Published in final edited form as:

Forum Health Econ Policy. ; 15(2): 1–25. doi:10.1515/fhep-2012-0016.

Can Centralization of Cancer Surgery Improve Social Welfare?

Vivian Ho, Ph.D.^{a,b,c}, Marah Short, M.A.^a, Meei-Hsiang Ku-Goto, M.S.^a

^aJames A. Baker III Institute for Public Policy, Rice University

^bDepartment of Economics, Rice University

^cDepartment of Medicine, Baylor College of Medicine

Abstract

The empirical association between high hospital procedure volume and lower mortality rates has led to recommendations for the centralization of complex surgical procedures. Yet redirecting patients to a select number of high-volume hospitals creates potential negative consequences for market competition. We use patient-level data to estimate the association between hospital procedure volume and patient mortality and costs. We also estimate the association between hospital market concentration and mortality, cost, and prices. We use our estimates to simulate the change in social welfare resulting from redirecting patients at low-volume hospitals to high-volume facilities. We find that higher procedure volume leads to significant reductions in mortality for patients undergoing surgery for pancreatic cancer, but not colon cancer. Procedure volume also influences costs for both surgeries, but in a nonlinear fashion. Increased market concentration is associated with higher costs and prices for colon cancer, but not pancreatic cancer patients. Simulations indicated that centralizing pancreatic cancer surgery is unambiguously welfare enhancing. In contrast, there is less evidence to suggest that centralizing colon cancer surgery would be welfare improving.

1. INTRODUCTION

Hospitals performing more surgical procedures tend to have better patient outcomes. This relation has been identified for several complex operations, including coronary artery bypass graft surgery (CABG), gastric bypass surgery, and eight cancer resection operations (J. D. Birkmeyer *et al.* 2002; H. S. Luft *et al.* 1979; W. E. Encinosa *et al.* 2009). These findings have led to recommendations to “regionalize” complex surgeries; patients seeking surgery at low-volume hospitals should be re-directed to a nearby higher volume facility (J. D. Birkmeyer 2000; A. M. Epstein 2002).

However, efforts to centralize care in order to reduce poor outcomes fail to consider the welfare consequences of increased market concentration. The economics literature suggests that increased market concentration leads to higher prices for hospital care. Moreover, some studies have found that increased hospital competition improves patient outcomes. The

implications of centralizing surgery for consumer welfare require a careful assessment of both the benefits and costs of policy intervention.

We examine colon and pancreatic cancer surgery to estimate the welfare consequences of centralizing surgery. We choose cancer surgery, because of its substantial cost to the U.S. health care system. The cost to Medicare of colon cancer surgery was estimated to exceed \$1 billion in 2002 (J. L. Warren *et al.* 2008). We choose two operations that differ in terms of frequency performed and difficulty, so that we can examine how these factors influence our welfare calculations. Pancreatic cancer surgery has been demonstrated to have a relatively large volume-outcome relation, while the volume-outcome effect for colon cancer surgery is significant, but modest (D. Schrag *et al.* 2000). Thus, the mortality benefits of regionalizing pancreatic surgery may have a larger impact on social welfare than for colon cancer resection. On the other hand, colon cancer resection is performed 13 times more often than pancreatic resection each year. The revenue impact on each hospital of the more common procedure may lead to stronger competitive effects across hospitals relative to pancreatic resection.

We begin by estimating the association between hospital procedure volume, and both patient mortality and costs. We also estimate the association between hospital market concentration and mortality, cost, and prices. We then use our estimates to simulate the change in welfare resulting from redirecting patients at low-volume hospitals to higher-volume facilities.

We find that higher procedure volume leads to significant reductions in mortality for patients undergoing surgery for pancreatic cancer, but not colon cancer. Procedure volume influences costs for both surgeries in a nonlinear fashion. Increased market concentration is associated with higher costs and prices for colon cancer, but not pancreatic cancer patients. Simulations indicate that centralizing pancreatic cancer surgery is unambiguously welfare enhancing, but there is less evidence to suggest that centralizing colon cancer surgery would be welfare improving.

The results have important implications for policy makers. The Leapfrog Group and several states publish information on hospital pancreatic cancer procedure volume. Leapfrog explicitly recommends that patients seek pancreatic cancer surgery in hospitals performing 11 or more procedures per year (The Leapfrog Group for Patient Safety 2005). Yet rising costs for complex surgery pose a substantial financial burden for those paying for care. Greater market concentration may contribute to higher costs and prices for colon cancer surgery, so that centralization of this surgery should not be encouraged.

Section 2 reviews the literature on the relationship between provider volume and patient outcomes; and the effect of market competition on patient outcomes, costs, and prices. Section 3 presents our empirical model. Section 4 contains our results, and we conclude in Section 5.

2. PREVIOUS LITERATURE

In 1979, Luft *et al.* determined that hospitals that annually performed 200 or more operations of open-heart surgery, vascular surgery, or transurethral resection of the prostate

had lower casemix-adjusted death rates than hospitals with lower volumes (H. S. Luft *et al.* 1979). Since then, hundreds more articles have been published documenting a volume-outcome relationship for various complex operations (E. A. Halm *et al.* 2002).

Luft *et al.* observed that the volume-outcome relationship could reflect a learning effect; the quality of care should improve with the experience of those providing it. However, the authors noted that the volume-outcome effect could signify selective referral. Larger numbers of patients may be referred to institutions or surgeons known to have better outcomes. The volume-outcome could also reflect unobserved factors that lead some hospitals to treat patients with lower casemix severity, which would produce better patient outcomes.

Two strategies have been used to address the potential endogeneity between hospital volume and patient outcomes. Some researchers have included hospital fixed effects when regressing inpatient mortality on hospital volume (Martin Gaynor *et al.* 2005; Ho V. 2002; A. Sfeka 2008). The fixed effects allow one to examine how within-hospital increases in procedure volume affect within-hospital changes in patient outcomes, so the results are uncontaminated by cross-sectional unobserved heterogeneity across hospitals.

Some studies have also controlled for endogeneity in the volume-outcome relationship by instrumenting for hospital volume. Gaynor *et al.* instrument for CABG surgery volume using the number of residents and the number of other hospitals performing CABG within a fixed geographic radius of the patient's hospital (Martin Gaynor *et al.* 2005). They cannot reject the null hypothesis that hospital volume is an exogenous predictor of inpatient mortality. Furthermore, their instrumental variable estimates yield a larger estimate of the effect of hospital volume on inpatient mortality, which contradicts the selective referral hypothesis. Gowrisankaran *et al.* control for endogeneity by estimating a first-stage multinomial model of hospital choice for each patient, with distance from each hospital as an explanatory variable. The predicted probabilities of choosing each hospital are summed across patients, yielding a predicted value of hospital volume that is unconfounded by unobservables for the second stage of estimation (G. Gowrisankaran *et al.* 2006). Gowrisankaran *et al.* cannot reject the hypothesis that hospital volume is an exogenous predictor of inpatient mortality for patients who undergo surgery for pancreatic cancer. They also analyze CABG surgery, where they find that hospital volume is endogenous. However, they obtain the same finding as Gaynor *et al.*; accounting for endogeneity leads to a larger negative relationship between hospital volume and inpatient mortality.

Given these past results, we estimate regressions in this study which include hospital fixed effects, but we will not instrument for hospital volume. The past literature cannot reject the null hypothesis that hospital volume is exogenous for pancreatic cancer resection. Colon cancer resection is similar to CABG surgery, in that it is a common procedure, with relatively high procedure volumes for those hospitals performing the operation. When interpreting our results for colon cancer, we keep in mind that we may have underestimates of the relationship between higher hospital procedure volume and reduced inpatient mortality.

A separate literature examines the relationship between hospital market concentration and patient outcomes. McClellan and Kessler found that areas with higher hospital market competition had lower mortality rates for heart attack patients (D. P. Kessler, M. B. McClellan 2000). However, two other studies found no significant association between hospital competition and patient outcomes. One study was based on pancreatic cancer surgery (V. Ho *et al.* 2007), and another study was based on overall hospital risk-adjusted mortality (D. B. Mukamel *et al.* 2001). Another study concludes that the association between hospital competition and 30-day mortality varies across regions and the condition being studied (J. J. Escarce *et al.* 2006). An additional study found that increased competition for HMO patients admitted for heart attack or pneumonia reduces inpatient mortality, while greater competition for Medicare patients is associated with higher mortality; so that increased competition for patients had little net effect in their study sample (G. Gowrisankaran, R. Town 2003). Thus the association between hospital competition and inpatient mortality varies by disease class, and perhaps by payer status.

Several studies conclude that increased market concentration is associated with higher hospital prices (M. Gaynor, W. B. Vogt 2000). However, these studies examined the association between market concentration and price at the aggregate level for all patients in a hospital; rather than for a particular disease. One study examined the association between hospital competition and price for CABG patients (Avi Dor *et al.* 2004). In that study, an increase in the Herfindahl index from a low (0.25) to a high level of concentration (0.75) is associated with a 15 percent increase in the price of treatment. Previous studies examining overall hospital services and disease-specific data (for heart attack patients) have also found that increased market competition is associated with lower average patient costs (D. P. Kessler, M. B. McClellan 2000; J. Zwanziger, G. A. Melnick 1988). However, we know of no previous studies which have measured the association between hospital competition and average costs for cancer surgery.

Despite numerous articles of the volume-outcome relationship for surgery for pancreatic and colon cancer, only one study has controlled for unobserved characteristics across hospitals with fixed effects. Similarly we know of only one study which has examined the association between hospital competition and inpatient mortality for pancreatic cancer surgery, and we know of no such studies for colon cancer surgery. There are no studies which examine the association between hospital market competition and either prices or costs for cancer surgery. In addition, we know of no studies estimating the volume-cost relationship for cancer surgery that utilize hospital fixed effects. Previous studies find that higher hospital volume is associated with lower costs for complex cardiac procedures (Ho V. 2000; V. Ho, L. A. Petersen 2007), so additional economies of scale resulting from regionalization of cancer surgery could be possible as well.¹

¹One may question whether hospitals have already exhausted all economies of scale in complex surgery, using higher volume to undercut the prices of competitors. However, cancer surgery is relatively expensive. Thus, relatively low copayment and coinsurance rates for hospitalization, as well as relatively low limits on out-of-pocket payments for private health insurance in the U.S. suggest that patients bear little if any of the marginal cost of higher priced hospitals. Other patient and referring-physician factors are more likely to influence hospital choice.

The previous literature implicitly recognizes that knowledge of patient outcomes, hospital prices, and costs are essential for understanding the implications of hospital size and hospital competition on consumer welfare. Yet no previous studies have simultaneously examined all of these factors to quantify the potential impact of centralizing complex surgery for social welfare or consumer welfare. We attempt to distinguish between these two welfare calculations, because social welfare incorporates potential cost savings resulting from regionalization. In contrast, changes in consumer welfare resulting from centralization do not include hospital cost savings, because they may not be passed on to the consumer as lower prices. We have detailed patient information on treatment, costs, and prices, which allows us to fill this void in the literature.

3. EMPIRICAL MODEL AND DATA

We use patient-level data on colon or pancreatic cancer surgery to estimate the potential change in social welfare from centralizing surgery at high-volume hospitals. To estimate the change in societal welfare resulting from centralizing surgery, we calculate:

$$\Delta SW_{ih} = (\Delta V_{ih} - \Delta C_{ih}) \quad (1)$$

where ΔSW_{ih} represents the change in societal welfare for patient i at hospital h of centralizing surgery, ΔV_{ih} represents the change in the value of surgery to society with regionalization, and ΔC_{ih} represents the estimated change in hospital costs resulting from regionalization.

When deriving ΔV_{ih} , we assume that the set of patients receiving surgery remains the same after regionalization. That is, doctors will continue to refer patients for surgery based on their clinical prognosis rather than marginal changes in the quality of care. In addition, insured patients who have reached this stage of treatment are likely to be relatively insensitive to price increases when deciding whether to undergo surgery. For both pancreatic and colon cancer, surgery is the only option for treatment with curative intent. Chemotherapy and radiation therapy are potential adjuvant treatments, but not substitutes. It might have been helpful to estimate demand curves for each of the operations we study to verify this assumption. However, the dataset we are using to estimate the determinants of surgery prices does not contain information on several hospital characteristics which are needed to estimate a well-specified demand curve. Thus, ΔV_{ih} depends only on the change in inpatient mortality resulting from centralization and the value of the corresponding life years gained.

Computation of the change in the expected value of surgery begins with coefficient estimates from the regression:

$$Mortality_{iht} = f(HERF_{ht}, Volume_{ht}, Z_{ht}, X_{iht}, \eta_t, \phi_h) \quad (2)$$

where the unit of observation is a patient i admitted to hospital h in year t . Mortality is set equal to 1 if patient i in hospital h in year t dies inhospital, and 0 otherwise. Separate logistic specifications of Equation (2) are estimated for colon and pancreatic cancer operations.

The variable $HERF_{ht}$ represents the Herfindahl index in the market in year t for hospital h where the patient received surgery. We hypothesize that the coefficient on $HERF_{ht}$ will be positive in Equation (2); patients treated at a hospital facing less competition (higher market concentration) will have higher inpatient mortality. We defined two different versions of $HERF_{ht}$. Market concentration at either the procedure level or the level of the overall hospital could influence the competitive behavior of the facility.

In the first case, $HERF_{ht}$ was defined based only on the number of either colon or pancreatic resections performed by each hospital. For this case, we address concern that the conventional measure of $HERF_{ht}$ (the sum of each hospital's market share squared) is endogenous. Increased competition may lead hospitals to draw patients from a larger geographic area, which in turn influences the boundaries of markets defined using patient flows. Because we know the residential zip code for each patient, we used distance from each hospital to construct a first stage multinomial choice model to predict the probability the patient chose each hospital in their state.² The predicted probabilities derived from these regressions were then used to create a hospital-specific measure of $HERF_{ht}$ (D. P. Kessler, M. B. McClellan 2000; G. Gowrisankaran, R. Town 2003).

In the second case, $HERF_{ht}$ was defined based on the total number of admissions of all patients for each hospital as reported in the American Hospital Association annual survey. Because we lack data on the zip code of all patients (not only cancer patients) treated by each hospital, we use the Dartmouth Atlas Hospital Referral Regions (HRRs) to define local hospital market borders and compute the sum of market shares squared by HRR. The 306 HRRs were defined based on a combination of the geographic availability of tertiary care facilities in the U.S., the proportion of patients in each zip code treated in these facilities, and geographic contiguity taking into account major travel routes (e.g. interstate highways) (Center for the Clinical Evaluative Sciences, Dartmouth Medical School 2000). HRRs satisfy a basic criteria for definition of markets in antitrust: Few patients living within the HRR travel outside the HRR to receive care, and few patients living outside the HRR receive hospital care within the HRR.

The variable $Volume_{ht}$ represents annual procedure volume in the admitting hospital h in year t . In addition to a linear specification of $Volume_{ht}$ in the mortality regressions, we experiment with several specifications of volume as a piecewise linear spline, with the knot at multiple different values of $Volume_{ht}$ observed in the data. This approach allows us to test for potential nonlinear relationships between procedure volume and mortality, as well as determine whether there is a threshold volume at which the volume-outcome relationship becomes flat.

²The choice set for patients in New Jersey and New York included hospitals from both states.

The vector X_{iht} represents indicator variables for patient characteristics. The regressions include a vector of year indicators η_t and a vector of hospital specific fixed effects ψ_h . With these fixed effects, the coefficients represent the effect of within-hospital changes in procedure volume on inpatient mortality. Because very few hospitals in our sample experienced a change in ownership, teaching status, or bedsize during the sample period, the hospital fixed effects also absorb these characteristics, so these variables are not included in the regressions.

For both cancer surgeries, we predict the changes in mortality from two potential centralization strategies. While proposal (1) represents a relatively modest attempt to centralize care, plan (2) represents an aggressive approach. These two scenarios serve as a lower and upper bound to the potential impact that regionalization could have on consumer and social welfare.

Proposal 1): For each procedure we identify those hospitals in the lowest volume quartile for the most recent sample year. We use the residential zip code for patients treated in these hospitals to “reassign” them to the closest hospital exceeding this volume cutoff. After calculating the simulated hospital volume and market concentration each patient would experience under this scenario, the coefficient estimates from equation (2) are used to predict the change in mortality each patient would experience under this regionalization policy.

Proposal 2): For pancreatic cancer surgery, (which is commonly referred to as the Whipple procedure), we identify hospitals which are below the highest volume quartile for the most recent sample year. For colon resection, we identify hospitals below the median volume for the most recent sample year. For both procedures, we again use residential zip code for patients treated in these hospitals to “reassign” them to the closest hospital which exceeds their respective volume cutoff. We then calculate the simulated hospital volume and market concentration each patient would experience under this scenario. We choose a higher volume criterion for pancreatic versus colon cancer surgery, because pancreatic surgery is more rare. Thus, more aggressive regionalization would be less disruptive system-wide. We only use the coefficients from the volume and market concentration variables in the simulations if they were statistically significant in the regressions. In addition, market concentration will only increase in cases where $HERF_{ht}$ is calculated based on the number of cancer operations performed at a particular hospital. Regionalization of cancer operations would have a negligible impact on the total number of admissions for any hospital. Coefficients on $HERF_{ht}$ which are based on total admissions remain of interest, because they examine how generally concentrated markets influence consumer prices.

Deriving an estimate of V_{iht} requires an estimate of the increase in life expectancy resulting from regionalization. Post-discharge life expectancy by hospital volume for colon and pancreatic cancer patients has been estimated using long-term survival data and Markov modeling (E. V. Finlayson, J. D. Birkmeyer 2003). Life expectancy for each patient is derived by multiplying the patient’s predicted mortality in hospital by their estimated post-discharge life expectancy derived from the previous literature. Thus, regionalization can

increase life expectancy either through a reduction in in-hospital mortality or a volume-outcome effect on long-term survival post-discharge.

The resulting life expectancy figures must be multiplied by a dollar value per year of life to calculate V_{ih} . Many studies value a year of life in perfect health between \$75,000 and \$150,000 (D. M. Cutler 2004). We construct an estimate of V_{ih} using \$100,000 to value a year of life.

An estimate of C_{ih} is derived from the following regression:

$$Cost_{iht} = f(HERF_{rt}, Volume_{ht}, Z_{ht}, X_{iht}, \phi_h, \eta_t) \quad (3)$$

where $Cost_{iht}$ represents the hospital costs associated with treating patient i in hospital h in year t , and the other explanatory variables are as described above.

We utilize patient-level hospital discharge abstract data from four U.S. states to estimate the mortality and cost regressions. We obtained discharge data from the states of California, Florida, New Jersey, and New York for the years 2001 through 2005. Following previous studies, these colon and Whipple procedures were identified based on ICD-9-CM procedure codes with a corresponding diagnosis of cancer (J. D. Birkmeyer *et al.* 1999; G. S. Cooper *et al.* 1996; J. B. Dimick *et al.* 2003; T. A. Gordon *et al.* 1998).

The dependent variable in the cost regressions reflects the cost of the entire inpatient stay. Provider volume may lead to efficiencies in the operating room, but case volume may also reduce postoperative complications or length of stay, which also influence costs. The discharge abstracts report hospital charges for each patient's stay. These charges were inflated to year 2005 dollars using the All-Urban Consumer Price Index, then multiplied by a hospital- and year-specific cost-to-charge ratio to reflect inpatient costs. Annual cost-to-charge ratios for each hospital were derived from Medicare cost reports.

Patients with estimated costs exceeding \$1 million for their entire stay or costs per day exceeding \$50,000 were dropped from the sample. Colon cancer patients with total costs less than \$1,000 and Whipple procedure patients with total costs under \$8,000 for their entire stay were also excluded from the analysis. These values likely reflect coding error.

The patient characteristics X_{iht} in the mortality and cost regressions include: age (<60, 60–69, 70–79, 80+), female, black or other race, urgent/emergent admission, and cancer stage (no nodal involvement/nodal involvement/metastasis). To control for patient casemix, we include indicator variables for each non-cancer comorbidity specified in the AHRQ Elixhauser comorbidity index (A. Elixhauser *et al.* 1998). The regressions include a set of cancer-specific indicators that we identified from previous literature. These indicators control for different types of pancreatic cancer (J. D. Birkmeyer *et al.* 1999) or reasons for colon cancer resection (D. Schrag *et al.* 2000).

We also test whether patients face an increase in the price of surgery following regionalization due to lower hospital market competition. To construct P_i , we estimate the following equation:

$$Price_{iht} = f(HERF_{ht}, Z_{ht}, X_{iht}, \phi_h, \eta_t) \quad (4)$$

where $Price_{iht}$ represents the payment to hospital h for treating patient i in year t . Because Medicare and Medicaid prices are set administratively, equation (4) is only estimated for a sample of private-pay patients. The coefficients from this regression and the simulated values of the Herfindahl index described above can be used to predict price changes resulting from a modest versus an aggressive attempt to centralize cancer surgery. Changes in prices do not enter directly into the social welfare simulations, because a change in price (assuming the total number of patients treated remains constant) represents a transfer from patients to hospital providers.

The price regressions are estimated using Medstat's MarketScan Commercial Claims and Encounters database, which contains privately insured paid medical claims. The data come from approximately 45 large employers (most with employees in several states), health plans, and government and public organizations. The database encompasses almost 100 payers, including commercial insurance companies, Blue Cross and Blue Shield plans, and third-party administrators, covering more than 6 million covered lives in 2003.

The MarketScan database lists the "gross payment" to the hospital for a particular admission. The gross payment represents the actual dollar amount that the hospital received for an admission from all sources; from the insurer, as well as patients' out-of-pocket deductibles and copayments. The MarketScan hospital gross payment is the most accurate measure of hospital "price" that we have located from any geographically diverse data source. We cannot use the MarketScan data to estimate the relation between hospital volume and mortality, because the database reports on only some discharges from each hospital. Medstat used patient zip code to identify the HRR for each admission, so that we can estimate the association between market concentration and hospital prices.

The price regressions include controls similar to those for the mortality and cost regressions, although the MarketScan database does not report patient race. Because the MarketScan data did not include the universe of cancer surgery patients treated in any HRR, we could only calculate a Herfindahl index based on the total number of hospital admissions for each facility. The sample sizes for the MarketScan data were much smaller than for the state discharge databases. To conserve on degrees of freedom, comorbidity dummies were included in the regressions only if they had a p-value less than .25 in a regression of price on the full set of comorbidities.

The fixed effect regressions were estimated using Stata 10.0 with the generalized linear model (glm) command, with a logit link for the mortality regressions and a log link for the cost regressions. Panel data regressions with log(price) as the dependent variable yielded better fit for the price regressions. The standard errors were estimated accounting for

clustering at the hospital level in the mortality and cost regressions and at the level of the HRR for the price regressions.

4. RESULTS

The mortality and cost regressions were based on 102,044 colon cancer surgery patients and 6,857 Whipple procedure patients from California, Florida, New Jersey, and New York between 2001 and 2005. The price regressions were estimated using 8,694 colon cancer and 760 Whipple procedure patients in the MedStat data. Table I presents descriptive statistics for the years 2001 and 2005. Mortality rates for both procedures dropped over time, particularly for Whipple patients (39.4%). Average hospital volume rose 58.7% for the Whipple procedure. Volume declined by 2.4% for colon resection, suggesting that the volume-outcome effect may not have driven outcome improvements for this procedure. Real patient costs rose 14.3% for colon cancer, but by only .01% for the Whipple procedure.

Herfindahl indices calculated using either the total number of admissions for each hospital or procedure-specific admissions changed by less than 2% for colon cancer patients. Admission-based market concentration also stayed relatively constant for Whipple patients. However, procedure-based market concentration for the Whipple procedure increased substantially (15.6%) between 2001 and 2005. Managed care penetration rates declined 11.2% for colon cancer patients and 9.1% for Whipple patients. The Medstat data indicate that the real price of cancer surgery rose 23.4% for colon cancer patients and 10.2% for Whipple patients between 2001 and 2005.

4.1 Regression results

Table II presents estimates of the relationship between surgical procedure volume and inpatient mortality.³ We find no association between increased hospital volume and death rates for colon resection. The coefficient on volume was negative, but imprecisely estimated. We also experimented with piecewise linear splines in volume to test for a nonlinear volume-outcome effect. We estimated 11 different regressions, with a knot ranging in value from 9 to 150 colon resections per year. In each case the coefficients for both pieces of the spline in volume were imprecisely estimated. This finding differs from previous studies in the literature (J. B. Dimick *et al.* 2003; D. Schrag *et al.* 2000). However, previous studies did not include hospital-specific fixed effects, which focus on how within-hospital increases in volume influence mortality.

In contrast, the effect of volume is negative and precisely estimated for Whipple procedure patients. In addition to the linear specification reported in Table II, we used a succession of piecewise linear spline regressions in an attempt to identify a threshold effect at which the volume-mortality relationship became flat. The knots in the 16 different spline regressions ranged from values of 3 to 37 pancreatic resections per year. In each case, the coefficients on both pieces of the spline are imprecisely estimated. There could still be a volume level at

³A total of 2,651 (2.6%) colon cancer patients and 1,354 (19.7%) Whipple patients are dropped from the regressions, because all of the patients in these hospitals either died or were discharged alive. There is no within-variation in outcomes to identify, so these observations contribute no information in a fixed-effects regression specification.

which more pancreatic resections performed per year would fail to yield additional mortality reductions. However, we do not have sufficient sample size in our data to identify this threshold.

The procedure-based Herfindahl index is not associated with inpatient mortality for either colon cancer or Whipple patients. However, a higher admissions-based HHI is associated with lower mortality for Whipple patients. Thus, Whipple patients who are treated in areas with high overall market concentration tend to have better outcomes. We find no association between increased managed care penetration and patient outcomes for either procedure.

Table III presents the cost regressions. Because reduced form cost functions tend to be nonlinear in output, we estimated these regressions with a cubed polynomial in volume. Although the individual coefficients were statistically insignificant, the coefficients on the polynomial variables were jointly significant with p-values less than .05 in each specification⁴. We will examine the implications of these coefficients when we conduct simulations to predict the impact of regionalization on patient costs.

We tested for linear and quadratic relationships between hospital market concentration and patient costs. We found a precisely estimated association in one case. Higher admissions-based market concentration led to higher patient costs for colon cancer patients, but at a decreasing rate. We found no association between managed care penetration and costs for either cancer operation.

Table IV reports price regression estimates. Higher admissions-based market concentration is associated with higher prices, and increased managed care penetration leads to lower prices for colon cancer patients. We find no such relationships for the Whipple procedure, although the sample size is much smaller for this operation.

4.2 Simulations

Tables V and VI report simulations for alternative regionalization strategies. We first predict the consequences of referring all patients who were treated in a hospital in the lowest volume quartile in 2005 to the closest hospital exceeding this volume cutoff. The volume and market concentration variables were insignificant in the colon resection mortality regressions and were therefore not used in the simulations. However, the hospital fixed effects were jointly significant in explaining mortality. Therefore, the hospital fixed effects were included in our simulations. The fixed effects capture all time-invariant determinants of mortality, costs, or prices. These determinants could represent anything from ownership status or teaching status, to urban/rural location or an unusually talented long-term hospital CEO. We cannot distinguish between these effects, and therefore assume that they remain constant after regionalization. But given that both cancer operations we study represent a relatively small share of all hospital admissions, regionalization of these surgeries is unlikely to cause a change in any of these fixed factors we mention. For patients treated in low-

⁴Individual coefficients can appear to be insignificant even if they are jointly significant due to multicollinearity between the variables comprising the polynomial. See section 4.5 of Wooldridge (J. M. Wooldridge 2000).

volume hospitals who would be moved to a higher volume hospital, the fixed effects in the higher volume hospital are applied.

Table V, Panel A indicates that regionalization of colon cancer surgery patients from the lowest quartile to hospitals performing 12+ colon resections per year is predicted to reduce the average mortality rate .038 percentage points (from an initial mortality rate of 3.817%). Thus, predicted life expectancy for the average patient increases only slightly, by .0023 years.⁵ The regression coefficients from Table III imply that there will be a slight cost increase from eliminating colon resection at hospitals in the lowest volume quartile. This cost increase combined with the change in life expectancy imply an increase in social welfare of \$200 per patient.

For the Whipple procedure, Table VI, Panel A indicates that regionalization of patients from the lowest volume quartile to hospitals performing 2+ Whipple operations per year is predicted to reduce inpatient mortality slightly, by 0.172 percentage points (from an initial mortality rate of 5.986 percent). Predicted life expectancy is expected to increase 0.037 years. There are slight cost savings associated with the increase in average hospital volume under this scenario, so that the total gain in social welfare from eliminating Whipple procedures in the lowest quartile hospitals improves social welfare by an average of \$3,891 per patient.

We next simulate a more aggressive regionalization strategy, where all colon cancer patients are referred for treatment in the closest hospital with volume above the median, which is 24 or more operations per year. Similar to the previous simulation, the consumer surplus gain for colon cancer patients is from unobserved hospital differences, because we found no mortality benefit from higher hospital volume in Table II. Average mortality would decline by 0.03 percentage points, implying a 0.0019 increase in life expectancy. The polynomial cost regression implies a \$70 decline in costs. Thus, welfare would increase by \$257 per patient. We next simulate the consequences of centralizing Whipple procedures to the closest hospital in the top quartile in 2005, which is 6 or more Whipple operations per year. Average mortality is predicted to decline 1.59 percentage points, increasing life expectancy by 0.243 years per patient. The value of these additional life years translates to \$24,264 in additional consumer surplus per patient. Average costs are predicted to increase by \$3,175, so that the total improvement in social welfare is \$21,089.

We also simulate the consequences of following the Leapfrog group's recommendation to limit surgery to hospitals performing 11+ Whipple operations annually. The mortality benefits are greater than for centralizing care to the highest quartile hospitals. The larger volume implies that costs per patient would rise by \$4,154, so that social welfare rises by \$29,649.

We conducted several analyses to examine the sensitivity of our conclusions to alternative assumptions. First, recall that there were modest welfare gains from regionalizing colon resection even without a volume-mortality effect, because there was a slight tendency of

⁵Recall that we found no significant volume-outcome relationship in the colon resection regressions, so this mortality reduction results from a slight tendency of higher volume hospitals to have fixed effects coefficients with more negative values.

higher volume hospitals to have fixed effect coefficients with more negative values. We therefore repeated the regionalization simulations for pancreatic resection allowing only the volume coefficient to influence mortality, in order to gauge the relative importance of varying volume versus changing the hospital fixed effects. The estimated changes in mortality and resulting improvements in social welfare are slightly smaller in Panel B versus Panel A in Table VI. Therefore, the volume effect is much more important than hospital-specific unobservables in determining the welfare gains from regionalization for pancreatic resection.

Next, given that referring colon cancer patients to higher volume hospitals was predicted to reduce mortality, we asked whether regionalizing patients based explicitly on the magnitude of hospitals' fixed effects (and ignoring volume) would change mortality rates. Table V, Panel B simulates the effect of closing hospitals in the highest quartile of fixed effects in the mortality regression and referring their patients to the nearest hospital outside this quartile for colon resection. The predicted decrease in mortality of .613 percentage points is substantially larger than in Panel A, leading to a sizeable gain in social welfare of \$4,558. If one closes hospitals with fixed effects in the top half of the distribution and refers patients to the closest hospital in the lowest half of the distribution, the implied welfare gain rises even further, to \$13,018. We repeat this exercise for pancreatic resection patients in Table VI, Panel C. Unlike the simulations for colon cancer, closing hospitals in the highest quartile of mortality fixed effects for pancreatic resection reduces social welfare by \$2,022. Mortality rises by .091 percentage points, suggesting that the volume-mortality effect would be the main driver for welfare improvements if pancreatic resection were regionalized. However, a more aggressive regionalization policy that closes hospitals in the 3 highest quartiles of mortality fixed effects leads to mortality reductions and social welfare gains that are comparable in magnitude to the policy of referring all hospitals to patients performing 11 or more pancreatic resections per year.

Our estimates of the change in life expectancy resulting from regionalization rely on previous literature that estimated the relationship between hospital volume and long term survival. It would be helpful to know how much the welfare calculations depend on the volume-mortality relation in the hospital, versus the volume-life expectancy gradient after discharge. To answer this question, we set the life expectancy values after discharge at the values for a medium volume hospital as reported in the previous literature (E. V. Finlayson, J. D. Birkmeyer 2003) and recalculated social welfare. Table V, Panel C shows that the welfare calculations for colon resection change only minimally. This result is expected, because the absence of a volume-mortality effect implies minimal improvement in life expectancy in both the original and the alternate scenario. In contrast, Table VI, Panel D suggests that ignoring the volume-life expectancy relation reduces welfare gains from regionalization for pancreatic resection dramatically. For example, the welfare gain from closing hospitals in the lowest quartile of volume drops from \$3,891 in Panel A to \$641 in Panel D. Thus, although pancreatic cancer is generally associated with low life expectancy, the value of increased life expectancy resulting from treatment at high-volume facilities is substantial.

For patients with pancreatic cancer, life after surgery is unlikely to be spent in “perfect” health. Thus, the welfare calculations should account for lower quality of life during survival after surgery. There are a handful of studies which measure quality of life after pancreatic resection for patients with cancer, but none of these studies explicitly measures quality of life in terms of quality adjusted life years (QALYs) (R. Carter *et al.* 2009; R. Pezzilli *et al.* 2011). One study converts multiple responses from a health survey to estimate that pancreatic resection patients experienced 1.13 QALYs over 5 years of follow-up (D. Ljungman *et al.* 2011). Suppose we use the ratio of 1.13 to 5 to adjust each measure of life expectancy by volume in our simulations to estimate the quality-adjusted welfare gains of regionalization. The QALY-adjusted gains in life expectancy from regionalization of pancreatic resection in Table VI, Panel E are substantially smaller than they were in Panel A. For example, the welfare gains from aggressive regionalization that refers all patients to hospitals performing 11 or more pancreatic resections per year falls from the original estimate of \$29,649 per patient to \$3,485. One must keep in mind that quality of life after surgery may also vary by volume, although we found no published studies on this issue. If surgery at higher volume hospitals yields better quality of life, then the estimates in Table VI, Panel E may underestimate the welfare gains of regionalizing pancreatic resection. We did not conduct simulations for colon resection regionalization, because the original estimates of life expectancy gains were so small.

5. CONCLUSION

Our results suggest that regionalizing care would be welfare enhancing for pancreatic surgery. These welfare gains derive from the value of extended life expectancy due to better outcomes at higher volume hospitals. The simulation results provide a particularly compelling argument for an aggressive intervention that limits operations to those facilities in the top quartile, performing 6+ operations per year. One may be concerned that aggressive regionalization would significantly raise travel costs for patients. A previous study found that 77% of pancreatic patients traveled 60 minutes or less to receive surgery, and 10% of patients travelled more than 2 hours (J. D. Birkmeyer *et al.* 2003). The study predicted that imposing a minimum volume standard of 6+ operations would reduce the number of patients traveling 60 minutes or less to 53% and raise the percent of patients traveling 2 hours or more to 24%. While the implied increase in travel costs is significant, the welfare gain of \$21,089 per patient is likely to exceed these costs. Our simulations suggest that the argument for centralizing the Whipple procedure weakens substantially if quality of life after successful surgery is less than perfect health. The social welfare gains from regionalizing patients to hospitals performing 6+ Whipple procedures per year falls to \$2,309 per patient. However, these estimates provide a lower bound of welfare gains in the absence of literature on whether higher volume hospitals also yield improved long-term QALY's after successful surgery.

The simulations suggest that the benefits of centralizing colon cancer surgery are marginal. We find no volume-outcome effect for colon cancer, and the cost savings from higher procedure volume are minimal at best. We did not have the data to test whether greater market concentration resulting from regionalization would raise the price of colon or pancreatic resection. However, the estimates suggest that patients treated in areas with

higher market concentration overall pay higher prices for these procedures. Nevertheless, the simulations suggest that there are substantial fixed differences in mortality rates across hospitals, and referring patients to the hospitals with the lower than predicted mortality rates (based on hospital fixed effects) could substantially improve social welfare. The feasibility of this alternative regionalization policy should be further considered.

This study differs from previous literature in several ways. In contrast to previous colon resection studies, we find no evidence of a volume-mortality effect. This finding results from the fixed effects regression methods we use, and possibly the more recent data with generally higher colon cancer volumes than studies from the 1990's. In contrast to previous studies of heart attack patients, we find less consistent evidence of an effect of market concentration or managed care penetration on hospital outcomes or costs. We find no statistically significant relationship between managed care penetration and either mortality or costs for colon resection and Whipple surgery. Procedure-based market concentration is also unassociated with patient mortality and costs. Colon resection and pancreatic resection are not as common as treatment of heart attacks. Thus, competitive effects may only influence hospital quality and cost for patient groups that comprise a large portion of a hospital's overall patient population.

There are only a handful of studies that examine the relationship between market concentration and prices, and none have examined cancer care. We find that hospitals with greater market concentration have higher prices for colon cancer surgery. This result suggests that more attention should be paid to hospital antitrust issues for cancer care.

Reference List

1. Birkmeyer JD 2000 "Should we regionalize major surgery? Potential benefits and policy considerations." *Journal of the American College of Surgeons*, 190(3): 341–349. [PubMed: 10703862]
2. Birkmeyer JD, Finlayson SRG, Tosteson ANA, Sharp SM, Warshaw AL, and Fisher ES. 1999 "Effect of hospital volume on in-hospital mortality with pancreaticoduodenectomy." *Surgery*, 125(3): 250–256. [PubMed: 10076608]
3. Birkmeyer JD, Siewers AE, Finlayson SR, Stukel TA, Lucas FL, Batista I, Welch HG, and Wennberg DE. 2002 "Hospital volume and surgical mortality in the United States." *N Engl J Med*, 346(15): 1128–1137. [PubMed: 11948273]
4. Birkmeyer JD, Siewers AE, Marth NJ, and Goodman DC. 2003 "Regionalization of high-risk surgery and implications for patient travel times." *The Journal of the American Medical Association*, 290(20): 2703–2708. [PubMed: 14645312]
5. Birkmeyer JD, Warshaw AL, Finlayson SRG, Grove MR, and Tosteson ANA. 1999 "Relationship between hospital volume and late survival after pancreaticoduodenectomy." *Surgery*, 126(2): 178–183. [PubMed: 10455881]
6. Carter R, Stocken DD, Ghaneh P, Bramhall SR, Olah A, Kelemen D, Bassi C, Friess H, Dervenis C, Spry N et al. 2009 "Longitudinal quality of life data can provide insights on the impact of adjuvant treatment for pancreatic cancer-Subset analysis of the ESPAC-1 data." *Int.J.Cancer*, 124(12): 2960–2965. [PubMed: 19330830]
7. Center for the Clinical Evaluative Sciences and Dartmouth Medical School. 2000 *The Dartmouth atlas of vascular health care*. Dartmouth, N.H.:
8. Cooper GS, Yuan Z, Landefeld S, and Rimm AA. 1996 "Surgery for colorectal cancer: race-related differences in rates and survival among Medicare beneficiaries." *American Journal of Public Health*, 86(4): 582–586. [PubMed: 8604797]

9. Cutler DM 2004 "Pricing the priceless" In *Your money or your life: strong medicine for America's health care system*. New York: Oxford University Press, 10–21.
10. Dimick JB, Cowan JA Jr., Upchurch GR Jr., and Colletti LM. 2003 "Hospital volume and surgical outcomes for elderly patients with colorectal cancer in the United States." *J.Surg.Res*, 114(1): 50–56. [PubMed: 13678698]
11. Dor Avi, Grossman Michael, and Koroukian Siran M.. 2004 "Hospital Transaction Prices and Managed-Care Discounting for Selected Medical Technologies." *American Economic Review*, 94(2): 352–356. [PubMed: 29068188]
12. Elixhauser A, Steiner C, Harris DR, and Coffey RM. 1998 "Comorbidity measures for use with administrative data." *Medical Care*, 36(1): 8–27. [PubMed: 9431328]
13. Encinosa WE, Bernard DM, Du D, and Steiner CA. 2009 "Recent improvements in bariatric surgery outcomes." *Med.Care*, 47(5): 531–535. [PubMed: 19318997]
14. Epstein AM. 2002 "Volume and outcome--it is time to move ahead.[comment]." *New England Journal of Medicine*, 346(15): 1161–1164. [PubMed: 11948278]
15. Escarce JJ, Jain AK, and Rogowski J. 2006 "Hospital competition, managed care, and mortality after hospitalization for medical conditions: evidence from three states." *Med.Care Res.Rev*, 63(6 Suppl): 112S–140S. [PubMed: 17099132]
16. Finlayson EV and Birkmeyer JD. 2003 "Effects of hospital volume on life expectancy after selected cancer operations in older adults: A decision analysis." *J.Am.Coll.Surg*, 196(3): 410–417. [PubMed: 12648693]
17. Gaynor M and Vogt WB. 2000 "Antitrust and competition in health care markets" In *Handbook of Health Economics*, 1B. ed. Culyer AJ and J. P Newhouse. Amsterdam: North Holland, 1405–1487.
18. Gaynor Martin, Seider Harald, and Vogt William B.. 2005 "The Volume-Outcome Effect, Scale Economies, and Learning-by-Doing." *American Economic Review*, 95(2): 243–247.
19. Gordon TA, Bowman HM, Tielsch JM, Bass EB, Burleyson GP, and Cameron JL. 1998 "Statewide regionalization of pancreaticoduodenectomy and its effect on in-hospital mortality." *Annals of Surgery*, 228(1): 71–78. [PubMed: 9671069]
20. Gowrisankaran G, Ho V, and Town RJ. 2006 "Causality, Learning and Forgetting in Surgery."
21. Gowrisankaran G and Town R. 2003 "Competition, payers, and hospital quality." *Health Services Research*, 38(6): 1403–1421. [PubMed: 14727780]
22. Halm EA, Lee C, and Chassin MR. 2002 "Is volume related to outcome in health care? A systematic review and methodologic critique of the literature." *Ann.Intern.Med*, 137(6): 511–520. [PubMed: 12230353]
23. Ho V. 2000 "Evolution of the volume-outcome relation for hospitals performing coronary angioplasty." *Circulation*, 101: 1806–1811. [PubMed: 10769281]
24. Ho V. 2002 "Learning and the evolution of medical technologies: The diffusion of coronary angioplasty." *Journal of Health Economics*, 21(5): 873–885. [PubMed: 12349886]
25. Ho V and Petersen LA. 2007 "Estimating cost savings from regionalizing cardiac procedures using hospital discharge data." *Cost.Eff.Resour.Alloc*, 5: 7. [PubMed: 17603890]
26. Ho V, Town RJ, and Heslin MJ. 2007 "Regionalization versus competition in complex cancer surgery." *Health Economics, Policy and Law*, 2: 51–71.
27. Kessler DP and McClellan MB. 2000 "Is hospital competition socially wasteful?" *The Quarterly Journal of Economics*, 115(2): 577–615.
28. Ljungman D, Lundholm K, and Hylander A. 2011 "Cost-utility estimation of surgical treatment of pancreatic carcinoma aimed at cure." *World J.Surg*, 35(3): 662–670. [PubMed: 21132294]
29. Luft HS, Bunker J, and Enthoven A. 1979 "Should operations be regionalized? An empirical study of the relation between surgical volume and mortality." *The New England Journal of Medicine*, 301(25): 1364–1369. [PubMed: 503167]
30. Mukamel DB, Zwanziger J, and Tomaszewski KJ. 2001 "HMO penetration, competition, and risk-adjusted hospital mortality." *Health Serv.Res*, 36(6 Pt 1): 1019–1035. [PubMed: 11775665]
31. Pezzilli R, Falconi M, Zerbi A, Casadei R, Valli L, Varale R, Armatura G, Feliciani C, and Morselli-Labate AM. 2011 "Clinical and patient-reported outcomes after pancreatoduodenectomy for different diseases: a follow-up study." *Pancreas*, 40(6): 938–945. [PubMed: 21562441]

32. Schrag D, Cramer LD, Bach PB, Cohen AM, Warren JL, and Begg CB.2000 “Influence of hospital procedure volume on outcomes following surgery for colon cancer.” The Journal of the American Medical Association, 284(23): 3028–3035. [PubMed: 11122590]
33. Sfekas A2008 “Learning, forgetting, and hospital quality: an empirical analysis of cardiac procedures in Maryland and Arizona.” Health Econ..
34. Evidence-based hospital referral fact sheet. 2005 http://www.leapfroggroup.org/media/file/Leapfrog-Evidence-Based_Hospital_Referral_Fact_Sheet.PDF.
35. Warren JL, Yabroff KR, Meekins A, Topor M, Lamont EB, and Brown ML.2008 “Evaluation of trends in the cost of initial cancer treatment.” J.Natl.Cancer Inst, 100(12): 888–897. [PubMed: 18544740]
36. Wooldridge JM 2000 Introductory Econometrics: A Modern Approach. Mason, OH: South-Western College Publishing
37. Zwanziger J and Melnick GA.1988 “The effects of hospital competition and the Medicare PPS program on hospital cost behavior in California.” J.Health Econ, 7(4): 301–320. [PubMed: 10303150]

Table I:

Descriptive Statistics for Colon Cancer Resection and Whipple Procedure Patients

	Colon Cancer Resection			Whipple Procedure		
	(1)	(2)	(3)	(4)	(5)	(6)
	mean 2001	mean 2005	% Change 2001–2005	mean 2001	mean 2005	% Change 2001–2005
Inhospital mortality rate	0.0387	0.0372	–3.90%	0.0891	0.0540	–39.43%
Patient cost (in 2005 dollars)	16539.88	18896.64	14.25%	42488.50	42492.21	0.01%
Annual hospital volume	54,3796	53,0784	–2.39%	19,5442	31,0230	58.73%
HHI (procedures-based)	0.2482	0.2437	–1.81%	0.1281	0.1480	15.56%
HHI (admissions-based)	0.1364	0.1358	–0.39%	0.1081	0.1134	4.86%
Managed care penetration rate	38.3894	34.1025	–11.17%	40.1735	36.5138	–9.11%
N	21023	19938		1279	1519	
Price	\$20,435	\$25,221	23.40%	\$49,405	\$54,458	10.23%
N	795	2231		54	204	

Table II:

Regression Estimates of the Determinants of Inhospital Mortality^a

	Colon Cancer Resection ^b				Whipple Procedure ^c			
	(1) coef.	(2) t-statistic	(3) coef.	(4) t-statistic	(5) coef.	(6) t-statistic	(7) coef.	(8) t-statistic
Annual hospital volume	-0.003599	-1.54	-0.00345	-1.47	-0.02327**	-3.72	-0.0235**	-3.76
HHI (procedures-based) ^d	0.5288	0.61			0.7865	0.40		
HHI (admissions-based)			3.061	1.70			-7.808*	-2.40
Managed care penetration rate	-0.0001527	-0.02	-0.000515	-0.07	0.04175	1.37	0.0442	1.44
N		99393				5503		

^a All regressions included age, sex, race, emergency care, cancer stage, length of stay, year, and hospital indicators.

^b Colon cancer regressions also included indicators for procedure type (partial excision of large intestine, total intra-abdominal colectomy) and Elixhauser comorbidities (Paralysis, Congestive heart failure, Peripheral vascular disease, Chronic pulmonary disease, Hypothyroidism, Renal failure, Liver disease, Rheumatoid arthritis/collagen vascular disease, Coagulopathy, Obesity, Weight loss, Fluid and electrolyte disorders, Chronic blood loss anemia, Deficiency anemias, Depression, and Hypertension).

^c Whipple regressions also included indicators for diagnosis type (malignant neoplasm of pancreas, malignant neoplasm of gallbladder and extrahepatic bile ducts, malignant neoplasm of duodenum, benign neoplasm of pancreas or diseases of pancreas, and injury or poisoning) and Elixhauser comorbidities (Other neurological disorders, Chronic pulmonary disease, Diabetes w/ chronic complications, Renal failure, Coagulopathy, Weight loss, Fluid and electrolyte disorders, Deficiency anemias, and Hypertension).

^d HHI for procedures based on predicted hospital choice model and patient distance to hospital.

* statistically significant at the 95% confidence level

** statistically significant at the 99% confidence level

Table III:

Regression Estimates of the Determinants of Patient Costs ^a

	Colon Cancer Resection ^b				Whipple Procedure ^c			
	(1) coef.	(2) t-statistic	(3) coef.	(4) t-statistic	(5) coef.	(6) t-statistic	(7) coef.	(8) t-statistic
Annual hospital volume	-0.004985	-1.14	-0.00395	-1.06	0.005189	0.57	0.00399	0.44
Volume ²	5.95E-05	1.35	5.11E-05	1.34	7.43E-06	0.06	2.98E-05	0.22
Volume ³	-1.44E-07	-1.13	-1.23E-07	-1.1	-3.9E-07	-0.67	-4.8E-07	-0.8
HHI (procedures-based) ^d	0.6684	1.75			-1.2675	-1.26		
HHI (admissions-based)			6.461 **	3.43			3.06	1.39
HHI ² (admissions-based)			-5.784 **	-2.76				
Managed care penetration rate	-0.002858	-1.00	-0.0046	-1.71	-0.002727	-0.49	-0.00281	-0.53
Joint significance of volume (p-value)	0.0547		0.0424 *		0.0078 **		0.011 *	
Joint significance of HHI (p-value)			0.0012 **					
N		102044				6857		

^a All regressions included age, sex, race, emergency care, cancer stage, mean nurse wages, year, and hospital indicators.

^b Colon cancer regressions also included indicators for procedure type (partial excision of large intestine, total intra-abdominal colectomy) and Elixhauser comorbidities (Paralysis, Other neurological diseases, Congestive heart failure, Valvular disease, Peripheral vascular disease, Chronic pulmonary disease, Diabetes w/o chronic complications, Hypothyroidism, Renal failure, Liver disease, AIDS, Rheumatoid arthritis/collagen vascular disease, Coagulopathy, Obesity, Weight loss, Fluid and electrolyte disorders, Chronic blood loss anemia, Deficiency anemias, Alcohol abuse, Drug abuse, Psychoses, and Hypertension).

^c Whipple regressions also included indicators for diagnosis type (malignant neoplasm of pancreas, malignant neoplasm of gallbladder and extrahepatic bile ducts, malignant neoplasm of duodenum, benign neoplasm of pancreas or diseases of pancreas, and injury or poisoning) and Elixhauser comorbidities (Diabetes w/o chronic complications, Hypothyroidism, Renal failure, Weight loss, Fluid and electrolyte disorders, Deficiency anemias, and Hypertension).

^d HHI for procedures based on predicted hospital choice model and patient distance to hospital.

* statistically significant at the 95% confidence level

** statistically significant at the 99% confidence level

Table IV:

Regression Estimates of the Determinants of Procedure Price ^a

	Colon Cancer Resection ^b		Whipple Procedure ^c	
	(1) coef.	(2) t-statistic	(3) coef.	(4) t-statistic
HHI (admissions-based)	1.387 *	2.08	4.952	1.01
Managed care penetration rate	-0.006 **	-2.95	0.002	0.48
N	8694		760	

^a All regressions included age, sex, emergency care, cancer stage, year, and hospital indicators.

^b Colon cancer regressions also included indicators for procedure type (partial excision of large intestine, total intra-abdominal colectomy) and Elixhauser comorbidities (congestive heart failure, valvular disease, perivascular disease, paralysis, chronic pulmonary disease, diabetes with chronic complications, hypothyroidism, renal failure, liver disease, chronic peptic ulcer disease, coagulation deficiency, weight loss, fluid and electrolyte disorders, blood loss anemia, deficiency anemias, drug abuse, psychoses, and hypertension).

^c Whipple regressions also included indicators for diagnosis type (malignant neoplasm of pancreas, malignant neoplasm of gallbladder and extrahepatic bile ducts, malignant neoplasm of duodenum, benign neoplasm of pancreas or diseases of pancreas, and injury or poisoning) and Elixhauser comorbidities (congestive heart failure, valvular disease, perivascular disease, paralysis, other neurological disorders, chronic pulmonary disease, diabetes, diabetes with chronic complications, renal failure, chronic peptic ulcer disease, coagulation deficiency, weight loss, fluid and electrolyte disorders, and deficiency anemias).

* statistically significant at the 95% confidence level

** statistically significant at the 99% confidence level

Table V:

Colon Regionalization Policy Experiment

Regionalization rule	average mortality rate	average life expectancy	\$ Value of QALY impact per patient	consumer surplus	costs	social welfare
<i>A. Assuming patients experience fixed effects of the larger hospital</i>						
Close hospitals in lowest quartile	-0.038	0.00231	\$100,000	\$231	\$31	\$200
Close hospitals below median	-0.030	0.00187	\$100,000	\$187	-\$70	\$257
<i>B. Assuming patients are reallocated based on hospital fixed effects</i>						
Close hospitals in highest quartile FE	-0.613	0.04324	\$100,000	\$4,324	-\$234	\$4,558
Close hospitals above median FE	-1.411	0.12895	\$100,000	\$12,895	-\$123	\$13,018
<i>C. Assuming life expectancy does not vary by volume</i>						
Close hospitals in lowest quartile	-0.038	0.00266	\$100,000	\$266	\$31	\$235
Close hospitals below median	-0.030	0.00211	\$100,000	\$211	-\$70	\$281

Whipple Regionalization Policy Experiment

Table VI:

Regionalization rule	average mortality rate	average life expectancy	\$ Value of QALY impact per patient	consumer surplus	costs	social welfare
<i>A. Assuming patients experience fixed effects of the larger hospital</i>						
Close hospitals in lowest quartile	-0.172	0.03697	\$100,000	\$3,697	-\$194	\$3,891
Close hospitals in lower 3 quartiles	-1.595	0.24264	\$100,000	\$24,264	\$3,175	\$21,089
Close hospitals <11 procedures	-3.001	0.33803	\$100,000	\$33,803	\$4,154	\$29,649
<i>B. Assuming patients experience fixed effects of the original hospital</i>						
Close hospitals in lowest quartile	-0.110	0.03488	\$100,000	\$3,488	-\$194	\$3,682
Close hospitals in lower 3 quartiles	-1.379	0.23530	\$100,000	\$23,530	\$3,175	\$20,355
Close hospitals <11 procedures	-2.758	0.32813	\$100,000	\$32,813	\$4,154	\$28,659
<i>C. Assuming patients are reallocated based on hospital fixed effects</i>						
Close hospitals in highest quartile FE	0.091	0.00504	\$100,000	\$504	\$2,526	-\$2,022
Close hospitals in highest 3 quartiles FE	-3.671	0.30099	\$100,000	\$30,099	-\$95	\$30,194
<i>D. Assuming life expectancy does not vary by volume</i>						
Close hospitals in lowest quartile	-0.172	0.00447	\$100,000	\$447	-\$194	\$641
Close hospitals in lower 3 quartiles	-1.595	0.04147	\$100,000	\$4,147	\$3,175	\$972
Close hospitals <11 procedures	-3.001	0.07802	\$100,000	\$7,802	\$4,154	\$3,648
<i>E. Adjusting life expectancy for reduced QALYs after surgery</i>						
Close hospitals in lowest quartile	-0.172	0.00836	\$100,000	\$836	-\$194	\$1,030
Close hospitals in lower 3 quartiles	-1.595	0.05484	\$100,000	\$5,484	\$3,175	\$2,309
Close hospitals <11 procedures	-3.001	0.07639	\$100,000	\$7,639	\$4,154	\$3,485