U.S. population estimates; the underlying enrollment data pertain to the enrollee residence and do not rely upon HMO headquarters location. HHI and HMO penetration were previously used as proxies for the hospital's and the insurer's bargaining power (Dor, Grossman, and Koroukian, 2004).

While we are precluded from identifying individual hospitals and employers in these data, our analysis informs consumers and decision makers alike about the extent to which performance and the complexity of the underlying medical case contributes to the eventual pricing of a colorectal surgery.

4.2.b Hospital Performance Measures

We focus on hospital mortality, which has formed the basis of hospital level performance measures in numerous studies and in a variety of clinical settings, including that of colon resection (Hayanga et al., 2010). In particular we consider two measures of excess mortality, namely the standardized mortality ratio (SMR) and the risk standardized mortality ratio (RSMR). The SMR is the relatively simpler measure, thus more likely to have been accessible to various group purchasers in the study period for purposes of actuarial calculations (Rothman, 2012). On the other hand the RSMR involves more

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[12] Similarly, we experimented with hospital market shares based on the number of inpatient days; however this affected the indices only marginally.

complex methodology and was recently incorporated into the Hospital Compare rating system for the diagnoses of AMI and heart failure (CMS, 2012; Krumholz et al., 2005). We replicated the statistical approach with some modifications in risk-adjustment variables to reflect the diagnosis of colon cancer.

The SMR is defined as the ratio of “actual” mortality to “expected” mortality in the hospital. Actual mortality is calculated as the sample mortality rate for each hospital. Expected mortality is calculated as the average of predictions from a logistic regression that adjusts for patient-level characteristics and severity measures. RSMR is the ratio of “predicted” to “expected” mortality rates in the hospital, where both the predicted mortality rate and the expected mortality rate are estimated by Hierarchical (Random effects) Logistic regression model (see Krumholz et al., 2006a, 2006b). The hierarchical logistic regression incorporates a hospital-specific random intercept (which can be interpreted as a measure of the hospital’s adverse quality) in addition to adjusting for patient characteristics. The hospital predicted mortality is calculated as the average of patient level predictions from the pooled model that take both effects of covariates and estimated random intercepts into account. Here, expected mortality is the average of predictions assuming that each hospital random intercept is zero, or in other words, holding hospital quality constant.

Further emulating the Hospital Compare methodology, we estimate predicted mortality with Medicare administrative claims data, matching hospitals from this analysis to hospitals in the main analysis file. We use 3-year moving averages of hospital-level SMR and RSMR in our regression analyses.

5 Results

Table 2 allows for a comparison of results from price regressions using our alternative definitions of hospital performance, namely the standardized mortality ratio (SMR), and the risk-standardized mortality ratio, the RSMR. While the vast majority of employers in the MarketScan data offer employees one type of benefit plan only, the data would not allow us to identify the subset of employees who were offered a choice, thus endogeneity of plan choice is a concern. To avoid confounding effects due to potential endogeneity biases in the plan variables, we estimated pairings of models, with the plan indicators included and omitted. As seen in the table, omitting these variables had no substantive effects on coefficients of all other variables, thus we focus our discussion primarily on the models with all variables included. We report cluster-robust standard errors, to adjust for within-hospital correlations for patients treated in the same hospital.

In general, coefficient estimates were qualitatively similar across specifications. Noting that the coefficients in these semi-log models are simply the percent effect on price of a unit change in the variable, for expositional convenience we rescaled continuous variables with values between 0 and 1 (times 100); thus coefficients of the indices HMO penetration and HHI are interpreted as the effect of a percentage point change in the index on price. We further applied the adjustment $e^{\beta} - 1$ to the coefficients of binary explanatory variables in the discussion below.

As discussed earlier, the variables of greatest interest in this analysis were the measures of hospital quality as measured by SMR and RSMR. The coefficients on both measures of mortality are negative, but none of them is statistically significant. While the coefficients on SMR are very close to zero, those on RMSR are larger, and if statistically significant, would indicate a substantive negative relationship between quality and price. To show effect sizes, we changed SMR and RSMR in standard deviation units. We observe that increases by one, two, and three standard deviations of SMR corresponded to 0.36%, 0.74%, and 1.10% declines in price; the same analysis for RSMR yielded 1.19%, 2.35%, and 3.51% declines.

Among other possible determinants, there was no significant variation in prices due to age or gender (a minor exception occurred between age 50 and 60), payment differences tend to reflect illness severity and complexity of the underlying procedure significantly. While there was no difference in the price of partial surgery versus total surgery (referring to the surgical removal of part or the whole patient's colon), the price of laparoscopic surgery, a less invasive form of the procedure was 5.7-5.9% lower compared with surgery using standard incision. On the other hand, the price of surgery involving colostomy, a complex procedure that can be performed in conjunction with the main surgery, was about 26% higher than surgery alone in all model specifications. Prices for cases involving metastases and prices of emergency surgery are also significantly higher than the baseline case, (+21% and +35% respectively). The higher price associated with emergency surgeries might be due to the fact that these cases were taken outside of insurers' network. Similar to the effect of metastases, payments increase significantly in a step-wise fashion as patient severity rises, as reflected in the Elixhauser index.

Focusing on hospital type and benefit plan characteristics, the results are generally in line with what might be anticipated due to gradations in pricing power. Thus, prices at not-for-profit hospitals were about 10% lower relative to the default category, namely hospitals sponsored by local governments, whereas prices at for-profit hospitals were 8% higher. Prices at teaching hospitals were 4.6-5.4% higher compared with non-teaching hospitals, and prices at system-owned hospitals slightly lower compared with non-teaching and non-system hospitals, but statistically significant. Similarly, price differences associated with type of benefit plan are as anticipated, with prices at fee-based plans and point-of-service plans slightly higher than prices at the default category (PPOs), while prices lower in closed- HMO plans; however none of these price differences were statistically significant.

Turning next to market structure, we find that HMO penetration is highly significant, and exerts moderate downward pressure on prices. We interpret the results in Table 2 to mean that a one percentage point increase, relative to a mean HMO penetration rate of 10.9 on the 0-100 scale, is associated with a 0.004% reduction in price, or \$87; equivalently, a 10% increase in the penetration rate leads to a \$81 decrease in price, implying an elasticity =-0.04. We also find that hospital market concentration as measured by HHI tends to increase prices although the related coefficients were not statistically significant. However, we note that the HHI variables pertain to all inpatient admissions in the hospital and may not accurately reflect pricing power in the cancer segment of the market; cancer-specific market shares were not available in our data.[13]

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[13] We also explored system-based HHIs, whereby two or more hospitals located in a given market area and belonging to the same multi-hospital system are counted as a single entity (by summing their market shares). As expected, this resulted in more concentrated markets (the mean HHI was 0.201 compared with 0.142 for the hospital-based HHI), but with no improvement is statistical significance in our price models

6 Summary and Implications

Previous literature on hospital markets and pricing tended to focus on cardiac procedures or diagnoses. In this study we focus on the lesser explored case of colorectal cancer, a leading cause of death among all cancers, and its surgical treatments. In particular we explore transaction prices paid by benefit plans administered by large employers. While there were no significant differences by plan types administered this way, our analysis revealed a rational pricing structure, with price difference matching gradients in severity and complexity of the main surgical procedure and its variants.

The effects of greatest interest were those of the standardized mortality ratio (SMR) and the risk-standardized mortality ratio (RSMR), which are based on methodologies that are now standard under the federal Hospital Compare and other public reporting systems. Although measures focused particularly on cancer diagnoses are rarely included in such rankings, they are potentially accessible to large group purchasers that characterize our data. For both of the mortality measures studied, namely the SMR and the RSMR we found negative effects on price (adverse quality reduces price) which were consistent in all model specifications; however, the results were not significant. One possible explanation for this weak effect is that purchasers are not able to replicate quality scores for purposes of price negotiations. Another explanation is that such scores are accessible, but underlying demand for cancer treatment is not highly sensitive to quality differences among providers[14]. We are unable to distinguish between these explanations, and leave this for future exploration. Finally, we find high correlation between the SMR and RSMR (e.g. Figure A.1), suggesting that simply adding hospital

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[14] In the simple theoretical model this corresponds to the case in which a quality improvement causes the slope of the demand curve to become flatter.

random effects in the latter (and as reported on the Hospital Compare website) does not contribute additional information about the underlying hospital rankings.

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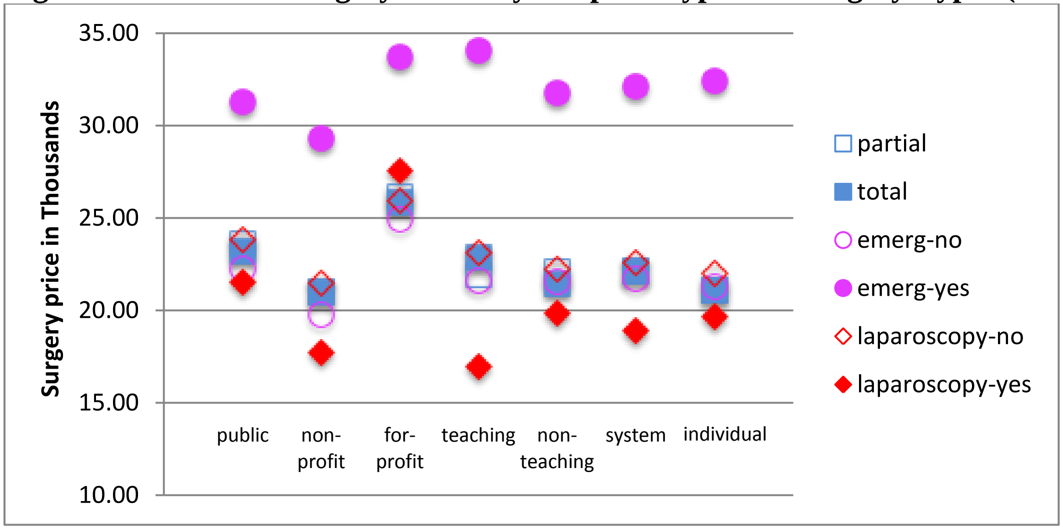
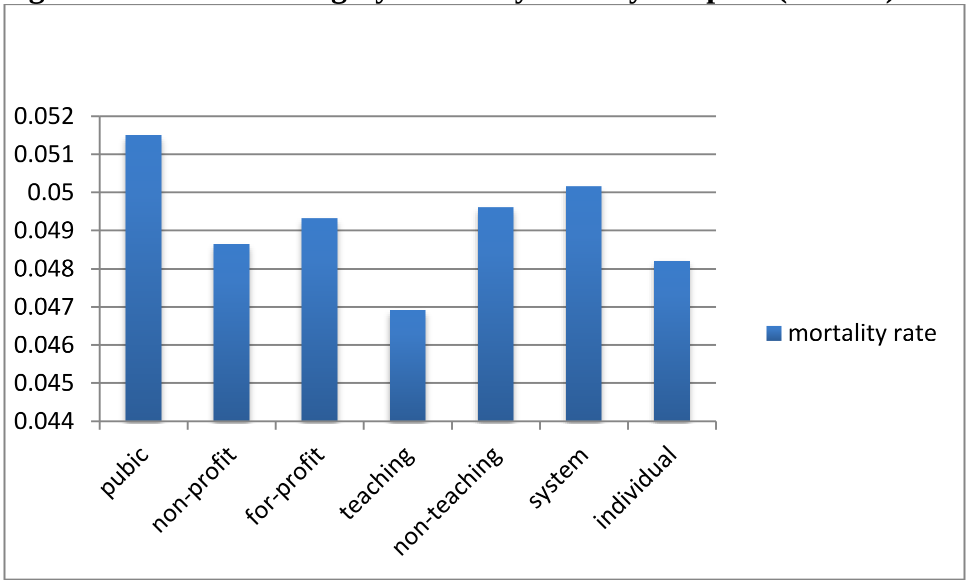
Figure 1. Colorectal Surgery Prices by Hospital Type and Surgery Types (Means)



Source: Authors' calculations from the 2002-2007 MarketScan Commercial Claims Encounter Files; 2007 prices, CPI adjusted, sample means;

Figure 2. Colorectal Surgery Mortality Rate by Hospital (Means)



Source: Authors' calculations from the Combined MEDPAR-MarketScan files.

Table 1: Variable Definitions and Summary Statistics

Variables	Data Source/Period	Mean	S.D.
Dependent Variable			
Hospital price ($)	MarketScan 2002-2007	21980.33	13683.78
Hospital-level outcomes			
Expected mortality	MEDPAR 2000-2007	0.049	0.069
Standardized Mortality Ratio	Same as above, (SMR)	1.038	1.443
Risk Adjusted SMR	Same as above, (RSMR)	1.013	0.131
Patient-level Severity			
Age	MarketScan 2002-2007	54.905	7.468
Male	Same as above, binary	0.510	0.500
Partial colectomy	Same as above, binary	0.791	0.406
Total colectomy	Same as above, binary	0.209	0.407
Colostomy	Same as above, binary	0.041	0.198
laparoscopy	Same as above, binary	0.122	0.327
Emergency	Same as above, binary	0.133	0.340
Metastasis	Same as above, binary	0.170	0.375
Elixhauser comorbidity	MarketScan 2002-2007, (0-4)	0.796	1.029
Elixhauser 1	MarketScan 2002-2007, binary	0.293	0.455
Elixhauser 2	Same as above, binary	0.127	0.333
Elixhauser 3	Same as above, binary	0.072	0.259
Insurer and hospital characteristics			
PPO	MarketScan 2002-2007	0.630	0.483
Fee based	Same as above, binary	0.144	0.351
POS	Same as above, binary	0.130	0.336
HMO+EPO	Same as above, binary	0.096	0.294
Teaching hospital	AHA-MarketScan Crosswalk, binary	0.180	0.384
System hospital	Same as above, binary	0.649	0.477
Public (local government)	Same as above, binary	0.143	0.350
Non-for-profit	Same as above, binary	0.735	0.441
For-Profit	Same as above, binary	0.122	0.328
Market Structure			
Hospital Herfindahl index	AHA, 2002-2007	0.147	0.123
System Herfindahl index	AHA, 2002-2007	0.205	0.130
HMO penetration	Area Resource File, 2002-2007	0.109	0.090
Total Patients		5293	
Total hospitals		1141	

Notes: a) Expected mortality rate: Based on Medicare Provider Analysis and Review (MEDPAR), the model includes covariates such as age, gender, Elixhauser index, metastasis status, emergency colorectal resection, procedure type, year of procedure. b) Standardized Mortality Rate (SMR): “30 day risk-adjusted mortality rate” is computed by the statistical methods of Centers for Medicare & Medicaid Services. SMR = actual mortality rate / expected mortality rate

Table 2: Results from Log Price Models

	Models with SMR		Models with RSMR	
VARIABLES	*β*	*β*	*β*	*β*
smr_moving average	-0.001	-0.001		
	(0.012)	(0.013)		
rsmr_moving average			-0.090	-0.086
			(0.108)	(0.107)
age50	-0.058**	-0.057**	-0.058**	-0.057**
	(0.024)	(0.025)	(0.024)	(0.025)
age60	-0.010	-0.009	-0.010	-0.008
	(0.031)	(0.031)	(0.031)	(0.030)
Male	0.025	0.026	0.025	0.026
	(0.018)	(0.018)	(0.018)	(0.018)
Partial	0.014	0.014	0.016	0.016
	(0.024)	(0.025)	(0.025)	(0.025)
Laparoscopic	-0.059*	-0.059	-0.060*	-0.061*
	(0.036)	(0.036)	(0.037)	(0.037)
Colostomy	0.230***	0.229***	0.232***	0.231***
	(0.041)	(0.041)	(0.041)	(0.041)
Metastasis	0.192***	0.191***	0.192***	0.192***
	(0.028)	(0.028)	(0.028)	(0.028)
Emerg	0.300***	0.301***	0.300***	0.301***
	(0.031)	(0.031)	(0.031)	(0.031)
elixhauser1	0.056***	0.057***	0.057***	0.058***
	(0.021)	(0.021)	(0.022)	(0.021)
elixhauser2	0.168***	0.170***	0.171***	0.172***
	(0.029)	(0.029)	(0.029)	(0.029)
elixhauser3	0.287***	0.288***	0.288***	0.290***
	(0.041)	(0.041)	(0.041)	(0.041)
non-profit	-0.103**	-0.104**	-0.106**	-0.107**
	(0.050)	(0.049)	(0.051)	(0.049)
for-profit	0.077	0.077	0.075	0.075
	(0.066)	(0.065)	(0.066)	(0.066)
Teaching	0.052	0.052	0.046	0.047
	(0.043)	(0.042)	(0.043)	(0.042)
System	0.007	0.008	0.008	0.008
	(0.035)	(0.034)	(0.035)	(0.034)
Fee-based	0.005		0.006	
	(0.033)		(0.033)	
POS	0.007		0.005	
	(0.045)		(0.045)	
HMO-EPO	-0.020		-0.023	
	(0.047)		(0.046)	
HMO rate x100	-0.004**	-0.004**	-0.004**	-0.004**
	(0.002)	(0.002)	(0.002)	(0.002)
Hospital HHI x100	0.0016	0.002	0.0015	0.002
	(0.001)	(0.001)	(0.001)	(0.001)
2002b.year	0.000	0.000	0.000	0.000

	(0.000)	(0.000)	(0.000)	(0.000)
2003.year	-0.076**	-0.077**	-0.077**	-0.078**
	(0.038)	(0.037)	(0.038)	(0.037)
2004.year	-0.109***	-0.109***	-0.109***	-0.109***
	(0.039)	(0.039)	(0.039)	(0.040)
2005.year	-0.098***	-0.098***	-0.099***	-0.099***
	(0.037)	(0.036)	(0.037)	(0.037)
2006.year	-0.178***	-0.178***	-0.177***	-0.178***
	(0.042)	(0.042)	(0.042)	(0.042)
2007.year	-0.171***	-0.172***	-0.171***	-0.172***
	(0.043)	(0.043)	(0.043)	(0.043)
Constant	10.032***	10.029***	10.121***	10.115***
	(0.059)	(0.058)	(0.127)	(0.124)
log likelihood	-57458.21	-57457.71	-57456.88	-57456.88
Observations	5,293		5,293	

Robust standard errors in parentheses
***p<0.01** p<0.05, * p<0.10

Appendix

The general methodology we use to estimated expected mortality and excess mortality for colorectal surgeries was based on the methodology found in Hospital Compare for AMI and heart failure[15]. We replicated this approach as closely as possible, with some modifications needed given the change in diagnosis and clinical setting to that of colon cancer.

Rather than providing simple standardized mortality ratios (SMRs), Hospital Compare provides rankings based on the more complex risk-standardized mortality ratio (RSMR). SMR is defined as the ratio of actual mortality to expected mortality in the hospital, or equivalently, the ratio of actual and expected mortality rates. Let the hospital h's actual rate is $y_h = d_h \,/\, n_h$, where d_h = number of actual deaths in hospital h, n_h = number of cases in the hospital.

$$S\widehat{M}R_h = \frac{y_h}{E(y_h|x_h;\beta)} = \frac{d_h}{p_r n_h}$$

Accordingly, x_h is the vector of patient characteristics and severity measures in the hospital (e.g. the hospital means)[16], and p is the probability of death in the population given the distribution of characteristics found in h. When actual mortality exceeds expected mortality, the hospital's performance is said to be worse than average. Expected

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[15] www.hospitalcompare.hhs.gov, accessed November 12, 2011. A more formal discussion is found in Krumholz et al., 2006.

[16] Expected mortality is simply the predicted value, based on the pooled regression of all patients in all hospitals and the hospital means of h. We use terminology found in the relevant literature.

mortality is typically estimated from patient level data using a binary logit model (Mohammed and Stevens, 2013; Silber et al., 2010)[17].

RSMR is the ratio of predicted to expected mortality rates in the hospital, where both the predicted mortality rate and the expected mortality rate are estimated by Hierarchical Generalized Linear Modeling (HGLM) with a logit link function (see Krumholz et al., 2006a, 2006b). Here, in addition to adjusting for patient characteristics, the predictive mortality model incorporates a random hospital-specific effect (α) that accounts for within-hospital correlations of the observed patient outcomes. Expected mortality in the denominator is also estimated by HGLM. Accordingly, the excess mortality score is redefined as the ratio of predicted to expected mortality rate, with a random effects term set equal to zero:

$$RS\widehat{M}R_h = \frac{E(y_h|x_h;\beta,\alpha_h)}{E(y_h|x_h;\beta,\alpha_h=0)}$$

As with the Hospital Compare methodology, we employ inpatient administrative claims data (MEDPAR files) for Medicare beneficiaries enrolled in Original Medicare (traditional fee-for-service Medicare) hospitalized in short-term acute care hospitals. Similarly, we followed Hospital Compare by tracking deaths that occur within 30 days of a hospital admission, rather than tracking in-hospital mortality only. Using pooled data for the years 2000-2007[18], resulted in a sample of 131,159 patients who underwent colon

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[17] When general measures of mortality are of interest, e.g., all-cause mortality or regional mortality, cruder estimators are often used, based on weighted averages of population mortality rates for broad patient groupings.

[18] Note that all of the expected and predicted mortality rates in any given year are obtained using covariate values for that year, while the regression coefficients are estimated from the pooled regression for all years. A Wald test for inter-temporal stability indicated that all explanatory

cancer surgery. Hospitals where colon resection was a fairly rare event (less than 21 cases in the entire period), were excluded from our mortality regressions[19]; 393 observations were dropped due to this restriction. The mean of 30-day mortality was 0.045, with a standard deviation of 0.207. Trendlines for all estimation approaches are found in Figure A-1. In practice, all of the models yield close results. There appears to be some fluctuations of 30-day mortality rates from between years, but all bends occur within a tight range around the mean.

Table A-1 presents regression coefficients and odds ratios from the predictive mortality regressions corresponding to SMR (generalized linear models with logit link function), and RSMR (HGLM with a logit link function). Risk adjusters include age, gender, an indicator of colorectal cancer severity (metastasis), and emergency[20]. The Elixhauser score is a summary measure of the presence of other diagnoses or comorbidities. The odds-ratios for risk adjusters in the two models were virtually identical. The results clearly indicate increases in mortality rates as patient severity increases (metastases, number of comorbidities), along with a 7% increase due to additional year of, and a 34% differential for males relative to females.

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variables interacted with the binary year indicators were not jointly significant, $\chi^2(54)=51.37$, p = 0.3433.

[19] Under Hospital Compare, hospitals with less than 21 cases were retained in the data, but assigned the (national) sample mean characteristics. Rather than lumping together all small hospitals in each with relatively rare occurrences of colorectal surgeries, we opted to exclude such hospitals from our mortality regressions. For sampling units with < 21 parametric methods for calculating standard errors do not apply (Kahn and Sempos, 1989).

[20] ICD-9 codes for metastatic disease are: 196.0, 196.1, 196.3-196.5, 196.7-196.9, 197.0-197.4, 197.6-199.0; ICD-9 codes for emergency surgery were: intestinal obstruction (560.8, 560.9), peritonitis (567.0, 567.2) and perforation (569.83). See Cooper et al., 1999, and Merkow et al., 2013.

The Hospital Compare web site further explains that mortality rankings are based on aggregating mortality for three years ending with the reference year. To emulate this aspect, we construct three-year moving averages of SMR and RSMR, and we incorporate the transformed values into our price regressions. Three year averaging has the added advantage of smoothing random temporal shocks. The price regressions in Tables 2-3 include SMR and RSMR as described above, namely with the averaging for years t, t-1, t-2 in the hospital matched to prices in year t[21].

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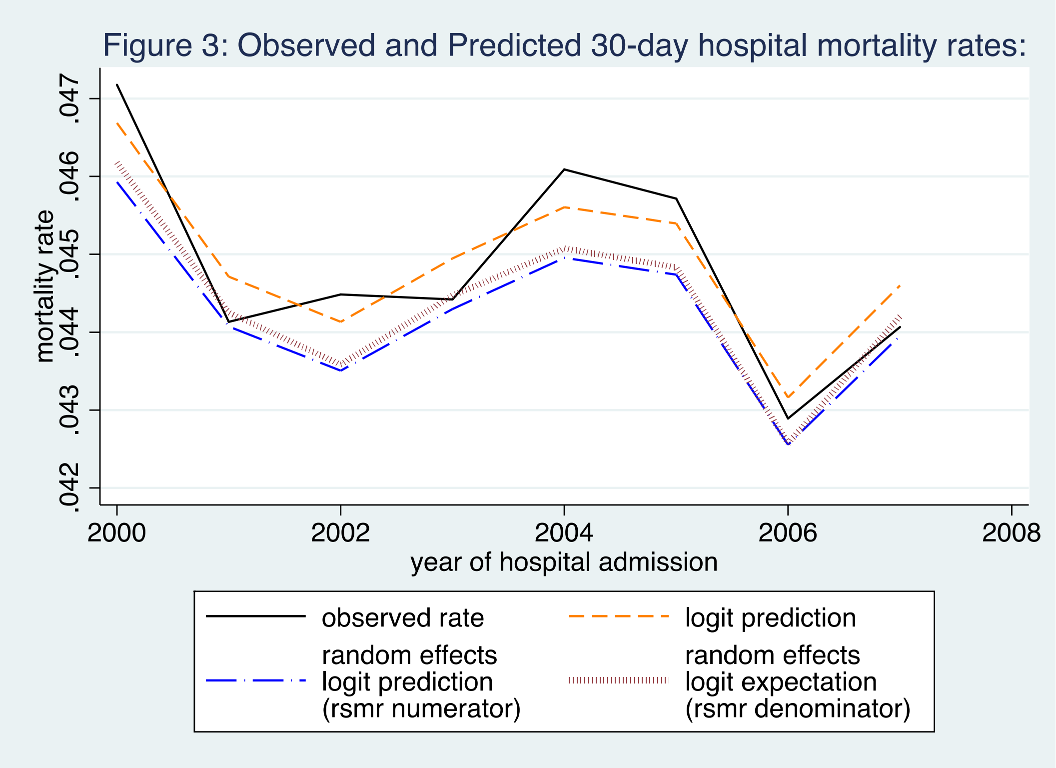
[21] We also explored alternative specifications such as entering mortality with a one-year lag only; in practice this yielded virtually identical results as the 3-year averaging. Results are available upon request.

Table A-1 Estimating SMR and RSMR

	SMR (logit)		RSMR (logit, random effects)	
VARIABLES	β	odds ratio	β	odds ratio
Age	0.068***	1.070	0.069***	1.071
	(0.003)		(0.003)	
Male	0.293***	1.341	0.292***	1.340
	(0.027)		(0.027)	
elixcat1	0.538***	1.712	0.541***	1.717
	(0.094)		(0.094)	
elixcat2	0.726***	2.066	0.728***	2.070
	(0.091)		(0.091)	
elixcat3	0.923***	2.518	0.922***	2.514
	(0.089)		(0.090)	
Metastasis	0.969***	2.635	0.978***	2.658
	(0.029)		(0.029)	
Emerg	1.066***	2.904	1.075***	2.930
	(0.032)		(0.033)	
Total.surg	0.743***	2.102	0.739***	2.093
	(0.083)		(0.084)	
2001.year	-0.041	0.960	-0.040	0.961
	(0.052)		(0.052)	
2002.year	-0.074	0.929	-0.076	0.927
	(0.052)		(0.053)	
2003.year	-0.050	0.951	-0.050	0.952
	(0.052)		(0.053)	
2004.year	-0.037	0.963	-0.038	0.963
	(0.053)		(0.053)	
2005.year	-0.047	0.954	-0.049	0.952
	(0.054)		(0.054)	
2006.year	-0.118**	0.888	-0.121**	0.886
	(0.055)		(0.056)	
2007.year	-0.099*	0.906	-0.096*	0.908
	(0.056)		(0.056)	
Constant	-9.532***	0.000	-9.617***	0.000
	(0.224)		(0.226)	
Random effects s.d.			0.277	
Observations	130,766		130,766	
Number of hospitals	1,154		1,154	

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Figure A-1: Observed and Predicted 30-day Hospital Mortality Rates:



Source: Authors' analysis of MEDPAR files.