NBER WORKING PAPER SERIES

HOW COSTLY IS HOSPITAL QUALITY? A REVEALED-PREFERENCE APPROACH

John A. Romley
Dana Goldman

Working Paper 13730
http://www.nber.org/papers/w13730

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
January 2008

The financial support of the Bing Center for Health Economics is gratefully acknowledged. The views expressed herein are those of the author(s) and do not necessarily reflect the views of the National Bureau of Economic Research.

How Costly Is Hospital Quality? A Revealed-Preference Approach
John A. Romley and Dana Goldman
NBER Working Paper No. 13730
January 2008
JEL No. D24,I11

ABSTRACT

One of the most important and vexing issues in health care concerns the cost to improve quality. Unfortunately, quality is difficult to measure and potentially confounded with productivity. Rather than relying on clinical or process measures, we infer quality at hospitals in greater Los Angeles from the revealed preference of pneumonia patients. We then decompose the joint contribution of quality and unobserved productivity to hospital costs, relying on heterogeneous tastes among patients for plausibly exogenous quality variation. We find that more productive hospitals provide higher quality, demonstrating that the cost of quality improvement is substantially understated by methods that do not take into account productivity differences. After accounting for these differences, we find that a quality improvement from the 25th percentile to the 75th percentile would increase costs at the average hospital by nearly fifty percent. Improvements in traditional metrics of hospital quality such as risk-adjusted mortality are more modest, indicating that other factors such as amenities are an important driver of both hospital costs and patient choices.

John A. Romley
RAND Corporation
1776 Main Street
P.O. Box 2138
Santa Monica, CA 90407-2138
John_Romley@rand.org

Dana Goldman
RAND Corporation
1776 Main Street
P.O. Box 2138
Santa Monica, CA 90407-2138
and NBER
dgoldman@rand.org

1 Introduction

In recent years there have been prominent calls for quality improvement within the health-care sector. The Institute of Medicine's report *Crossing the Quality Chasm* garnered national attention and spawned large research efforts devoted to measuring and improving quality (Institute of Medicine (2001)). Yet quality improvement may be costly, and the value of quality turns on its costs as well as its benefits (Cutler et al. (1998), Skinner et al. (2006)). The stakes are high. We focus on hospital care, for which expenditures totaled $611 billion in 2005 (Catlin et al. (2007))

The relationship between quality and costs in the hospital-care industry is not well understood. There are two significant challenges in understanding the cost of hospital quality. The first challenge is that quality is difficult to measure, potentially leading to attenuation bias in the cost of quality. Hospitals are plausibly differentiated in the eyes of their customers in multiple dimensions, and these patients may value aspects of the hospital experience that are difficult (if not impossible) for a researcher to observe.

Newhouse (1994) contrasts the hospital enterprise with an electric utility, likening it instead to an airline. As with an airline, hospital amenities such as caring and attentive staff, good food, and pleasant surroundings are plausibly important. Such amenities seem harder to quantify than clinical quality, and public measures are only now under development.[1]

The second challenge in understanding the cost of hospital quality is that more productive hospitals may supply higher quality. Economists have long recognized that a firm's levels of inputs and outputs can depend on productivity (Marschak and Andrews, Jr. (1944), Nerlove (1965)). When higher productivity lowers the marginal cost of quality or quantity, a relatively productive hospital may choose to supply relatively high quality. Higher quality hospitals are then relatively low-cost, and vice versa. If a researcher cannot observe productivity, then quality may again appear to be less costly than is truly the case.

Hospitals may be more or less productive because their boards of governors and/or managers are more or less effective. Furthermore, an unusual feature of this setting may contribute to productivity differences. Phelps (2002) emphasizes the simultaneous authority and lack of accountability of physicians within the hospital organization. Harris (1977) argues that a hos-

[1] See http://www.hcahpsonline.org/.

pital is actually two firms, the medical staff and the nominal administration, whose objectives may conflict. In addition to this issue of the physician's role, the boards that govern hospitals may confront more conventional challenges with respect to managerial agency.

As an empirical matter, Zuckerman et al. (1994)'s stochastic-frontier analysis of the performance of U.S. hospitals in the mid-1980s attributes nearly fourteen percent of total costs to inefficient behavior. Such "inefficiency" can be interpreted as efficient behavior among firms with heterogeneous productivity (Stigler (1976), Van Biesebroeck (2004)). Some of this apparent inefficiency may also be attributable to aspects of the hospital experience that the researcher does not observe, that is, to differences in unmeasured quality (Newhouse (1994)).

Evidence on the cost of hospital quality is remarkably limited. The most direct evidence is concerned with quality of care, or clinical quality. When Zuckerman et al. (1994) explicitly account for various measures of clinical quality, the share of costs attributable to inefficiency is unaffected, suggesting that quality is not costly. Carey and Burgess, Jr. (1999) even find that lower mortality decreases costs, albeit modestly, after instrumenting to deal with measurement error. On the other hand, Morey et al. (1992) conclude that a one-percent decrease in mortality is associated with a 1.34 percent increase in hospital costs.

Carey (2000) offers indirect evidence pertinent to a broader conception of quality that accounts for hospital amenities. In an analysis of hospital costs, Carey finds diseconomies of hospital scale under ordinary least squares but scale economies under fixed-effects and correlated random-effects specifications. In light of strong evidence (described later in the paper) that quality influences hospital choice by patients, this pattern is consistent with unobserved but costly quality. The author also remarks that other unobserved factors, such as managerial effectiveness, may be important.

Our aim here is to understand the cost of hospital quality. Our framework for meeting the challenges just described rests fundamentally on the assumption that patients are informed about hospitals. As we discuss below, there is considerable evidence that patients are at least somewhat aware of (and value) clinical quality, and hospitals market themselves to patients on the basis of amenities. We therefore infer quality from the revealed preference of Medicare pneumonia patients for hospitals in greater Los Angeles. This quality measure — which we call "revealed quality" — embodies all of the aspects of the hospital experience that patients value, including amenities as well as clinical quality. We estimate revealed quality on the basis of existing methods for analyzing consumer choices among differentiated products with unobserved attributes (e.g., Berry et al. (1995)).

We then analyze the relationship between revealed quality and hospital costs, again appealing to revealed preference. The hospital-choice analysis demonstrates that patients prefer hospitals that are close to home, yet vary in their taste for quality and hence their willingness to travel for it. As a result, a hospital whose neighboring patients are more responsive to quality has a greater incentive to supply costly quality. We argue that the "quality responsiveness" of hospital demand is plausibly uncorrelated with unobserved productivity and use it as an instrument for quality. Motivated by the existing evidence on the cost of quality, we compare the cost of our revealed-quality measure to the cost of clinical quality, as measured by pneumonia mortality.

Our aim and revealed-preference approach are similar to those in Gertler and Waldman (1992). This latter study is concerned with the cost of quality in the nursing-home industry, for which quality is also difficult to measure. The authors deal with unobservable quality by specifying a reduced-form model for a firm's latent choice of quality. The behavior of consumers is essential to identification: the taste for quality facing each firm is assumed to be exogenous, and variation across firms in the strength of these tastes induces variation in the marginal value of quality and thus firms' optimal qualities. The authors estimate their models of cost and quality choice in the nursing-care industry and find that quality is costly, with a 1.3% increase in quality leading to a 10% increase in nursing-home costs.

Our study differs from theirs in three respects. First, we impose more structure on (and estimate) hospital-level demand, while Gertler and Waldman (1992) impose more structure on (and estimate) a model of quality choice by hospitals. Second, and more importantly, we are concerned with unobserved productivity differences among firms. Finally, we assess the importance of clinical quality for revealed quality by comparing the costs of each.

While our particular application is to hospital care in greater Los Angeles, we believe that our analytical framework can contribute more broadly to understanding the cost structure of firms in differentiated-product industries when quality and productivity are heterogeneous and difficult to observe. Recent studies that share this concern about unobserved productivity include Olley and Pakes (1996) and Ackerberg et al. (2006), with the latter focusing on the costs of alcohol-abuse treatment.[2]

2 A Framework for Analyzing Hospital Quality and Costs

Researchers confront two challenges in investigating the cost of quality in the hospital-services industry. First, hospital quality is difficult to measure. We use existing methods for analyzing consumer choices among differentiated products with unobserved attributes, together with data on hospital choice, to infer quality from the revealed preference of patients. Second, a hospital may exercise discretion over its quality according to factors that researchers do not observe, particularly productivity. We motivate this concern with a model of quality choice by hospitals and explain an identification strategy that exploits variation in the responsiveness of hospital demand to quality.

2.1 Quality and hospital choice by patients

We assume that a patient is informed about hospital characteristics and chooses the hospital that maximizes her utility. The assumption that patients exercise choice over hospitals might be doubted, insofar as a patient must be admitted to a hospital by her doctor. Yet nearly half of patients maintain that they, not their doctors, choose their hospital (Wolinksy and Kurz (1984)). In addition, Burns and Wholey (1992) concluded that, while a patient is more likely to receive care at a hospital that is close to her doctor's office, the patient is still influential in hospital choice. This evidence is consistent with the view that hospitals compete for doctors through a "medical arms race" in quality (Phelps (2002)), with patients choosing their doctors in turn. In addition, hospitals refer patients to physicians with admitting privileges (Gray (1986)).

Empirical evidence also supports the view that patients are informed about and value a hospital's clinical quality. For a variety of medical diagnoses and procedures, Luft et al. (1990) found that patients in three California hospital markets in 1983 were more likely to receive care at hospitals with favorable health outcomes (mortality and complications) and other clinical

[2] For a review of alternative approaches to the analysis of productivity itself, see Van Biesebroeck (2004).

quality indicators. The authors suggested that lay referral networks may have been useful sources of information about clinical quality during the period studied, when hospital-level outcomes were not publicly reported. When the state of New York began to report cardiac mortality rates in the early 1990s, the market shares of hospitals with low rates grew (Mukamel and Mushlin (1998)). More recently, Geweke et al. (2003) have found that hospitals with high clinical quality (again measured by mortality) tend to treat pneumonia patients whose illness is relatively (and unobservably) severe.[3]

There is also reason to believe that patients are informed about amenities. Hospitals promote themselves on the basis of the availability of gourmet food and weekend surgeries (Gray (1986)), and market analysts have found that patients care about cleanliness and similar aspects of the hospital experience (Lane and Lindquist (1988)). Economic analyses of hospital choice and costs have largely neglected amenities, likely because of the difficulty of measuring them.[4] Finally, the proximity of a patient's home to a hospital, while not an intrinsic hospital attribute, is nevertheless a kind of amenity. Such proximity, which a researcher frequently can observe, has consistently been found to be valued by patients.

Patient utility U_{ih} is comprised of systematic and idiosyncratic utility, denoted $\overline{U}_{ih}$ and ϵ_{ih}, respectively:

$$U_{ih} = \overline{U}_{ih} + \epsilon_{ih} = \beta_{d,i} D_{ih} + \beta_{p,i} P_{ih} + \boldsymbol{\beta}_{\mathbf{x},i} \mathbf{X}_h + \boldsymbol{\beta}_{\boldsymbol{\xi},i} \boldsymbol{\xi}_h + \epsilon_{ih}, \qquad (1)$$

in which D_{ih} is the distance between patient i's home and hospital h (i.e., the converse of proximity); P_{ih} is the patient's price for the hospital's care; $\mathbf{X}_h$ is a vector of hospital attributes that both the patient and researcher observe; and $\boldsymbol{\xi}_h$ is a vector of attributes that only the patient observes. If the marginal rate of substitution among these unobserved attributes is identical across patients $\left(\beta_{\xi_j,i} \middle/ \beta_{\xi_k,i} = \lambda_{j,k} \forall i, j, k\right)$, then equation 1 can be rewritten as follows:

$$U_{ih} = \beta_{d,i} D_{ih} + \beta_{p,i} P_{ih} + \boldsymbol{\beta}_{\mathbf{x},i} \mathbf{X}_h + \beta_{q,i} Q_h + \epsilon_{ih},\ Q_h = \beta_{q,i}^{-1} \boldsymbol{\beta}_{\boldsymbol{\xi},i} \boldsymbol{\xi}_h \qquad (2)$$

[3] Town and Vistnes (2001), Gaynor and Vogt (2003) and Tay (2003) present further evidence that patients value hospital quality.

[4] The number of nurses per bed, which Tay (2003) considers, contribute to amenities but also to clinical quality. The analysis of hospital choice in Town and Vistnes (2001) includes hospital-level indicator variables that may embody amenities (as we do), yet quality is not the focus of their study.

in which Q_h is a latent index of quality.

Intuitively, this index of quality that the research does not observer is revealed by the preferences of patients over hospitals that differ in their distances from home. Consider two hospitals whose observed attributes are identical but whose locations differ. If patients in an area favor the hospital that is farther away over the closer hospital, utility can be higher at the farther hospital only because its Q_h is greater. Table 1 describes the behavior of the patients we study (described in section 3.1). Only 40.6% of patients chose the nearest hospital, and slightly more than a third of patients did not choose one of the three nearest hospitals. This behavior suggests that our approach to inferring quality can succeed.

The quality index Q_h is similar to the unobserved product attribute frequently included in differentiated-products discrete-choice models (Berry et al. (1995)). Under either approach, the level of an unobservable cannot be disentangled from the taste for it. When consumers may have heterogeneous tastes — as in our model — utility is identical for $\beta_{q,i} \cdot Q_h$ and $\left(\beta_{q,i} / \rho\right) \cdot (\rho Q_h)$, and so the parameter $\beta_{q,i}$ must be normalized for some consumer. Harris and Keane (1998) and Harris et al. (2002) also allow for variation in tastes. These studies use stated preferences for unobserved attributes, while we use data on patient characteristics. Our approach cannot distinguish among the components of Q_h yet relies on data that is more widely available.

The potential variability of tastes across patients in equation 2 is important for several reasons. First, this variability can help clarify the identification of hospital demand. Suppose that tastes for the jth hospital attribute depend on observed and unobserved patient characteristics — denoted $\mathbf{K}_i$ and ν_{ij}, respectively — as follows: $\beta_{j,i} = \mathbf{\Pi}_j \mathbf{K}_i + \nu_{j,i}$ For concreteness, consider the assumption that the taste for Q_h depends on observed comorbidities and unobserved health status. Then equation 1 becomes:

$$U_{ih} = \beta_{d,i} D_{ih} + \boldsymbol{\beta}_{\mathbf{x},i} \mathbf{X}_h + \mathbf{\Pi}_q \mathbf{K}_i Q_h + \left\{\nu_{q,i} Q_h + \epsilon_{ih}\right\}, \tag{3}$$

in which the model's composite disturbance appears in braces. In order to recover demand in our model, all observables in equation 3 must be distributed independently of $\nu_{q,i} Q_h$. This would not be the case if unobservably healthy or sick patients chose where to live based on the quality of hospitals.

An assumption that unobserved tastes are distributed with mean zero and independently of all observables is sufficient for identification of the demand parameters. Ideally, this assumption could be empirically assessed, yet we are not aware of a means of doing so. In our opinion, this assumption, which is typically maintained in studies of hospital choice, is not unreasonable.

Second, variability in the taste for Q_h is one source of heterogeneity in the responsiveness of hospital demand to quality. We assume in our empirical analysis in section 3.1 that all potential patients elect to receive care at some hospital; we also assume that idiosyncratic tastes are distributed type-1 extreme-valued. Then the probability that the ith patient chooses the jth hospital takes the following form (McFadden (1974)):

$$\pi_{ih} \equiv \Pr\left(U_{ih} > U_{ih'} \forall h'\right) = e^{\overline{U}_{ih}} \Big/ \sum\nolimits_{h'} e^{\overline{U}_{ih'}} \tag{4}$$

In expectation, hospital demand, denoted Y_h, is the sum of patients' demands:

$$Y_h = \sum\nolimits_i \pi_{ih} \tag{5}$$

The derivative of demand with respect to Q_h — which we term "quality responsiveness" — is then:

$$\frac{\partial Y_h}{\partial Q_h} = \sum\nolimits_i \boldsymbol{\beta}_{q,i} \pi_{ih} \left(1 - \pi_{ih}\right) > 0 \tag{6}$$

Because patients prefer hospitals that are located near their homes, a hospital's demand will increase more with Q_h when patients near the hospital have a stronger taste for quality, that is, a larger $\boldsymbol{\beta}_{q,i}$. In addition, the tastes for both distance and quality indirectly affect quality responsiveness through π_{ih}. We would expect quality responsiveness to be greater when the marginal rate of substitution between distance and quality is high. Finally, variation in the geographic distribution of patients (i.e., in the number of patients near particular hospitals) affects the average level of π_{ih} at a hospital, creating additional variation in quality responsiveness. This variation is central to our strategy, discussed in the next section, for distinguishing the contribution of quality to costs from that of productivity.

2.2 Quality choice by hospitals

In the context of production, it has long been recognized that firms may choose the levels of factor inputs based on heterogeneous productivity, inducing a correlation between the independent variables and the disturbance in an empirical model of the production function (Marschak and Andrews, Jr. (1944)). Because of the duality of production and costs, a similar problem applies to the cost function, as has also long been recognized (Nerlove (1965)). We argue here that differences in unobserved productivity across hospitals can lead to differences in quality and then describe a strategy for recovering the true cost of quality.

We assume that a hospital produces an output whose quality may be represented by an index. Moreover, the price of hospital output is fixed. For the Medicare fee-for-service patients we study, prices are regulated, and hospitals cannot compete in prices. We also assume that productivity is fixed, at least during a time frame within which quality is variable.

The hospital's problem is thus to choose quality to maximize utility. Utility depends on expected profits Π and, perhaps, quality Q as follows[5]:

$$U = \Pi + \gamma Q \tag{7}$$

Because patients benefit from quality, the interpretation of $\gamma > 0$ is that the hospital is altruistic, much as in Newhouse (1970) and Lakdawalla and Philipson (2006). Even if $\gamma = 0$, utility depends indirectly on quality through its impact on profits:

$$\Pi = PY\left(Q, \mathbf{Q}^{-}, \mathbf{X}\right) - C\left(Y, Q, \mathbf{Z}, A, \mathbf{W}\right) \tag{8}$$

in which $Y(\cdot)$ is expected hospital output/demand, $\mathbf{Q}^{-}$ is a vector of competitors' qualities, $\mathbf{X}$ is a vector of demand shifters, $C(\cdot)$ is cost, $\mathbf{Z}$ is a vector of cost factors, A is productivity, and $\mathbf{W}$ is a vector of input prices. The role (if any) of the regulated price in demand has been suppressed in equation 8 for expositional simplicity.

Productivity is distinct from all other determinants of costs in equation 8 and, in particular, from medical technologies and amenities that alter both quality and costs. This treatment is broadly consistent with analyses that compare outcomes and expenditures across areas (Skinner et al. (2006)). We have suggested that hospital governance and management influence productivity. Under this view, productivity is especially hard for a researcher to observe.

In choosing quality, a hospital obtains the following marginal utility:

$$U_Q = (P - C_Y)\, Y_Q + \gamma - C_Q \tag{9}$$

[5] For the sake of expositional simplicity, we assume that the non-distribution constraint on a not-for-profit hospital does not bind.

The first term in equation 9 is a demand effect, according to which higher quality draws additional patients, increasing profits when $P > C_Y$. Marginal utility is also comprised of the benefit of any warm glow and the direct financial cost of quality. These margins cancel at an optimum. Under some regularity conditions, a unique solution to the utility-maximization problem exists, and a hospital's optimal quality and realized level of demand can be expressed as $Q^*(\mathbf{Q}^-, \mathbf{X}, \mathbf{Z}, A, \mathbf{W}, \gamma)$ and $Y^*(\mathbf{Q}^-, \mathbf{X}, \mathbf{Z}, A, \mathbf{W}, \gamma) \equiv Y\left(Q^*(\mathbf{Q}^-, \mathbf{X}, \mathbf{Z}, A, \mathbf{W}, \gamma), \mathbf{Q}^-, \mathbf{X}\right)$, respectively.

The relationships between optimal quality and realized demand, on the one hand, and productivity, on the other, can be characterized as follows:

$$Q_A^* = \frac{C_{YA} Y_Q + C_{QA}}{U_{QQ}} \geq 0, \tag{10a}$$

$$Y_A^* = Y_Q Q_A^* \geq 0 \tag{10b}$$

In this model, higher productivity can raise the marginal utility of quality, both directly and indirectly. Marginal utility (and hence quality) increases directly when the marginal cost of quality decreases with productivity ($C_{QA} < 0$). It decreases indirectly when the marginal cost of output decreases with productivity ($C_{YA} < 0$), and demand increases with quality (consistent with the evidence reviewed in the preceding section). Intuitively, a hospital that can supply quality relative cheaply chooses to supply relatively high quality. By equation 10b, if quality increases, so must output.

Figure 1 illustrates an important implication of this model for the empirical analysis of the quality-cost relationship. The true quality-cost curves of a more and less productive hospital appear in the figure; these curves condition on all other determinants of costs. Our aim is to measure the rate at which costs at either hospital increases with its quality. When the observed data is fit by least squares, the true cost of quality is understated. The reason is that hospitals that tend to choose high quality also tend to be low-cost.

If this model is correct, the cost of quality can be identified with variation in quality that is unrelated to productivity. Our approach appeals to the model for additional determinants of hospital quality. Features of hospital demand are promising candidates, as these features can be inferred from the model of hospital choice in the preceding section. Kessler and McClellan (2000) take a similar approach in analyzing the impact of competition on hospital expenditures and outcomes; Gaynor and Vogt (2003) use demand to instrument for price in their analysis of hospital mergers and competitive outcomes. In the context of production with unobserved productivity, Olley and Pakes (1996) appeal to a model of investment in their study of the telecom industry.

In our case, the marginal utility of quality in equation 9 turns on the responsiveness of hospital demand to quality, i.e., to Y_Q. This aspect of hospital demand — which we term "quality responsiveness" — depends on patient tastes for quality and distance, as well as market size (see equation 6). The relationship between a hospital's quality and a demand shifter X_j is as follows:

$$Q^*_{X_j} = -\frac{(P - C_Y)\, Y_{QX_j}}{U_{QQ}} \tag{11}$$

Intuitively, patients "pay for" quality through the demand effect, that is, the first term in equation 9. If a hospital's demand is relatively responsive (Y_{QX_j} is positive and large), many patients will switch to the hospital in response to an increase in quality. A hospital reacts to this high return by supplying high quality, so long as marginal patients are profitable ($P - C_Y > 0$).

Our empirical analysis focuses on Medicare fee-for-service patients receiving care for pneumonia. There is some evidence that reimbursement for pneumonia care does not fully covers costs (Medicare Payment Advisory Commission (2005)). Yet quality for these patients may be a good measure of quality for more profitable patients. If so, quality as revealed by pneumonia patients should increase with the responsiveness of demand among pneumonia patients to hospital quality; we investigate this hypothesis below. We also consider heart-attack care, which is relatively profitable (Horwitz (2005), Medicare Payment Advisory Commission (2005)).

Quality responsiveness may vary across hospitals within greater Los Angeles. Patients prefer hospitals close to home, implying that hospitals within this large market tend to compete in localized submarkets. Table 2 demonstrates that patients residing near the hospitals we study do differ in socio-demographic characteristics plausibly related to tastes for quality and distance. For example, the coefficient of variation across hospitals in the percentage of pneumonia patients residing within 2.5 miles who were black is 1.98, while that for average income is 0.22. There is also considerable variation in the number of patients residing near hospitals—the coefficient of variation is 0.58 at a distance of 2.5 miles.

The validity of quality responsiveness as an instrument requires that it be uncorrelated with productivity. Drawing on the results from the model of hospital choice, the response to quality within a market depends on actual quality, recognizing that $Y_Q = Y_Q\left(Q, \mathbf{Q}^{-}, \mathbf{X}\right)$. Under the model, variation in quality responsiveness is generally indirectly correlated with productivity through the latter's impact on actual quality. Potentially exogenous variation in quality responsiveness can be obtained by purging quality responsive of actual quality, which can be achieved by fixing quality throughout the market at some uniform level $\overline{Q}$.

Quality responsiveness and productivity could be correlated for other reasons. For example, patients with a strong taste for quality could reside near hospitals that are well-managed. Sicker patients may choose to live near high-quality hospitals, which tend to be more productive under the model. We cannot rule out such hypotheses without information on hospital productivity, the lack of which is precisely the problem that we face.

The framework just presented circumvents this problem on the basis of models of patient and hospital behavior. Any empirical analysis is necessarily based on some maintained assumptions, and a virtue of our framework is that its structure is transparent (Reiss and Wolak (2005)).

3 Empirical Approach

In this section we explain our empirical approach, first to inferring hospital quality from the revealed preference of hospital patients, then to assessing the joint contribution of quality and productivity to hospital costs, and finally to distinguishing the contribution of quality to costs from that of productivity.

3.1 Hospital choice

We analyze choice among elderly Medicare patients who received care for pneumonia at a hospital in greater Los Angeles in 2002. The hospital choices and characteristics of these patients are disclosed in a data set on hospital discharges compiled annually by the California Office of Statewide Health Planning and Development (OSHPD).[6] In the remainder of this section, we motivate our focus on this context while describing our empirical analysis of hospital choice.

Pneumonia care is sensible for our purposes. As we noted in section 2.1, there is persuasive evidence that patients view hospitals as differentiated in

[6] http://www.oshpd.ca.gov/

clinical quality for a variety of conditions, including pneumonia. In addition, pneumonia patients plausibly exercise considerable discretion over the hospital at which care is received. In a sensitivity analysis we also consider hospital choice among heart-attack patients.[7]

Our definition of the greater Los Angeles hospital market begins with general acute-care hospitals located in the five counties comprising the Los Angeles Consolidated Metropolitan Statistical Area. In exploratory analysis we found that hospitals at the geographic extremes of this metropolitan area tended to have implausibly extreme quality. We therefore exclude hospitals in the Ventura and Palm Springs hospital referral regions from our benchmark definition of the market (Dartmouth Medical School, The Center for the Evaluative Clinical Sciences (1998)). In addition, we exclude some remote hospitals. We also exclude 12 Kaiser Permanente hospitals, which belong to an integrated delivery system to which access may be limited.

Figure 2 illustrates the 129 hospitals in greater Los Angeles chosen in 2002 by at least one patient in our benchmark pneumonia sample (described below). This market definition is generally broader than that of Geweke et al. (2003), who analyze hospitals in Los Angeles County that averaged at least 20 pneumonia admissions per year. In a sensitivity analysis, we consider this latter definition. We also consider all hospitals in the metro area's five counties.

We analyze hospital choice among Medicare fee-for-service (FFS) patients who resided in the five metropolitan counties, who were admitted from home, and who were aged 65 or older. We focus on FFS patients because Medicare HMOs may limit beneficiary choice, as Tay (2003) has noted. We consider patients admitted from home for two reasons. First, the zip code of a patient's home is generally known in the discharge data, and so the distance between home and hospital is also known. Second, the choice problem facing patients admitted from nursing homes or other settings is susceptible to misspecification with the information available (Geweke et al. (2003)).[8] Medicare beneficiaries under age 65 are few in number and unrepresentative,

[7] Patients with each condition are identified in the discharge data on the basis of ICD9 codes. In particular, the principal diagnosis of a pneumonia patient begins with the numbers *481*, *482*, *485*, *486* or *4838*, while that of a heart-attack patient begins with *410*.

[8] Indeed, a lack of information about the source of admission (e.g., from home) motivated Tay (2003)'s use of a mixed-logit analysis for hospital choice among heart-attack patients. One "type" of patient was found to obtain relatively little disutility from distance, a finding that is interpreted as absence from home when the heart attack occurred.

with end-stage renal diseases being a source of eligibility.

We exclude patients whose age, sex or race was censored (for privacy reasons) in the discharge data, because these characteristics are plausibly related to tastes (Geweke et al. (2003), Tay (2003)). In our benchmark sample, we also exclude patients whose nearest hospital is not in the greater LA market.

Our benchmark sample of 9,006 pneumonia patients is summarized in Table 3. Nearly three-quarters were aged 75 or older; slightly more than half were female; and nearly eight percent were black. We estimate patients' household income based on Census information, closely following Geweke et al. (2003)'s approach.[9] Finally, the Charlson-Deyo index is a measure of comorbidities as recorded in the discharge record (Quan et al. (2005)).

Our empirical model of the utility that a patient expects to receive from a hospital is as follows:

$$U_{ih} = \beta_{di} D_{ih} + \beta_{qi} \sum\nolimits_{h'} Q_{h'} I\left(h' = h\right) + \epsilon_{ih}, \tag{12}$$

in which D_{ih} is the distance between the patient's home and the hospital, Q_h is revealed quality, and $I(\cdot)$ is an indicator function equaling one when a statement is true and zero otherwise.

The term Q_h embodies all aspects of the hospital experience that patients are aware of and value (see section 2.1). We refer to Q_h as "revealed quality" in order to distinguish it from its component attributes.[10] Rele-

[9] We first match the five-digit zip code of a patient's home to the five-digit Zip Code Tabulation Area (ZCTA) defined by the Census to approximate U.S. Postal Service zip codes. Where there is no match, we match the patient to the ZCTA whose centroid is nearest to the centroid of her USPS zip code. We then estimate average income among black and non-black households headed by persons aged 65-74 and 75 or older within the ZCTA. The Census reports the number of households within income intervals (e.g., $35,000 to $39,999), and we use the midpoint of each bounded interval (and a value of $280,000 for the unbounded highest-income interval) to compute an average. When there are no black households within the ZCTA, we use the average income among all racial groups.

[10] This approach aggregates all hospital attributes into revealed quality. Comparing equations 12 and 1, such aggregation is valid if the marginal rate of substitution between any two attributes embodied in revealed quality is identical across patients. While we are not aware of any direct evidence on this issue, this is a seemingly strong assumption. This assumption can be tested and relaxed when a researcher observes some potential components of quality. In the context of health-plan choice, Harris and Keane (1998) and Harris et al. (2002) use stated-preference data to infer unobserved attributes while accounting for observed attributes.

vant attributes include clinical quality as well as amenities. This model of choice behavior is consistent with the selective-referral hypothesis, in which patients are more likely to choose hospitals with high clinical quality (Luft et al. (1987)). An alternative explanation of the observed positive association between hospital volume and favorable health outcomes is the hypothesis that "practice makes perfect," for which there is some evidence (Gaynor et al. (2005), Gowrisankaran et al. (2006)). Our model is also consistent with this latter hypothesis, if patients form rational expectations about hospital volumes and the clinical quality that results and choose hospitals accordingly. Revealed quality may also embody "brand image," as distinct from "actual" hospital attributes, due to advertising that is persuasive rather than informative (Bagwell (2007)). We discuss below why marketing expenditures are unlikely to contribute significantly to the cost of revealed quality.

Motivated by existing evidence on the cost of clinical quality, we also analyze hospital choice with negative hospital mortality rates substituted for Q_h in equation 12. Lower mortality represents higher quality, and the use of negative mortality eases the comparison between revealed and clinical quality. Annual risk-adjusted 30-day mortality rates for community-acquired pneumonia are averaged over the period 2000-2004 (California Office of Statewide Health Planning and Development (2006)). OSHPD constructed these rates by comparing the actual number of deaths for each hospital to the predicted number based on patient characteristics, as in Morey et al. (1992) and Carey and Burgess, Jr. (1999); the resulting ratio was then multiplied by the average actual mortality rate among California hospitals.[11]

In contrast with equation 1, this model does not include the price of a hospital's care. For a Medicare fee-for-service beneficiary, out-of-pocket costs are essentially identical across hospitals (see, for example, Department of Health and Human Services (2001)). Under the assumptions maintained below, these costs do not influence the hospital choice of our patients. This feature of the model is convenient, because hospital pricing is complex, and important determinants of a patient's price (such as insurance copayments or anticipated writeoffs) are not observed. We are reluctant to model and estimate prices, because their relationship to revealed quality is susceptible to misspecification.

In the empirical model of utility, we allow the tastes for distance and

[11] OSHPD considers two risk-adjustment models. We use the mortality rate that accounts for do-not-resuscitate orders.

quality to differ across patients as follows:

$$\beta_{x,i} = \beta_{x,0} + \beta_{x,75+years} I\left(Age_i \geq 75\right) + \beta_{x,Female} I\left(Sex_i = Female\right)$$
$$+ \beta_{x,Black} I\left(Race_i = Black\right) + \beta_{x,Income} Income_i + \beta_{x,CDI} CDI_i,\ x = d, q,$$

in which CDI_i is the Charlson-Deyo index for the ith patient. Because quality is latent (see section 2.1), the taste for revealed quality must be normalized; we fix the intercept at one ($\beta_{q,0} = 1$). This normalization implies that quality as revealed by patients cannot be compared in levels across specifications.

In order to derive the likelihood that a patient is observed to choose a hospital, some additional assumptions are necessary. First, patients in need of care always elect to receive care, meaning that there is no "outside" good. This assumption is particularly plausible for heart-attack patients. Second, ϵ_{ih} is assumed to be distributed type-I extreme-valued. Then the probability that patient i chooses hospital h is:

$$\pi_{ih} = \frac{\exp\left[\beta_{di} D_{ih} + \beta_{qi} \sum_{h'} Q_{h'} I\left(h' = h\right)\right]}{\sum_{h''} \exp\left[\beta_{di} D_{jh''} + \beta_{qi} \sum_{h'} Q_{h'} I\left(h' = h''\right)\right]} \tag{13}$$

A hospital's expected demand follows immediately: $Y_h = \sum_i \pi_{ih}$.

Revealed quality is measured with sampling variability in the subsequent analysis of hospital costs. We obtain bootstrapped revealed-quality estimates by reestimating the choice model on 100 samples of patients drawn (with replacement) from the original sample. To speed up bootstrapping, the analysis restricts each patient's choice set in equation 13 to her nearest 50 hospitals, as Tay (2003) does. (We also consider choice sets that include hospitals located within 20 and 50 miles of the patient's home.) In addition, we limit the analysis to patient choice within a single year (2002).

We estimate the model's parameters, including each hospital's revealed quality Q_h, by maximizing the joint likelihood of patients' observed choices. As is typical in discrete-choice models with unobserved product attributes, a normalization is necessary on the revealed quality of some hospital (Berry et al. (1995), Town and Vistnes (2001)).[12]

[12] The quality of Beverly Hospital is normalized to zero.

3.2 Hospital costs

We analyze hospital costs by specifying a translog cost function and estimating this model over multiple years. The translog is a flexible functional form consistent with cost-minimizing behavior (Christensen et al. (1973)); it has been used to study the cost structures of a wide variety of firms, including hospitals.[13] Our benchmark analysis is a fixed-effects regression of the relationship between costs and quality as revealed by pneumonia patients.

Our empirical approach to hospital costs rests on two important assumptions. The first assumption is that productivity is additively separable from all other determinants of costs. That is, productivity differences shift the hospital's production frontier proportionally, with a neutral impact on inputs (Van Biesebroeck (2004)).[14] This assumption, which has been widely maintained in productivity-related empirical analyses, is essential for our purposes because productivity is unobserved.

The second assumption is that hospital productivity is fixed in the short run. This assumption implies that a fixed effect in each hospital's costs embodies its unobserved productivity, eliminating a potential source of correlation between the model disturbance and observed determinants of costs. The sensitivity of the results to this assumption can be assessed by analyzing costs over an abbreviated horizon, as described below. We further assume that hospital quality is fixed.[15] This assumption is not essential but is consistent with the analysis of hospital choice, in which quality is revealed by patient choice in a single year (2002). Under this approach, productivity and quality are a stable component of hospital costs over time.

Given these assumptions, hospitals produce quantity and quality according to the transformation function:

$$F\left(Y_{ht}, Q_h, \mathbf{Z}_{ht}, A_h\right) = 0 \tag{14}$$

[13] Cowing and Holtmann (1983), Zuckerman et al. (1994), and Dor and Farley (1996) are just a few applications of the translog to hospital costs.

[14] This assumption implies, by Shepherd's lemma, that factor shares do not vary with productivity. We do not analyze factor shares here.

The assumption also implies that productivity is effectively one-dimensional. Productivity is typically treated as one-dimensional in empirical analyses (Van Biesebroeck (2004)).

[15] The assumption that quality is fixed does not necessarily follow from the assumption that productivity is fixed. For example, demand conditions may change over time, leading to changes in optimal quality.

in which Y_{ht} is quantity at hospital h in year t, Q_h is quality, $\mathbf{Z}_{ht}$ is a vector of observed "cost factors," and A_h is productivity. Quantity is one-dimensional in this model. Feldstein (1965) and Lave and Lave (1970) long ago recognized the challenge of aggregating heterogeneous hospital stays; we describe our approach to this problem below.[16]

The solution to the hospital's cost-minimization problem gives the cost function:

$$C_{ht} = C\left(Y_{ht}, Q_h, \mathbf{Z}_{ht}, A_h, \mathbf{W}_{ht}\right),$$

in which $\mathbf{W}_{ht}$ is a vector of input prices. This function is assumed to be translog:

$$\begin{aligned}
\ln C_{ht} \;=\;& \alpha_0 + \alpha_Y \ln Y_{ht} + \alpha_Q Q_h + \sum\nolimits_j \alpha_{Z_j} \ln Z_{htj} \qquad (15)\\
&+ \sum\nolimits_j \alpha_{W_j} \ln W_{htj} + \frac{1}{2}\alpha_{Y^2}\left(\ln Y_{ht}\right)^2 + \alpha_{Y,Q} \ln Y_{ht} \cdot Q_h \\
&+ \sum\nolimits_j \alpha_{Y,Z_j} \ln Y_{ht} \ln Z_{htj} + \sum\nolimits_j \alpha_{Y,W_j} \ln Y_{ht} \ln W_{htj} \\
&+ \frac{1}{2}\alpha_{Q^2} Q_h^2 + \sum\nolimits_j \alpha_{Q,Z_j} Q_h \ln Z_{htj} + \sum\nolimits_j \alpha_{Q,W_j} Q_h \ln W_{htj} \\
&+ \frac{1}{2}\sum\nolimits_j \alpha_{Z_j^2}\left(\ln Z_{htj}\right) + \frac{1}{2}\sum\nolimits_j \sum\nolimits_k \alpha_{Z_i,Z_k} \ln Z_{htj} \ln Z_{htk} \\
&+ \frac{1}{2}\sum\nolimits_j \sum\nolimits_k \alpha_{Z_j,W_k} \ln Z_{htj} \ln W_{htk} \\
&+ \frac{1}{2}\sum\nolimits_j \sum\nolimits_k \alpha_{W_i,W_k} \ln W_{htj} \ln W_{htk} \\
&- A_h + \varepsilon_{ht}
\end{aligned}$$

The negative sign preceding A_h in equation 15 reflects the fact that higher productivity lowers costs. In particular, higher productivity lowers the marginal cost of both quantity and quality, implying under the model of hospital behavior in section 2.2 that quality should be positively correlated with productivity. The cost analysis does not, however, place any structure on the relationship between quality and productivity, and we can and do test the model's prediction. The lack of interactions between productivity and other

[16] Quality is also one-dimensional here. Insofar as revealed quality embodies multiple attributes, aggregation requires restrictions on technology (Spady and Friedlaender (1978)). For example, the ratio of the marginal costs of any two attributes of revealed quality is independent of input prices.

factors in equation 15 follows from the assumption that productivity is separable. Productivity and quality appear in levels rather than logs because these variables may take negative values. Hence this model measures the cost of quality in percentage terms.

In our benchmark analysis, we consider total costs, which include capital as well as operating costs. Like McClellan and Newhouse (1997) and Picone et al. (2003), we measure hospital costs by applying a hospital's cost-to-charge ratio in each year to its charges in the same year. These ratios are available from the annual cost reports that hospitals file with the Centers for Medicare and Medicaid Services (CMS).[17] We have been able to obtain a hospital-level cost-to-charge ratio for at least one year for all but 3 of the 129 hospitals chosen by patients in the benchmark pneumonia choice analysis.

In a sensitivity analysis, we relax the assumption that a hospital's capacity minimizes its costs. Some have argued that the industry may not be in long-run equilibrium (Carey and Burgess, Jr. (1999), Carey (2000)), and so we analyze short-run costs. We exclude capital costs from this analysis by applying the operating cost-to-charge ratios reported to CMS. In addition, the number of hospital beds is included as a cost factor in equation 15. OSHPD generally reports the number of licensed general acute-care beds at each hospital in each year. This analysis may ignore some aspects of hospital quality, including any inputs that are either difficult to adjust in the short run or otherwise correlated with beds.

Hospital quantity Y_{ht} includes all inpatient stays, not just pneumonia stays. Like Carey and Burgess, Jr. (1999), we account for heterogeneity in these stays with an index of the annual mix of a hospital's cases in each year, obtained from OSHPD. This case-mix index (denoted *CMI*) reflects the relative resource intensivity of different stays classified according to hundreds of diagnosis-related groups (DRGs).[18] We include the mean Charlson-Deyo index (denoted *CDI*) among all of a hospital's stays in each year as another

[17] The discharge data containing charges is reported on a calendar-year basis. The CMS data is reported for a hospital's fiscal year, which typically coincides with the federal fiscal year beginning October 1. The synchronization of charges and cost-to-charge ratios is therefore "off," often by three months. We view this problem as insignificant and do not attempt to correct for it.

[18] Examples of DRGs include simple pneumonia and pleurisy among 17+ year olds, without complications; the same, but with complications; percutaneous coronary procedures with acute myocardial infarction (AMI); and vaginal delivery without complicating diagnoses.

cost factor. This index measures patient comorbidities and hence health status.

In the benchmark specification, quality as revealed by pneumonia patients serves as a proxy for all hospital patients. In a sensitivity analysis we focus on pneumonia care, excluding all non-pneumonia stays from Y_{ht} and defining costs accordingly. This analysis may not suffer from measurement error yet precludes economies of scale and scope between pneumonia and other kinds of care. We also analyze the cost of revealed heart-attack quality. Quality as revealed by heart-attack patients may reflect a different mix of clinical quality and amenities. Thus "revealed heart-attack quality" may be better (or worse) than "revealed pneumonia quality" as a proxy of quality for all patients.

Input prices also affect costs. We are concerned that heterogeneity in inputs is hard to measure and related to quality. This concern is reinforced by the evidence in Hendricks (1989) that the mix of employees at a hospital, and in particular the share of better paid (and more highly skilled) employees, explains some of the wage "gradient" across hospitals within urban areas. We believe it is reasonable to assume that the hospitals studied, which operate in a geographically small and seemingly homogenous market, face identical prices for identical inputs. This assumption is consistent with Hendricks (1989)'s finding that hospital wages in central cities are indistinguishable from wages in urbanized suburbs, after controlling for observed determinants of wages. If larger hospitals enjoy a greater degree of monopsony power in input markets (Sullivan (1989)), such a cost advantage will manifest itself as scale economies, which are not our concern. We make the additional assumption that prices evolve at a common rate during the period studied. Input prices are then:

$$\ln W_{htj} = \beta_j + \beta_t t \tag{16}$$

in which j indexes the jth input and which t is time. We measure time relative to the year 2002 (i.e., year 2002 is time 0).

With costs changing over time according to the rate of factor-price inflation, costs become:

$$\begin{aligned}\ln C_{ht} &= \widetilde{\alpha}_0 + \alpha_Y \ln Y_{ht} + \alpha_{CMI} \ln CMI_{ht} + \alpha_{CDI} \ln CDI_{ht} \\ &+ \frac{1}{2}\alpha_{Y^2}\left(\ln Y_{ht}\right)^2 + \alpha_{Y,Q} \ln Y_{ht} \cdot Q_h + \alpha_{Y,CMI} \ln Y_{ht} \ln CMI_{ht} \\ &+ \alpha_{Y,CDI} \ln Y_{ht} \ln CDI_{ht} + \alpha_{Q,CMI} Q_h \ln CMI_{ht} \\ &+ \frac{1}{2}\alpha_{CMI^2}\left(\ln CMI_{ht}\right)^2 + \alpha_{CMI,CDI} CMI_{ht} \ln CDI_{ht} \\ &+ \frac{1}{2}\alpha_{CDI^2}\left(\ln CDI_{ht}\right)^2 + \alpha_t t + \frac{1}{2}\alpha_{t^2} t^2 + \alpha_{t,Y} t \ln Y_{ht} \\ &+ \alpha_{t,Q} t Q_h + \alpha_{t,CMI} t \ln CMI_{ht} + \alpha_{t,CDI} t \ln CDI_{ht} + \phi_h + \varepsilon_{ht},\end{aligned} \tag{17}$$

in which the hospital's "cost fixed effect" ϕ_h is:

$$\phi_h = \phi_0 + \alpha_Q Q_h + \frac{1}{2}\alpha_{Q^2} Q_h^2 - A_h \tag{18}$$

Under the assumption that both quality and productivity are fixed in the short run, each contributes to this component of cost. That is, the cost of quality is not identified in the fixed-effect cost model of equation 17. The contribution of quality to costs is distinguished from that of productivity in a subsequent stage of analysis described in section 3.3.

In our benchmark cost analysis, we estimate equation 17 for the period 2000-2004, a moderately lengthy window around the year in which hospital choice is analyzed (2002). This analysis investigates the cost of revealed quality among the hospitals chosen by patients in the benchmark pneumonia choice analysis. This sample is described in Table 4. These hospitals are a diverse group, with total annual charges ranging from \$3.1 million to \$3,208.6 million, total costs ranging from \$1.5 million to \$842.6 million, total stays ranging from 124 to 53,060, and beds ranging from 17 to 1,357. Observations are drawn quite evenly across years.

We explore the sensitivity of our findings to some alternative specifications in addition to those already described. First, we relax the assumption that productivity and quality are fixed during the period 2000-2004, restricting the analysis to 2002-2003 instead. A state regulation mandating minimum nurse/patient ratios was to take effect in 2004, potentially altering both clinical quality and hospital amenities (Donaldson et al. (2005)). As a result, revealed quality in 2002 — the year in which hospital choice is studied — may have differed from quality in 2004. Second, we analyze the cost of revealed quality among the sample of hospitals that corresponds to Geweke et al. (2003)'s, namely, hospitals in Los Angeles County that treated at least 20 pneumonia patients per year on average.[19]

An issue for these analyses is that revealed quality is measured with sampling error from the analysis of hospital choice. Conventional standard errors will not reflect this sampling error (Murphy and Topel (1986)). Valid standard errors can be computed with bootstrapped revealed-quality estimates, as described in section 3.1.

Motivated by existing evidence on the cost of clinical quality, we also analyze the cost of lower mortality among pneumonia patients. In particular, following Carey and Burgess, Jr. (1999), we first consider *annual* mortality rates (as described in the preceding section). Substituting equation 18 into equation 17, we estimate a pooled version of the cost model, first by ordinary least squares (OLS), then by instrumental variables (IV). Instruments include one-year lagged mortality rates as well as their interactions with all quality-interacting covariates (e.g., lagged mortality interacted with log quantity). The IV analysis should deal with the problem of measurement error in the annual rates; the instruments may nevertheless be correlated with unobserved productivity. Standard errors are clustered on the hospital in these regressions. We then estimate the fixed-effect model of equation 17, again by both OLS and IV. The hospital-level fixed effects now embody *average* mortality during 2000-2004, as well as productivity. Instruments include the exogenous responsiveness of hospital demand with respect to average mortality — as described in subsequent section 3.3 — and its interactions with quality-interacting covariates. OLS on average mortality may suffer less from measurement error than OLS on annual mortality. The IV analysis of average mortality may deal with the endogeneity of mortality.

In all of these analyses, variables are demeaned so that the first-order parameters reflect phenomena of interest at a hospital with mean characteristics. For example, the "average" hospital experiences scale economies (diseconomies) if and only if $\alpha_Y < 1$ ($\alpha_Y > 1$). For consistency, we demean all variables (other than time) relative to the sample of hospitals in the benchmark pneumonia cost analysis.

[19] These hospitals are somewhat larger than the hospitals in the benchmark cost sample, with average beds of 247.8 and 229.7, respectively.

3.3 The cost of quality

Understanding the cost of quality is the aim of this paper. The preceding section implies that the cost of quality is:

$$\begin{aligned}\frac{\partial \ln C_{ht}}{\partial Q_h} &= \frac{\partial \phi_h}{\partial Q_h} + \alpha_{Y,Q} \ln Y_{ht} + \alpha_{Q,CMI} \ln CMI_{ht} \\ &\quad + \alpha_{Q,CDI} \ln CDI_{ht} + \alpha_{Q,t} t \\ &= \alpha_Q + \alpha_{Q^2} Q_h + \alpha_{Y,Q} \ln Y_{ht} + \alpha_{Q,CMI} \ln CMI_{ht} \\ &\quad + \alpha_{Q,CDI} \ln CDI_{ht} + \alpha_{Q,t} t\end{aligned} \tag{19}$$

Estimates of the final four parameters in equation 19 are available from the cost model of equation 17.

In the fixed-effect analyses of revealed quality and average mortality, the remaining parameters in equation 19 appear in the hospital cost fixed effect ϕ_h. We wish to decompose this effect:

$$\phi_h = \phi_0 + \alpha_Q Q_h + \frac{1}{2}\alpha_{Q^2} Q_h^2 - A_h \tag{20}$$

Estimates of the dependent variable ϕ_h are available from the cost model. Estimates of revealed quality are available from the analysis of hospital choice, while average mortality is observed.

Two challenges remain. First, we argued in section 2.2 that quality may be related to unobserved productivity; this concern applies to both revealed quality and mortality rates. A valid instrument is correlated with quality but uncorrelated with productivity. We have argued that the derivative of a hospital's demand with respect to quality — which we have referred to as "quality responsiveness" — affects the marginal utility of quality and thus its optimal level. Yet quality responsiveness depends on quality and is therefore generally correlated with productivity. To obtain an instrument, we evaluate this derivative with quality fixed at a uniform level, i.e., at $Q^{IV} \equiv Y_Q \left(\overline{Q}, \overline{\mathbf{Q}}, \mathbf{X}\right)$, drawing on the results of the analyses of hospital choice based on revealed quality as well as average pneumonia mortality.[20] Having argued earlier that this feature of hospital demand is plausibly uncorrelated with productivity, we refer to this instrument as "exogenous quality responsiveness." The strength of its relationship to quality is assessed based on the following:

$$Q_h = \theta_0 + \theta_q Q_h^{IV} + \nu_h \tag{21}$$

[20] Under the empirical choice model, the level at which quality is fixed is irrelevant.

For the case of one endogenous variable, Stock and Yogo (2005) suggest that a set of instruments has sufficient power if this first-stage regression's F statistic exceeds ten. We can use $(Q^{IV})^2$ as an additional instrument.

The second challenge concerns valid inference. To begin with, revealed quality and hence the dependent variable in equation 20 are measured with error from the choice analysis. In addition, for both revealed quality and average mortality, the fixed-effect dependent variable is not consistent in the number of hospitals but is unbiased, implying that the finite-sample performance of the estimator is of paramount importance (Wooldridge (2002)). To obtain valid standard errors, we apply bootstrapped revealed-quality estimates first in the cost model and then in the decomposition of quality and productivity.

3.4 Summary

Our empirical approach is comprised of three stages. In the first stage we estimate revealed quality using a conditional-logit model of hospital choice. Revealed quality embodies all aspects of the hospital experience that patients value, including amenities and clinical quality. The benchmark analysis focuses on pneumonia patients. In the second stage we estimate a translog model of hospital costs over time with hospital-level fixed effects that embody the joint contribution of revealed quality and productivity. The benchmark specification analyzes the total costs of all hospital stays during the period 2000-2004. In the third stage we regress the cost fixed effects from the second stage on revealed quality from the first stage, instrumenting for revealed quality with a measure of the responsiveness of hospital demand to quality. Motivated by existing evidence on the cost of clinical quality, we compare the cost of lower pneumonia mortality to the cost of revealed quality.

4 Findings

We now describe our findings from the analyses of hospital choice and costs. We then present our evidence on the cost of quality in hospitals.

4.1 Hospital choice

The results of the analysis of hospital choice (described in section 3.1) appear in Table 5. The benchmark specification analyzes hospital choice by pneumonia patients with a conditional-logit model which includes hospital indicator variables for revealed quality. The first set (column) of results in the table corresponds to this specification. We argued in section 3.1 that revealed quality embodies both clinical quality and amenities. An alternative specification replaces revealed quality with clinical quality, as measured by negative mortality rates for community-acquired pneumonia. We use this second set of results to compare the cost of clinical quality to that of revealed quality in section 4.3.

The fit of the revealed-quality model is substantial, with a pseudo-R^2 of 0.522. There is strong evidence that patients view hospitals as differentiated in revealed quality. Observed and predicted *hospital*-level demand are essentially perfectly correlated. When revealed quality is ignored (by evaluating demand at zero quality for every hospital), this correlation declines to 0.411.

A kernel density estimate of the distribution of revealed quality appears in Figure 3, and Table 6 lists the top and bottom 12 hospitals. (The revealed quality of all hospitals for this benchmark analysis is listed in Table A1.) A comparison of quality as revealed by pneumonia patients to alternative quality measures is interesting. The National Research Corporation (NRC) conducts market research on the health-care sector, undertaking consumer surveys concerning various aspects of hospital performance. Table 7 compares the top-12 hospitals by revealed quality in 2002 with NRC's assessment of "Most preferred for all health needs" and "Best overall quality" in Los Angeles in 2004. Our choice analysis excludes the five Kaiser Permanente hospitals that topped NRC's rankings while including Hoag Memorial, which belongs to NRC's Orange County market. Nevertheless, there is remarkable agreement between our measure and NRC's. Our 2 top hospitals received Consumer Choice Awards as the top hospitals in Los Angeles and Orange County. Moreover, only one of NRC's top-12 hospitals does not appear in our top 12.

Next, Figure 4 illustrates the relationship between revealed quality and pneumonia mortality. This strength of this relationship is only moderate (with a correlation coefficient $\rho = -0.256$), suggesting that patients perceive important variation in aspects of the hospital experience distinct from clinical quality, e.g., in amenities. In addition, the figure may suggest the volume-outcome relationship, in which a high patient volume is associated with favorable outcomes (Luft et al. (1987)). The revealed quality that differentiates hospitals is highly correlated with the number of patients who chose to receive pneumonia care at hospitals ($\rho = +0.704$). As we explained in section 3.1, our choice model is consistent with both the selective referral and "practice makes perfect" explanations of the volume-outcome relationship. Nevertheless, the costs of quality and quantity may prove difficult to distinguish.

Figure 5 compares revealed quality among pneumonia patients to revealed quality among heart-attack patients. Revealed quality is strongly correlated among pneumonia and heart-attack patients; this correlation is positive and fairly strong ($\rho = +0.797$). Nevertheless, heart-attack patients reveal some hospitals to be substantially lower in quality than do pneumonia patients, perhaps because these hospitals lack advanced technologies for cardiac care (such as a catheterization lab).

In sensitivity analyses, we consider alternative treatments of choice behavior, the market and patients' choice sets. The correlations between revealed quality in our benchmark pneumonia choice analysis and these alternatives (as described in Table A2 of the appendix) exceed +0.97. This similarity in revealed quality across alternative specifications is reassuring.

Our model of hospital choice permits the tastes for distance and quality to vary with patient characteristics. In the revealed-quality analysis, for example, older patients have a relatively strong distaste for distance between home and hospital, while higher-income and female patients have a relatively weak distaste. With respect to quality, older, higher-income, and relatively comorbid patients have a relatively strong taste, while there is some evidence that blacks value quality less than others. Tastes for clinical quality, as measured by negative mortality rates, also vary.

To aid in interpretation, Table 8 describes the willingness of different patients to travel for higher revealed quality. White males under age 75 with mean income and comorbidity would be willing to travel 2.88 miles farther for a hospital at the 75th percentile of the revealed-quality distribution rather than the 25th percentile (see Table A3 for these statistics). The same patients, only older (aged 75+), would be willing to travel farther, namely, 3.88 miles. While older patients dislike distance more than younger patients, their stronger preference for revealed quality dominates. The reference patients, only more affluent (1 standard deviation above mean income), would be willing to travel somewhat farther still (3.94 miles). At the other extreme, the reference patients, only black, would be willing to travel only 2.41 miles for higher quality.

We argued in section 2.2 that such variation in patient tastes can create variation in the responsiveness of hospital demand to quality and may therefore induce exogenous variation in hospital quality. We pursue this strategy below in identifying the cost of quality.

4.2 Hospital costs

The benchmark cost analysis (described in section 3.2) is a translog model of the total costs of all hospital stays during 2000-2004. This model, which includes hospital-level fixed effects, has substantial explanatory power, with an overall R^2 of nearly eighty-two percent and a within-hospital R^2 of nearly forty-eight percent. The results of this analysis appear in Table A4.[21]

The cost model assumes that productivity and quality are stable in the short run. There is strong evidence of a fixed component of hospital costs: the p value of an F test of the hypothesis that all hospital fixed effects are equal to zero is less than 0.001.

Some additional results are worth noting. We cannot reject constant returns to scale[22] At an average hospital, costs were increasing nearly five percent per year in 2002, and the elasticity of costs with respect to case mix was close to one ($\alpha_{CMI} = 0.889$). The interaction between case mix and quality is negative and statistically significant ($\alpha_{Q,CMI} = -0.563$). As a result, the elasticity of costs with respect to case mix is lower at hospitals with higher revealed quality, and the cost of revealed quality (in percentage terms) is lower at hospitals with more complex cases. We present evidence in

[21] At this juncture, the only standard errors affected by first-stage sampling variability that have been bootstrapped are those for the cost of quality improvement in section 4.3.

[22] Carey (2000)'s analysis of costs in U.S. hospitals finds scale diseconomies under a random-effects specification but scale economies under fixed effects. This pattern is consistent with a preference of patients for hospitals with high quality that the researcher does not observe. Our choice analysis delivers strong evidence that patients view hospitals in greater LA as differentiated in quality and choose accordingly. Nevertheless, a Hausman test cannot reject the null hypothesis that the results of a random-effects specification are consistent for the results of a fixed-effects specification for our benchmark cost analysis (Hausman (1978)). This failure to reject is consistent with a positive correlation between quality and productivity among our hospitals, which we find in the next section. We do find a pattern similar to Carey's in some sensitivity analyses (e.g., of hospital costs for pneumonia care).

the next section that amenities (rather than clinical quality) drive the cost of revealed quality, and so this finding suggests economies of scope in the provision of amenities and complex care. The interaction between quantity and quality ($\alpha_{Y,Q} = 0.082$) cannot be statistically distinguished from zero.

In the analysis of the cost of clinical quality, the results are quite imprecise when pneumonia mortality is interacted with itself and other covariates, and these second-order parameters are restricted to be zero in the reported specifications. All other results are qualitatively similar to those for the benchmark analysis of costs based on quality as revealed by pneumonia patients. The results from this analysis appear in Table A5.

4.3 The cost of quality

We first consider revealed quality. As Figure 6 illustrates, revealed quality is increasing in the exogenous quality responsiveness of hospital demand, consistent with our model of hospital behavior in section 2.2. The F statistic for the power of this instrument exceeds the usual threshold, with the first-stage regression appearing in Table A6.

We explore the source of our identification through this instrument by regressing it on the mean characteristics of patients residing within 2.5 miles of hospitals. The elasticities of exogenous quality responsiveness with respect to these characteristics appear in Table 9. Income and the number of patients are statistically significant, with elasticities of 1.08 and 0.41, respectively. The percentages of patients who were aged 75 or older and who were female were of marginal statistical significance, with respective elasticities of 0.34 and 0.30.

We use exogenous quality responsiveness as an instrument to decompose the contributions of revealed quality and productivity to hospital costs. In an exploratory analysis that included squared responsiveness as an instrument, we found that the cost of quality was imprecisely estimated. We therefore restrict the second-order parameter on quality (α_{Q^2}) to be zero, as Gertler and Waldman (1992) do.

Table 10 reports the results of this analysis. The cost of quality is positive and statistically significant under both ordinary least squares (OLS) and instrumental variables (IV). Yet the magnitude of this cost is greater by more than fourfold under IV. A Hausman test rejects the null that the OLS results are consistent for the IV results at a level of nearly four percent. Based on the IV results, we find that productivity A_h is strongly correlated

($\rho = +0.555$) with revealed quality Q_h, as our model of hospital behavior predicts. Figure 7 illustrates this relationship.

Having decomposed the contributions of revealed quality and productivity, the cost of quality can be discerned. Table 11 indicates that an increase in revealed quality from the 25th percentile of its distribution to the 75th percentile would increase costs by 50.2% at the average hospital, with a bootstrapped standard error of 16.6%.[23] If we ignore the relationship between productivity and quality and apply the OLS results, this quality improvement would appear to increase costs by only 9.4%.

We also consider the sensitivity of this finding to some alternative specifications, with Table 11 summarizing these results. First, we analyze costs for pneumonia patients only. The estimated cost of quality may be higher under this specification if quality as revealed by pneumonia patients is an imperfect measure of quality for other patients. The quality improvement now increases costs by more than one hundred percent, although this estimate is imprecise. Second, we relax the assumption that productivity and revealed quality are fixed over five years, limiting our analysis to 2002-2003. The cost of the quality improvement under this specification (+51.9%) is similar to the benchmark result. Third, we relax the assumption that a hospital's capacity is cost-minimizing, analyzing short-run operating costs with the number of beds in the model. The increase in costs is then smaller but still substantial (+31.0%). This finding suggests that aspects of the hospital experience which are unrelated to the number of beds are important. In particular, hospitals may have minimized the costs of those inputs to clinical quality and amenities that are easier to adjust than (and uncorrelated with) hospital beds.

Next, we consider the cost of quality within the market as defined by Geweke et al. (2003). The distribution of revealed quality differs between the benchmark and this market definition (see Tables A2 and A3). Based on the interquartile range under this definition, the cost of the improvement in revealed quality is +38.4% at an average hospital.

This finding may err in the direction of understating the cost of quality. An alternative approach would transform the 25th and 75th percentiles of revealed quality under the benchmark analysis into corresponding levels of

[23] The percentage change in costs is computed as $100\left[\exp\left[\alpha_Q\left(Q_h^{75} - Q_h^{25}\right)\right] - 1\right]$, in which Q_h^p is the pth percentile of the quality distribution. The reported standard error is the standard deviation of the preceding percentage among bootstraps on α_Q.

revealed quality for the alternative market definition by regressing the latter on the former. Under this approach, costs would increase by 67.8% rather than 38.4%.

Finally, we consider the cost of quality as revealed by heart-attack patients. The mix of clinical quality and amenities that comprise revealed heart-attack quality may be more or less representative of quality for the typical patient than is revealed pneumonia quality. Based on the distribution of revealed heart-attack quality, the cost of the quality improvement for the average hospital is smaller (+25.1%.) than the benchmark result, though this difference may be statistically insignificant. Had we transformed revealed pneumonia quality into revealed heart-attack quality as described in the preceding paragraph, costs would increase by more (+41.4% versus +25.1%). OLS again substantially understates the cost of quality (+9.8% versus +25.1%). We also find that revealed quality increases in the exogenous quality responsiveness of hospital demand among heart-attack patients and that quality is positively correlated with productivity.

Having analyzed the cost of revealed quality, we turn to the cost of lower pneumonia mortality. Table 11 also describes the cost of lowering mortality from the 75th percentile of the distribution of average mortality during 2000-2004 to the 25th percentile, that is, from 14.2% to 10.7%.[24]

We first analyze the cost of changes in *annual* mortality rates. The point estimates suggest that lower mortality is costly, though this estimate cannot be distinguished from zero (see specification 1 in Table A5). One possible explanation is that measurement error in annual mortality rates leads to attenuation bias. Carey and Burgess, Jr. (1999) find evidence of such bias, although the lower mortality is associated with somewhat *lower* costs in their analysis. We find that annual mortality rates are strongly related to one-year lagged mortality (see Table A7). When we instrument for annual mortality, the point estimate on quality (specification 2 in Table A5) increases in magnitude. As a result, the cost of the hypothetical improvement in pneumonia mortality rises from +1.6% to +6.2%.[25] We again cannot reject the hypothesis that costs are unchanged.

[24]Because this quality measure is not latent, we need not worry about changes in its distribution across specifications.

[25]Throughout the mortality analyses, the apparent cost of the quality improvement is even smaller when we transform the 25th and 75th percentiles of revealed pneumonia quality into predicted levels of pneumonia mortality based on a regression of the latter on the former.

We then consider the average mortality rate during 2000-2004. We estimate the fixed-effects cost model using this measure of quality. We then decompose the contribution of lower mortality both by OLS and IV, with exogenous quality responsiveness (with respect to average mortality) as an instrument. Average mortality smooths some of the measurement error in annual mortality, and the estimated cost of the hypothetical improvement in pneumonia mortality is higher for average mortality with OLS than for annual mortality with OLS, namely, 3.2% versus 1.6%. When we instrument for annual mortality, this estimate more than doubles to 7.1%. These estimates continue to be statistically indistinguishable from zero.

The cost of clinical quality appears to be modest in comparison to the cost of revealed quality. This evidence suggests that aspects of the hospital experience unrelated to clinical quality are an important driver of hospital costs as well as choice. Investments in persuasive advertising, while potentially contributing to brand image for hospitals, average only 0.1-0.2% of revenues (Barro and Chu (2002)). Thus the evidence is consistent with the view that hospitals differentiate themselves with costly investments in amenities such as caring and attentive staff, good food, and pleasant surroundings (Newhouse (1994)).

5 Conclusion

In clarifying the relationship between hospital quality and costs, we confronted two significant challenges. Hospital quality is difficult for a researcher to measure. In addition, quality is potentially confounded with unobserved productivity, in the sense that hospitals that are able to produce quality at relatively low cost have an incentive to supply relatively high quality. Each of these problems can make quality appear to be less costly than is truly the case.

Our strategy for dealing with these problems exploits the observed behavior of consumers in this industry. Patients are aware of clinical quality and are plausibly informed about amenities, and so we inferred quality at hospitals in greater Los Angeles from the revealed preference of patients. We then recovered the joint contribution of quality and productivity to costs from longitudinal data on hospital costs. In order to distinguish the contribution of quality, we again appealed to consumer behavior, arguing that differences in patient tastes within localized hospital markets lead to exogenous variation in hospitals' chosen qualities.

Our empirical findings suggest that the cost of quality as revealed by patients is substantial. In our benchmark analysis, an improvement in revealed quality from the 25th of its distribution to the 75th percentile would increase costs by 50.2% at the average hospital, a result that is robust to alternative specifications. When, however, we did not instrument for quality, this hypothetical quality improvement would appear to increase costs by only 9.4%.

Motivated by existing evidence on the cost of clinical quality, we also analyzed the cost of an equivalent improvement in pneumonia mortality. The cost of this quality improvement appears to be modest in comparison to the cost of the improvement in revealed quality; we could not even reject the hypothesis that lower pneumonia mortality is costless. This contrast between the costs of clinical and revealed quality suggests that amenities (such as caring, attentive staff, good food, and pleasant surroundings) are important determinants of hospital costs.

The present analysis suggests worthwhile directions for future research. For example, by specifying and estimating an empirical model of quality choice among hospitals, we could assess the distribution of costs in a counterfactual world with no productivity differences. We could also investigate the role of altruism in the hospital-care industry and, in particular, the relationship between altruism and hospital ownership. More generally, we believe that our approach holds promise for understanding the cost structure of firms in other differentiated-products industries.

References

Ackerberg, D. A., M. P. Machado, and M. H. Riordan (2006). "Benchmarking for Productivity Improvement: A Health-Care Application." *International Economic Review* 47(1):161–201.

Bagwell, K. (2007). "The Economic Analysis of Advertising." *Handbook of Industrial Organization.* M. Armstrong and R. Porter, eds. Vol. 3. New York: Elsevier. 1702–1844.

Barro, J. R., and M. Chu (2002). "HMO Penetration, Hospital Ownership, and the Rise of Hospital Advertising." *Working Paper 8899.* Cambridge, MA: National Bureau of Economic Research.

Berry, S., J. Levinsohn, and A. Pakes (1995). "Automobile Prices in Market Equilibrium." *Econometrica* 63(4):841–890.

Burns, L. R., and D. R. Wholey (1992). "The Impact of Physician Characteristics in Conditional Choice Models for Hospital Care." *Journal of Health Economics* 11(1):43–62.

California Office of Statewide Health Planning and Development (2006). "Community-Acquired Pneumonia in California: Hospital Outcomes 2002-2004." .

Carey, K. (2000). "A Panel Data Design for Estimation of Hospital Cost Functions." *Review of Economics and Statistics* 79(3):443–453.

Carey, K., and J. F. Burgess, Jr. (1999). "On Measuring the Hospital Cost/Quality Trade-Off." *Health Economics* 8(6):509–520.

Catlin, A., et al. (2007). "National Health Spending in 2005: The Slowdown Continues." *Health Affairs* 26(1):142–153.

Christensen, L. T., D. W. Jorgenson, and L. J. Lau (1973). "Transcendental Logarithmic Production Frontiers." *Review of Economics and Statistics* 55(1):28–45.

Cowing, T. G., and A. G. Holtmann (1983). "Multiproduct Short-Run Hospital Cost Functions: Empirical Evidence and Policy Implications from Cross-Section Data." *Southern Economic Journal* 49(3):637–653.

Cutler, D. M., M. B. McClellan, and J. P. Newhouse (1998). "The Costs and Benefits of Intensive Treatment for Cardiovascular Disease." *Working Paper 6514*. Cambridge, MA: National Bureau of Economic Research.

Dartmouth Medical School, The Center for the Evaluative Clinical Sciences (1998). *The Dartmouth Atlas of Health Care 1998*. Chicago, IL: American Hospital Publishing, Inc.

Department of Health and Human Services (2001). "HHS Announces Medicare Premiums and Deductible Rates for 2002." .

Donaldson, N., et al. (2005). "Impact of California's Licensed Nurse-Patient Ratios on Unit-Level Nurse Staffing and Patient Outcomes." *Politics, Policy and Nursing Practice* 6(3):198–210.

Dor, A., and D. E. Farley (1996). "Payment Source and the Cost of Hospital Care: Evidence from a Multiproduct Cost Function with Multiple Payers." *Journal of Health Economics* 15(1):1–21.

Feldstein, M. S. (1965). "Hospital Cost Variation and Case-Mix Differences." *Medical Care* 3(2):95–103.

Gaynor, M., H. Seider, and W. B. Vogt (2005). "The Volume-Outcome Effect, Scale Economies, and Learning-by-Doing." *American Economic Review* 95(2):243–247.

Gaynor, M., and W. B. Vogt (2003). "Competition among Hospitals." *RAND Journal of Economics* 34(4):764–785.

Gertler, P. J., and D. M. Waldman (1992). "Quality-Adjusted Cost Functions and Policy Evaluation in the Nursing Home Industry." *Journal of Political Economy* 10(6):1232–1256.

Geweke, J., G. Gowrisankaran, and R. J. Town (2003). "Bayesian Inference for Hospital Quality in a Selection Model." *Econometrica* 71(4):1215–1238.

Gowrisankaran, G., V. Ho, and R. J. Town (2006). "Causality, Learning and Forgetting in Surgery." Stanford University.

Gray, J. (1986). "The Selling of Medicine, 1986." *Medical Economics* .

Harris, J. E. (1977). "The Internal Organization of Hospitals: Some Economic Implications." *Bell Journal of Economics* 8(2):467–482.

Harris, K. M., R. Feldman, and J. Shultz (2002). "Measuring Consumer Perceptions of Quality Differences among Competing Health Plans." *Journal of Health Economics* 21(1):1–12.

Harris, K. M., and M. Keane (1998). "A Model of Health Plan Choice: Inferring Preferences and Perceptions from a Combination of Revealed Preference and Attitudinal Data." *Journal of Econometrics* 89(1).

Hausman, J. (1978). "Specification Tests in Econometrics." *Econometrica* 46(6):1251–1271.

Hendricks, A. M. (1989). "Hospital Wage Gradients within U.S. Urban Areas." *Journal of Health Economics* 8(2):233–246.

Horwitz, J. R. (2005). "Making Profits and Providing Care: Comparing Nonprofit, For-Profit, and Government Hospitals." *Health Affairs* 24(3):790–801.

Institute of Medicine (2001). *Crossing the Quality Chasm.* Washington, DC: National Academies Press.

Kessler, D. P., and M. B. McClellan (2000). "Is Hospital Competition Socially Wasteful?" *Quarterly Journal of Economics* 115(2):577–615.

Lakdawalla, D., and T. Philipson (2006). "The Nonprofit Sector and Industry Performance." *Journal of Public Economics* 90(8-9):1681–1698.

Lane, P. M., and J. D. Lindquist (1988). "Hospital Choice: A Summary of the Key Empirical and Hypothetical Findings of the 1980s." *Journal of Health Care Marketing* 8(4):5–20.

Lave, J. R., and L. B. Lave (1970). "Hospital Cost Functions." *American Economic Review* 60(3):379–95.

Luft, H. S., S. S. Hunt, and S. C. Maerki (1987). "The Volume-Outcome Relationship: Practice-Makes-Perfect Or Selective Referral Patterns?" *Health Services Research* 22(2):157–182.

Luft, H. S., et al. (1990). "Does Quality Influence Choice of Hospital?" *Journal of the American Medical Association* 263(21):2899–2906.

Marschak, J., and W. H. Andrews, Jr. (1944). "Random Simultaneous Equations and the Theory of Production." *Econometrica* 12(3/4):143–205.

McClellan, M., and J. P. Newhouse (1997). "The Marginal Cost-Effectiveness of Medical Technology: A Panel Instrumental-Variables Approach." *Journal of Econometrics* 77(1):39–64.

McFadden, D. (1974). "Conditional Logit Analysis of Qualitative Choice Behavior." *Frontiers in Econometrics.* P. Zaremba, ed. New York: Academic Press. 105–142.

Medicare Payment Advisory Commission (2005). "Report to the Congress: Physician-Owned Specialty Hospitals." *Technical report.*

Morey, R. C., et al. (1992). "The Trade-Off Between Hospital Cost and Quality: An Exploratory Empirical Analysis." *Medicare Care* 30(8):677–698.

Mukamel, D. B., and A. I. Mushlin (1998). "Quality of Care Makes a Difference: An Analysis of Market Share and Price Changes after Publication of the New York State Cardiac Mortality Report Cards." *Medical Care* 36(7):945–954.

Murphy, K. M., and R. H. Topel (1986). "Estimation and Inference in Two-Step Econometric Models." *Journal of Business and Economic Statistics* 3(4):370–379.

Nerlove, M. (1965). *Estimation and Identification of Cobb-Douglas Production Functions.* Chicago, IL: Rand McNally.

Newhouse, J. P. (1970). "Toward a Theory of Nonprofit Institutions: An Economic Model of a Hospital." *American Economic Review* 60(1):64–74.

Newhouse, J. P. (1994). "Frontier Estimation: How Useful a Tool for Health Economics?" *Journal of Health Economics* 13(3):317–322.

Olley, G. S., and A. Pakes (1996). "The Dynamics of Productivity in the Telecommunications Equipment Industry." *Econometrica* 64(6):1263–1297.

Phelps, C. E. (2002). *Health Economics.* New York: Addison-Wesley.

Picone, G. A., et al. (2003). "Does Higher Hospital Cost Imply Higher Quality of Care?" *Review of Economics and Statistics* 85(1):51–62.

Quan, H., et al. (2005). "Coding algorithms for defining comorbidities in ICD-9-CM and ICD-10 administrative data." *Medical Care* 43(11):1130–1139.

Reiss, P. C., and F. Wolak (2005). "Structural Econometric Modeling: Rationales and Examples from Industrial Organization." Stanford University.

Skinner, J. S., D. O. Staiger, and E. S. Fisher (2006). "Is Technological Change in Medicine Always Worth It? The Case of Acute Myocardial Infarction." *Health Affairs* 25:w34–w47.

Spady, R. H., and A. F. Friedlaender (1978). "Hedonic Cost Functions for the Regulated Trucking Industry." *Bell Journal of Economics* 9(1):159–179.

Stigler, G. J. (1976). "The Xistence of X-Efficiency." *American Economic Review* 66(1):213–216.

Stock, J. H., and M. Yogo (2005). "Testing for Weak Instruments in Linear IV Regression." *Identification and Inference in Econometric Models: Essays in Honor of Thomas Rothenberg*. D. W. Andrews and J. H. Stock, eds. New York: Cambridge University Press. 80–108.

Sullivan, D. (1989). "Monopsony Power in the Market for Nurses." *Journal of Law and Economics* 32(2):S135–S178.

Tay, A. (2003). "Assessing Competition in Hospital-Care Markets: The Importance of Accounting for Quality Differentiation." *RAND Journal of Economics* 34(4):786–814.

Town, R., and G. Vistnes (2001). "Hospital Competition in HMO Networks." *Journal of Health Economics* 20(5):733–753.

Van Biesebroeck, J. (2004). "Robustness of Productivity Estimates." *Working Paper 10303*. Cambridge, MA: National Bureau of Economic Research.

Wolinksy, F. D., and R. S. Kurz (1984). "How the Public Chooses and Views Hospitals." *Hospital and Health Services Administration* 29(6):58–67.

Wooldridge, J. M. (2002). *Econometric Analysis of Cross Section and Panel Data*. Cambridge, MA: MIT Press.

Zuckerman, S., J. Hadley, and L. Iezzoni (1994). "Measuring Hospital Efficiency with Frontier Cost Functions." *Journal of Health Economics* 13(3):255–280.

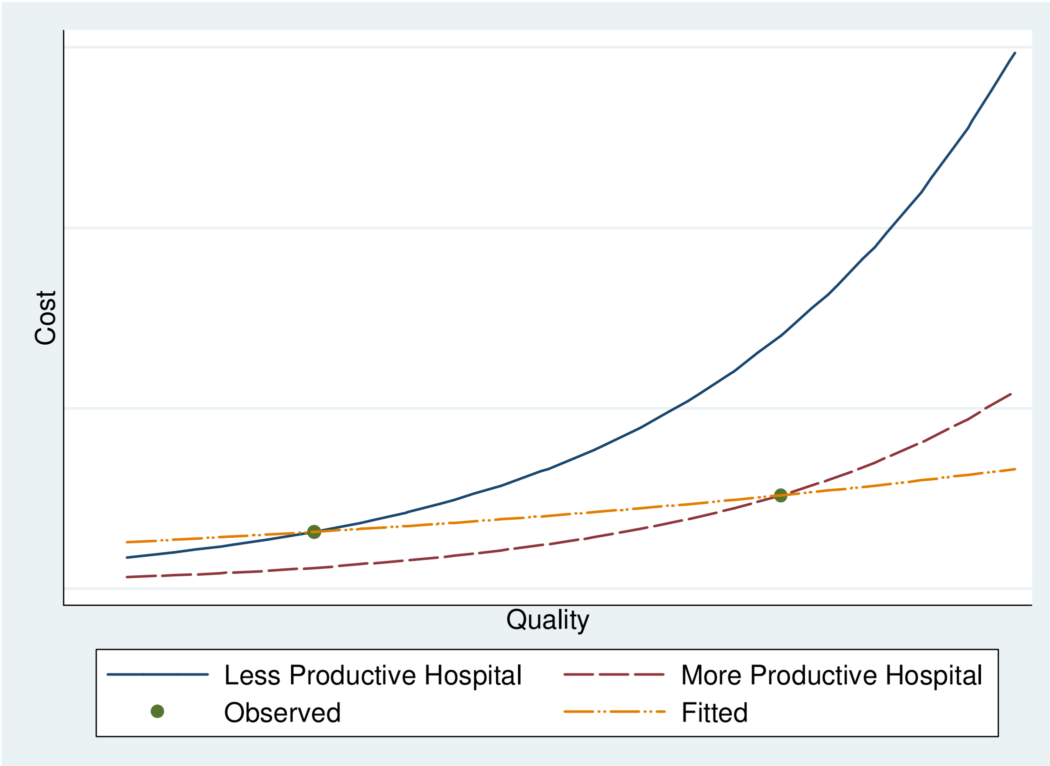

Figure 1:
Least squares understates cost of quality if
more productive hospital supplies higher quality

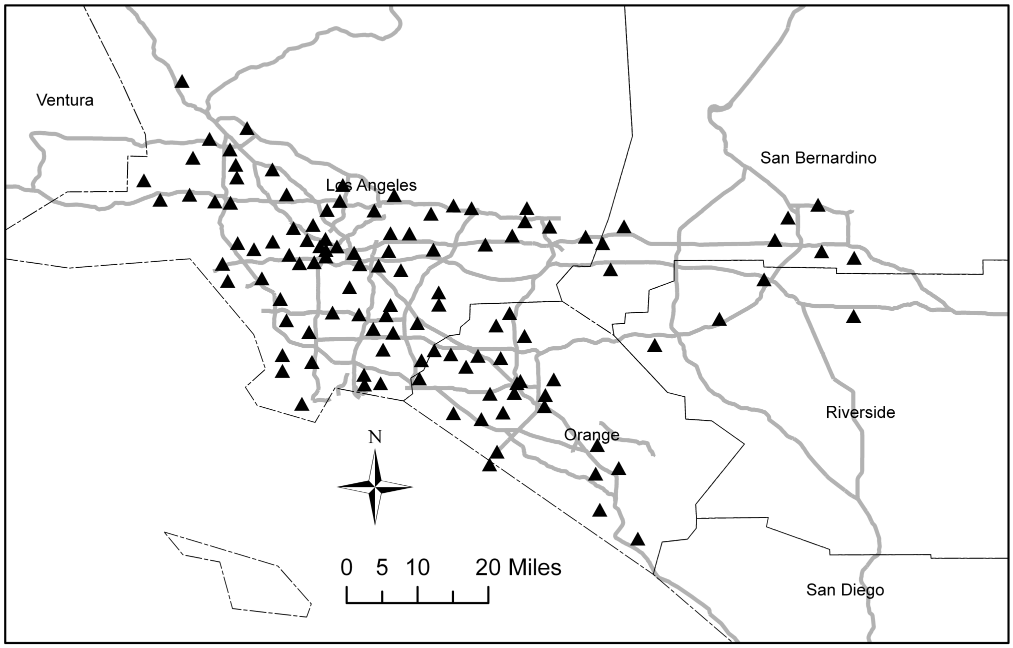

Figure 2:
Greater Los Angeles hospitals in benchmark pneumonia choice analysis

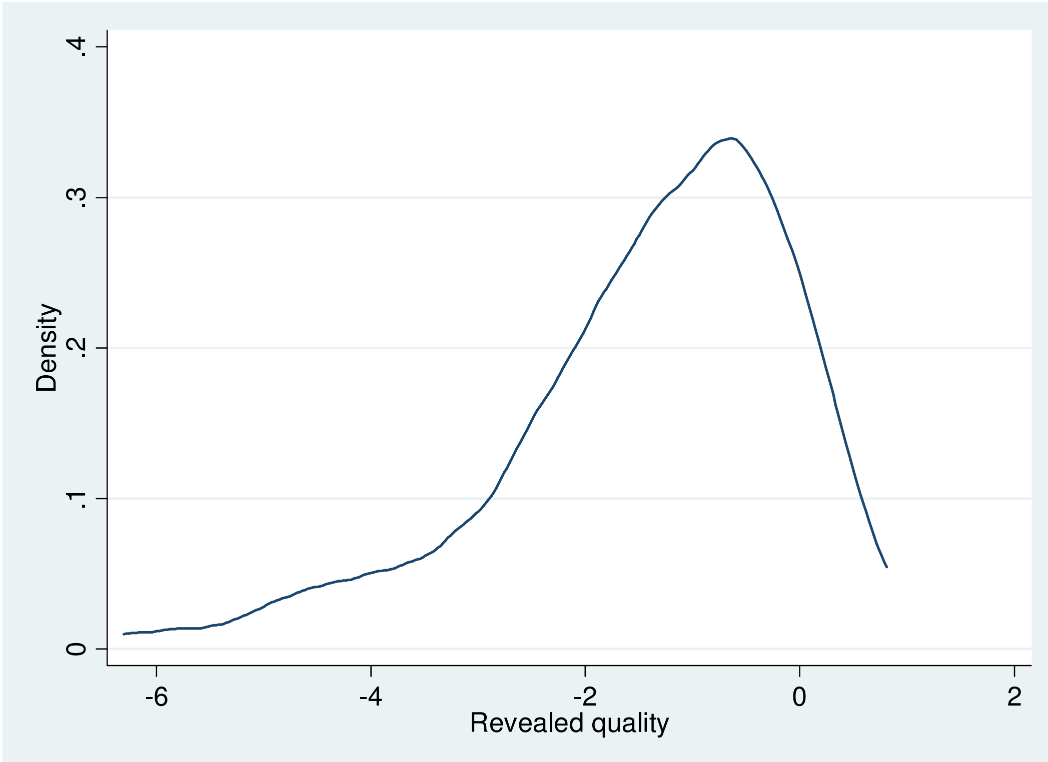

Figure 3:
Kernel density estimate of the distribution of revealed quality of hospitals in greater LA

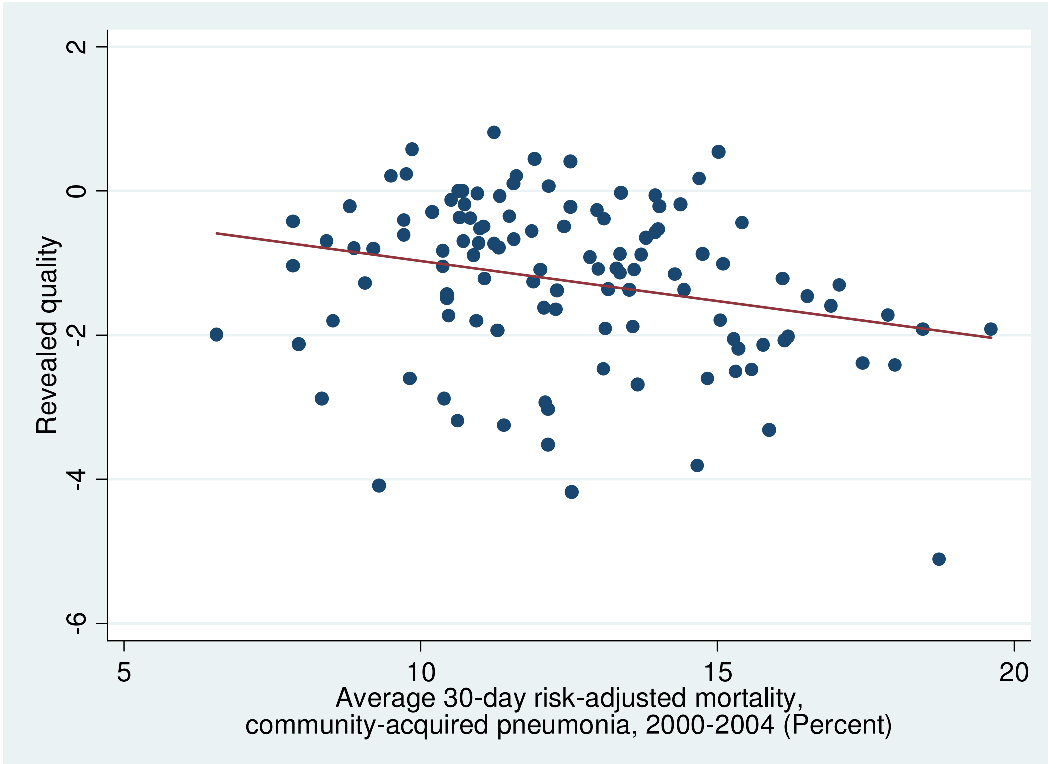

Figure 4:
Revealed quality versus average 30-day risk-adjusted mortality rates for community-acquired pneumonia, 2000-2004, among hospitals in greater LA

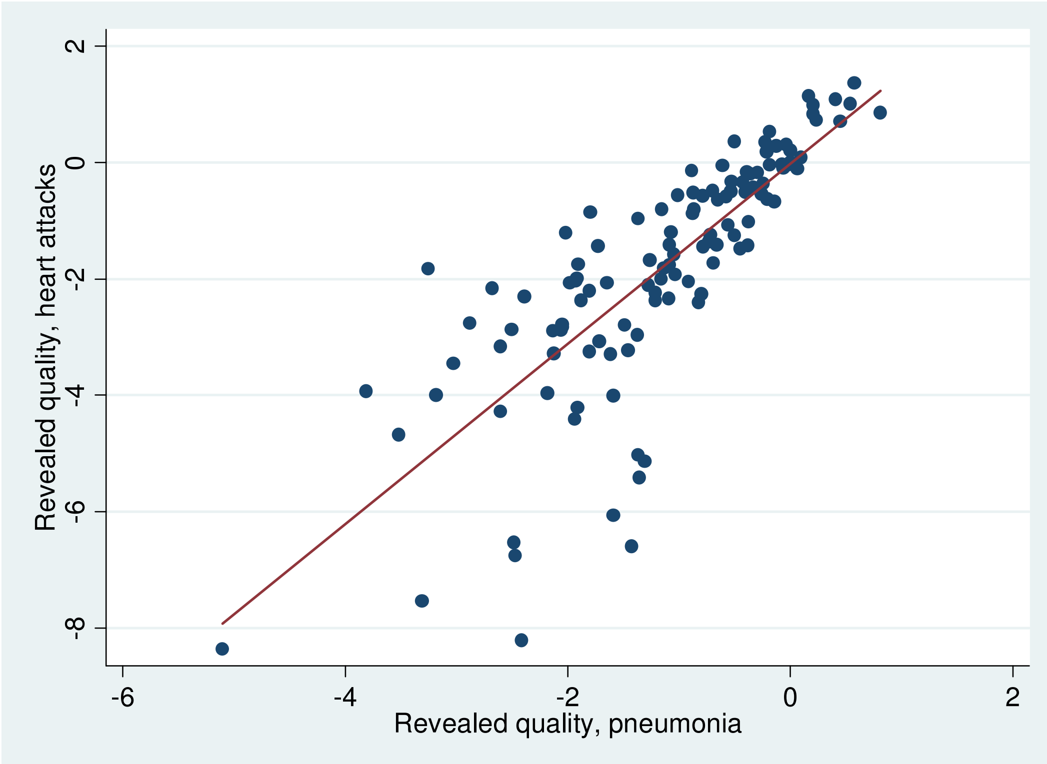

Figure 5:
Revealed quality,
benchmark pneumonia choice analysis versus heart-attack choice analysis ,
among hospitals in greater LA

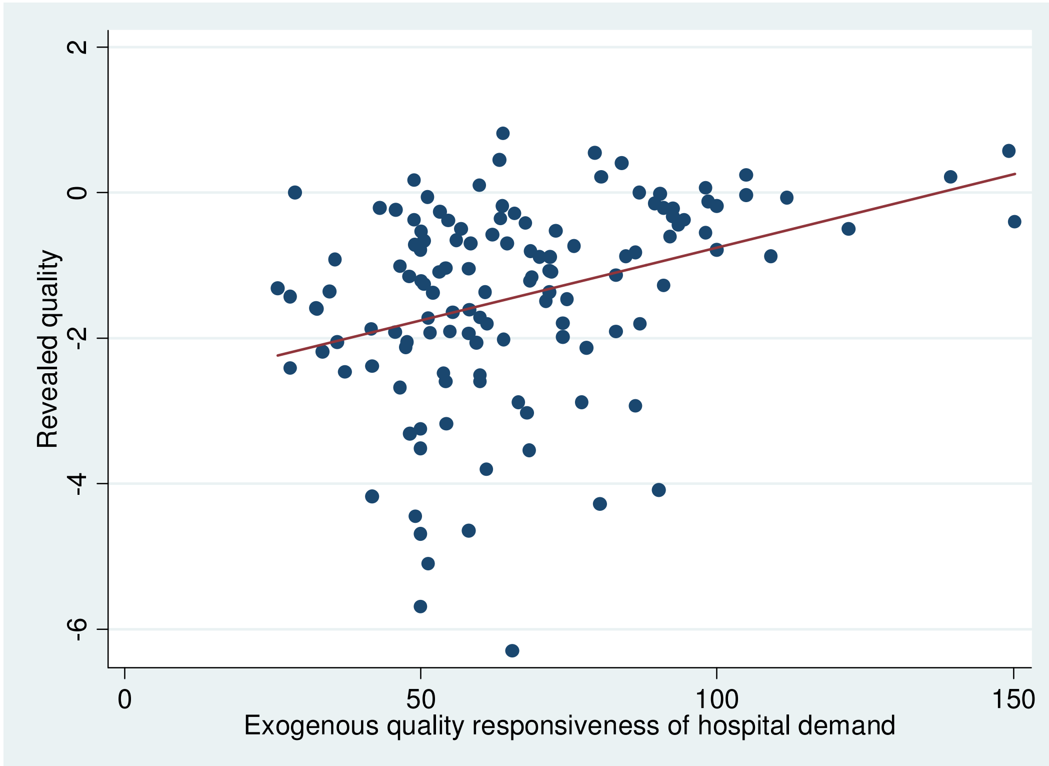

Figure 6:
First-stage estimate of revealed quality on instrument for hospitals in greater LA
F statistic for regression is 14.84; *p* value on instrument is 0.005 (see Table A6)

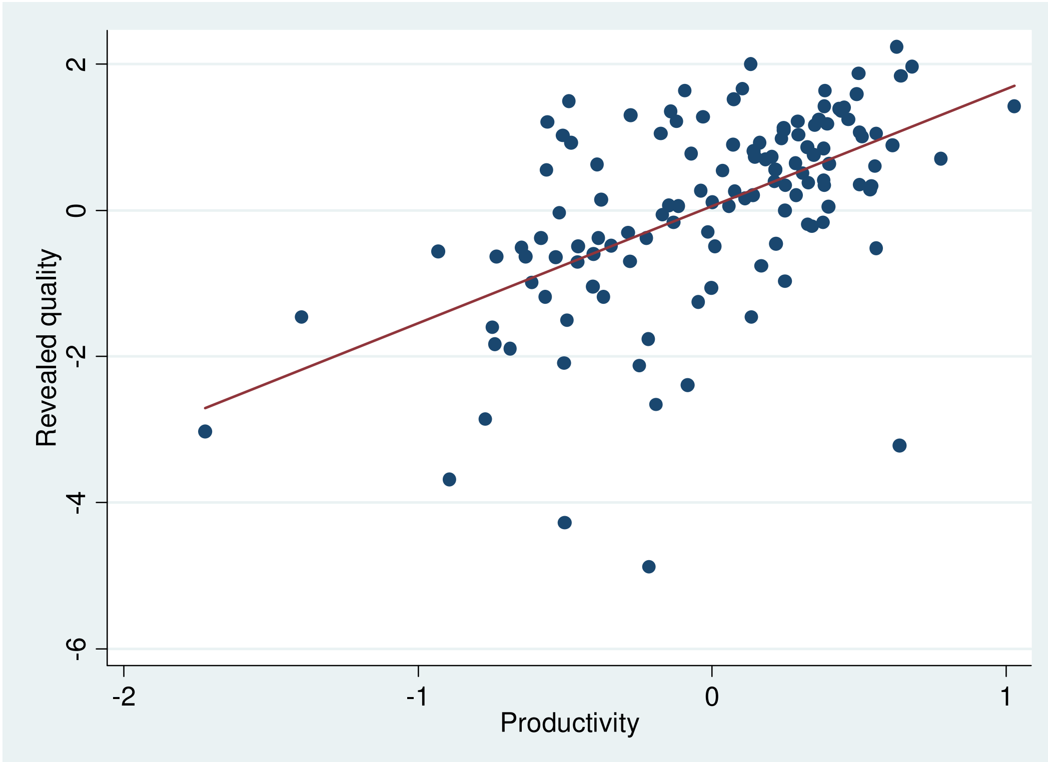

Figure 7:
Productivity and revealed quality among hospitals in greater LA

Table 1: Distance from Patient's Home and Hospital Choice	
Mean distance to nearest hospital (miles)	1.2
Mean distance to chosen hospital	2.8
Nearest hospital chosen	40.6%
2nd nearest hospital chosen	15.1%
3rd nearest hospital chosen	9.5%
Any other hospital chosen	34.8%

Notes: Based on benchmark pneumonia sample.

Table 2: Coefficient of Variation in Mean Characteristics of Patients Residing within Radial Distance of Hospitals

Characteristic	*2.5 miles*	*10 miles*
Percent 75+ years old	0.09	0.06
Percent female	0.09	0.04
Percent black	1.98	0.96
Mean income	0.22	0.13
Mean Charlson-Deyo index	0.12	0.07
Number of patients	0.58	0.47

Notes: Based on benchmark pneumonia sample.

Table 3: Summary Statistics for Hospital Patients				
Patient characteristic	*Mean*	*SD*	*Min*	*Max*
75+ years old	75.1%	—	—	—
Female	57.1%	—	—	—
Black	7.6%	—	—	—
Income	$43,930	$17,400	$5,000	$155,660
Charlson-Deyo index (CDI)	2.1	1.8	0	15
Number of patients	9008			
Number of hospitals	129			

Notes: Based on benchmark pneumonia sample.

Table 4: Summary Statistics for Hospitals				
Statistic	*Mean*	*SD*	*Min*	*Max*
Total annual gross charges (million $)	335.5	352.6	3.1	3208.6
Total annual costs (million $)	107.5	111.3	1.5	842.6
Total annual operating costs (million $)	97.2	101.0	1.4	757.2
Annual stays, total	11897	8999	124	53060
Annual stays, pneumonia only	337.6	196.0	2	1152
Mean Charlson-Deyo index (CDI), all stays	1.070	0.368	0.168	2.371
Mean Charlson-Deyo index (CDI), pneumonia only	1.711	0.365	0.565	3.800
Case-mix index (CMI), all stays	1.064	0.221	0.520	2.200
Licensed general acute-care beds	230.4	177.9	17	1357
Year 2000	20.1%	—	—	—
Year 2001	19.9%	—	—	—
Year 2002	20.4%	—	—	—
Year 2003	20.1%	—	—	—
Year 2004	19.4%	—	—	—
Number of hospitals	126			
Number of hospital-years	612			

Notes: Based on benchmark pneumonia sample of patients and hospitals.

Table 5: Results of Hospital-Choice Analysis

Variable	*Quality Measure*	
	Revealed quality	Negative mortality rate (%)
Distance, in miles	-0.594*** (0.013)	-0.540*** (0.012)
Distance*75+ years old	-0.072*** (0.013)	-0.090*** (0.012)
Distance*Female	0.024** (0.012)	0.024** (0.011)
Distance*Black	-0.069*** (0.025)	-0.032 (0.023)
Distance*Income ($000, demeaned)	0.014*** (0.004)	-0.007** (0.003)
Distance*Charlson-Deyo index (demeaned)	0.001 (0.003)	0.002 (0.003)
Quality	1.000 (—)	0.084*** (0.013)
Quality*75+ years old	0.339*** (0.052)	0.002 (0.011)
Quality*Female	-0.023 (0.037)	-0.036*** (0.013)
Quality*Black	-0.162** (0.069)	-0.119*** (0.022)
Quality*Income ($000, demeaned)	0.213*** (0.019)	0.001 (0.004)
Quality*Charlson-Deyo index (demeaned)	0.032*** (0.010)	0.015*** (0.003)
Hospital indicators	Included	Excluded
Other Statistics		
Number of patients	9008	8668
Number of hospitals	129	116
Log likelihood	-16870.56	-18547.50
Pseudo R squared	0.522	0.454
Correlation of observed and predicted hospital demand	0.996	0.446
Correlation given uniform revealed quality / mortality	0.411	0.441
Mean elasticity of demand with respect to mortality	—	-0.50

Notes: Mortality is risk-adjusted 30-day mortality rate for community-acquired pneumonia, averaged over 2000-2004 and measured in percent. The negative of mortality is analyzed, because lower mortality represents higher quality. Coefficient on revealed quality is normalized to one for reference group, because revealed quality is latent. Standard errors appear in parentheses. * indicates statistical significance at the 10% level, ** at 5%, and *** at 1%. Mean elasticity is calculated with respect to the characteristics and predicted choice probabilities of each patient in the sample.

Table 6: Top and Bottom 12 Hospitals in Revealed Quality		
Hospital	Revealed quality	Rank
Top 12		
Hoag Memorial Hospital Presbyterian	0.81	1
Cedars Sinai Medical Center	0.58	2
Torrance Memorial Medical Center	0.55	3
Huntington Memorial Hospital	0.45	4
Little Company Of Mary Hospital	0.41	5
St. John's Hospital & Health Center	0.24	6
Providence Saint Joseph Medical Center	0.21	7
UCLA Medical Center	0.21	8
Long Beach Memorial Medical Center	0.17	9
Glendale Adventist Medical Center - Wilson Terrace	0.10	10
Encino-Tarzana Regional Med Ctr-Encino	0.07	11
Henry Mayo Newhall Memorial Hospital	0.00	12
Bottom 12		
USC University Hospitals	-3.52	118
Orange County Community Hospitals	-3.54	119
City Of Angels Medical Center-Downtown Campus	-3.81	120
Hollywood Community Hospital Of Hollywood	-4.09	121
City Of Hope National Medical Center	-4.17	122
College Hospital Costa Mesa	-4.28	123
Lac/Rancho Los Amigos National Rehab Center	-4.45	124
Doctors Hospital Of West Covina, Inc	-4.64	125
USC Kenneth Norris, Jr. Cancer Hospital	-4.69	126
Parkview Community Hospital Medical Center	-5.10	127
Lincoln Hospital Medical Center	-5.70	128
Orthopaedic Hospital	-6.30	129

Notes: Based on benchmark pneumonia choice analysis.

Table 7: Rankings of Top-12 Hospitals by Revealed Quality and Survey Measures			
Hospital	*Revealed quality, 2002*	NRC[a], 2004 Los Angeles Survey	
		Most preferred for all health needs	*Best overall quality*
Hoag Memorial Hospital Presbyterian	1	*NRC Consumer Choice Award as top hospital in Orange County*	
Cedars Sinai[b]	2	1[b]	1[b]
Torrance Memorial Medical Center	3	6	5
Huntington Memorial Hospital	4	4	4
Little Company of Mary Hospital	5	12	11
Saint John's Health Center	6		12
Providence Saint Joseph Medical Center	7	11	9
UCLA Medical Center	8	2	2
Long Beach Memorial Medical Center	9	3	3
Glendale Adventist Medical Center	10		
Encino-Tarzana Regional Medical Center	11		
Henry Mayo Newhall Memorial Hospital	12		
Presbyterian Intercommunity Hospital		7	8
Kaiser Permanente — Baldwin Park	Not in sample	9	10
Kaiser Permanente — Bellflower	Not in sample		7
Kaiser Permanente — Harbor City	Not in sample	8	
Kaiser Permanente — Sunset	Not in sample	5	6
Kaiser Permanente — West Los Angeles	Not in sample	10	

Notes: Revealed quality is based on bechmark pneumonia choice analysis. [a]NRC is the National Research Corporation. [b]NRC Consumer Choice Award as top hospital in Los Angeles.

Table 8: Willingness To Travel for Revealed Quality at 75th Percentile of Distribution Rather than 25th Percentile

Type of patient	Miles
Baseline	
White male under 75 years old with mean income and comorbidity	2.88 (0.07)
Deviation from baseline	
Black	2.41 (0.21)
Female	2.81 (0.12)
Comorbidity +1 standard deviation above mean	3.05 (0.10)
Age 75+	3.85 (0.19)
Income +1 standard deviation above mean	3.94 (0.14)

Notes: Based on benchmark pneumonia choice analysis. Income is measured by mean household income within zip code; comorbidity is measured by Charlson-Deyo index. Standard errors appear in parentheses.

Table 9: Elasticity of Quality Responsiveness (Q^{IV}) with Respect to Mean Characteristics of Patients Residing within 2.5 Miles of Hospitals

Characteristic	*Mean elasticity*
Percent 75+ years old	0.34 (0.22)
Percent female	0.30 (0.20)
Percent black	0.01 (0.01)
Average income	1.06*** (0.09)
Average Charlson-Deyo index	0.09 (0.17)
Number of patients	0.41*** (0.04)

Notes: Based on benchmark pneumonia choice analysis. errors appear in parentheses. * indicates statistical significance at the 10% level, ** at 5%, and *** at 1%. Mean elasticities are computed at the sample means of the patient characteristics.

Table 10: Decomposition of Revealed Quality and Productivity

Specification	OLS	IV
Parameter (Standard Error)		
Constant	-0.004 (0.034)	-0.015 (0.042)
Revealed quality (Q)	0.054** (0.026)	0.247** (0.095)
Other Statistics		
R squared	0.034	—
N	126	
Hausman test of OLS vs. IV, *p* value	0.036	
Correlation between quality (Q) and productivity (A)	0.000	0.555

Notes: Based on benchmark pneumonia choice and cost analyses. Standard errors and p value are not corrected for first-stage sampling variability. * indicates statistical significance at the 10% level, ** at 5%, and *** at 1%.

Table 11: Percentage Change in Cost at Average Hospital Due to an Interquartile Improvement in Hospital Quality

Specification	Percent change in costs
Revealed quality	
OLS	
Benchmark analysis	+9.4% (7.1%)
IV	
Benchmark analysis	+50.2% (16.6%)
Pneumonia stays instead of all stays	+159.6% (79.8%)
2002-2003 instead of 2000-2004	+51.9% (21.6%)
With short-run operating costs as dependent variable and hospital beds in model	+31.0% (15.5%)
Sample consistent with Geweke, Gowrisankaran and Town (2003)	+38.4% (5.9%)
Quality as revealed by heart-attack patients	+25.1% (5.4%)
Pneumonia mortality	
Annual mortality rate	
OLS	+1.6% (2.0%)
IV	+6.2% (4.4%)
Average mortality rate, 2000-2004	
OLS	+3.2% (4.0%)
IV	+7.1% (15.7%)

Notes: Average hospital has mean characteristics relative to the benchmark pneumonia hospital sample. Interquartile improvement is an *increase* in revealed quality from the 25th percentile to the 75th percentile of its distribution and a *decrease* in the pneumonia mortality rate from the 75th percentile to the 25th percentile of the distribution of average pneumonia mortality, 2000-2004. Mortality rate is risk-adjusted 30-day mortality rate for community-acquired pneumonia. Instrumental variable for annual mortality rate is one-year lagged mortality rate; instrumental variable for revealed quality/average mortality rate is derivative of hospital demand with respect to the quality measure, evaluated at uniform quality throughout market. Standard errors appear in parentheses and are based on 100 bootstraps.

Table A1: Revealed Quality		
Hospital	*Revealed quality*	*Rank*
Hoag Memorial Hospital Presbyterian	0.81	1
Cedars Sinai Medical Center	0.58	2
Torrance Memorial Medical Center	0.55	3
Huntington Memorial Hospital	0.45	4
Little Company Of Mary Hospital	0.41	5
St. John's Hospital & Health Center	0.24	6
Providence Saint Joseph Medical Center	0.21	7
UCLA Medical Center	0.21	8
Long Beach Memorial Medical Center	0.17	9
Glendale Adventist Medical Center - Wilson Terrace	0.10	10
Encino-Tarzana Regional Med Ctr-Encino	0.07	11
Henry Mayo Newhall Memorial Hospital	0.00	12
Beverly Hospital	0.00	13
Methodist Hospital Of Southern California	-0.02	14
Santa Monica - Ucla Medical Center	-0.03	15
Verdugo Hills Hospital	-0.06	16
Sherman Oaks Hospital And Health Center	-0.07	17
Encino-Tarzana Regional Med Ctr-Tarzana	-0.12	18
Daniel Freeman Marina Hospital	-0.14	19
Glendale Memorial Hospital & Health Center	-0.18	20
Valley Presbyterian Hospital	-0.18	21
Garfield Medical Center	-0.21	22
St. Mary Medical Center	-0.21	23
Centinela Hospital Medical Center	-0.22	24
Little Company Of Mary Hosps-San Pedro, Torrance & Harbor City	-0.24	25
Downey Regional Medical Center	-0.26	26
Providence Holy Cross Medical Center	-0.29	27
Daniel Freeman Memorial Hospital	-0.33	28
Presbyterian Intercommunity Hospital	-0.36	29
Alhambra Hospital	-0.37	30
Pacific Hospitals Of Long Beach	-0.38	31
St. Jude Medical Center	-0.39	32
Century City Hospital	-0.40	33
Granada Hills Community Hospital	-0.42	34
Saddleback Memorial Medical Center	-0.44	35
Good Samaritan Hospital-Los Angeles	-0.50	36
Brotman Medical Center	-0.50	37
Queen Of Angels/Hollywood Presbyterian Med Center	-0.53	38
St. Francis Medical Center	-0.53	39
San Gabriel Valley Medical Center	-0.56	40
St. Joseph Hospital - Orange	-0.58	41
Northridge Hospital Medical Center	-0.61	42
Los Alamitos Medical Center	-0.65	43
Citrus Valley Medical Center - Ic Campus	-0.66	44
St. Vincent Medical Center	-0.69	45

West Hills Hospital & Medical Center	-0.69	46
Pacific Alliance Medical Center, Inc.	-0.71	47
Mission Hospital Regional Medical Center	-0.73	48
Northridge Hospital Medical Center - Sherman Way	-0.78	49
White Memorial Medical Center	-0.78	50
Irvine Regional Hospital And Medical Center	-0.80	51
Mission Community Hospitals	-0.82	52
Robert F. Kennedy Medical Center	-0.87	53
Midway Hospital Medical Center	-0.87	54
Anaheim Memorial Medical Centers	-0.88	55
Fountain Valley Rgnl Hosps & Med Ctrs	-0.88	56
Foothill Presbyterian Hospital-Johnston Memorial	-0.91	57
Community Hospital Of Long Beach	-1.01	58
East Los Angeles Doctors Hospital	-1.03	59
Citrus Valley Medical Center - Qv Campus	-1.05	60
Memorial Hospital Of Gardena	-1.07	61
Orange Coast Memorial Medical Center	-1.08	62
Huntington Beach Hospital	-1.09	63
San Antonio Community Hospital	-1.09	64
West Anaheim Medical Center	-1.14	65
Lakewood Regional Medical Center	-1.15	66
Elastar Community Hospital	-1.16	67
Bellflower Medical Center	-1.21	68
Garden Grove Hospital & Medical Center	-1.21	69
Pomona Valley Hospital Medical Center	-1.26	70
Monterey Park Hospital	-1.27	71
St. Bernardine Medical Center	-1.31	72
Loma Linda University Medical Centers	-1.35	73
Whittier Hospital Medical Center	-1.37	74
Community Hospital Of Gardena	-1.37	75
Chino Valley Medical Center	-1.37	76
Moreno Valley Community Hospital	-1.42	77
Coastal Communities Hospital	-1.46	78
South Coast Medical Center	-1.48	79
Redlands Community Hospital	-1.59	80
San Clemente Hospital & Medical Center	-1.59	81
Doctors' Hospital Medical Center Of Montclair	-1.61	82
La Palma Intercommunity Hospital	-1.65	83
Coast Plaza Doctors Hospital	-1.72	84
Los Angeles County Olive View-Ucla Medical Center	-1.73	85
Pacifica Hospital Of The Valley	-1.80	86
University Of California Irvine Medical Center	-1.80	87
Greater El Monte Community Hospital	-1.80	88
East Valley Hospital Medical Center	-1.88	89
California Hospital Medical Center - Los Angeles	-1.91	90
Anaheim General Hospitals	-1.91	91
Placentia Linda Hospital	-1.92	92
Los Angeles Co Martin Luther King Jr/Drew Med Ctr	-1.93	93
Monrovia Community Hospital	-1.94	94

Motion Picture & Television Hospital	-1.98	95
Los Angeles Co Harbor-Ucla Medical Center	-2.02	96
Suburban Medical Center	-2.05	97
San Dimas Community Hospital	-2.05	98
Western Medical Center Hospital - Anaheim	-2.06	99
Community & Mission Hosps Of Hntg Pk	-2.12	100
Western Medical Center - Santa Ana	-2.13	101
Corona Regional Medical Centers	-2.18	102
Santa Teresita Hospital	-2.39	103
Riverside County Regional Medical Center	-2.41	104
Community Hospital Of San Bernardino	-2.47	105
Riverside Community Hospital	-2.48	106
Norwalk Community Hospital	-2.51	107
Chapman Medical Center	-2.60	108
Los Angeles Community Hospital	-2.60	109
Brea Community Hospital	-2.68	110
Santa Ana Hospital Medical Center Inc	-2.88	111
Temple Community Hospital	-2.88	112
Los Angeles Metropolitan Medical Centers	-2.93	113
St. Luke Medical Center	-3.03	114
Tri-City Regional Medical Center	-3.18	115
Los Angeles Co Usc Medical Center	-3.25	116
Arrowhead Regional Medical Center	-3.31	117
Usc University Hospitals	-3.52	118
Orange County Community Hospitals	-3.54	119
City Of Angels Medical Center-Downtown Campus	-3.81	120
Hollywood Community Hospital Of Hollywood	-4.09	121
City Of Hope National Medical Center	-4.17	122
College Hospital Costa Mesa	-4.28	123
Lac/Rancho Los Amigos National Rehab Center	-4.45	124
Doctors Hospital Of West Covina, Inc	-4.64	125
Usc Kenneth Norris, Jr. Cancer Hospital	-4.69	126
Parkview Community Hospital Medical Center	-5.10	127
Lincoln Hospital Medical Center	-5.70	128
Orthopaedic Hospital	-6.30	129

Note: Based on benchmark pneumonia choice analysis.

Table A2: Correlation among Alternative Quality Measures									
	B	*CL*	*NNIM*	*5C*	*P- GGT*	*20M*	*50M*	*HA*	*MR*
Revealed quality, benchmark pneumonia analysis (*B*)	1.000 (129)								
Conditional-logit model (*CL*)	0.976 (129)	1.000 (129)							
Including patients whose nearest hospital is not in market (*NNIM*)	0.996 (129)	0.968 (129)	1.000 (129)						
Including all hospitals in 5 metro counties (*5C*)	0.994 (129)	0.972 (129)	0.993 (129)	1.000 (167)					
LA market consistent with Geweke, Gowrisankaran and Town (2003) (*GGT*)	0.974 (79)	0.957 (79)	0.968 (79)	0.826 (81)	1.000 (81)				
Choice set includes hospitals within 20 miles (*20M*)	0.994 (129)	0.967 (129)	0.985 (129)	0.992 (129)	0.977 (79)	1.000 (129)			
Choice set includes hospitals within 50 miles (*50M*)	0.994 (129)	0.972 (129)	0.986 (129)	0.990 (129)	0.987 (79)	0.994 (129)	1.000 (129)		
Quality as revealed by heart-attack patients (*HA*)	0.797 (118)	0.777 (118)	0.835 (118)	0.789 (118)	0.831 (78)	0.729 (118)	0.784 (118)	1.000 (118)	
Average pneumonia mortality rate, 2000-2004 (*MR*)	-0.256 (116)	-0.265 (116)	-0.265 (116)	0.074 (152)	-0.142 (76)	-0.231 (116)	-0.275 (116)	-0.367 (112)	1.000 (306)

Table A3: Summary Statistics for Alternative Quality Measures						
	Mean	Min	Max	Std. Dev.	IQR	N
Revealed quality, benchmark pneumonia analysis	-1.42	-6.30	0.81	1.37	1.65	129
Conditional-logit model	-1.78	-6.08	0.97	1.46	1.93	129
Including patients whose nearest hospital is not in market	-1.44	-6.31	0.81	1.38	1.63	129
Including all hospitals in 5 metro counties	-2.80	-84.66	6.44	8.90	2.09	167
LA market consistent with Geweke, Gowrisankaran and Town (2003)	-0.70	-3.73	1.80	1.05	1.48	81
Choice set includes hospitals within 20 miles	-1.32	-6.32	0.79	1.36	1.52	129
Choice set includes hospitals within 50 miles	-1.30	-6.21	0.85	1.38	1.65	129
Quality as revealed by heart-attack patients	-1.80	-8.37	1.37	2.03	2.49	118
Average pneumonia mortality rate, 2000-2004	12.5%	6.6%	19.6%	2.6%	3.5%	116

Note: IQR denotes interquartile range.

Table A4: Benchmark Fixed-Effects Regression of Total Annual Hospital Costs	
Parameter (Standard Error)	
Constant	-0.073 (0.052)
Natural log of total annual stays (Y_{ht})	1.007*** (0.138)
Revealed pneumonia quality (Q_h)	—
Natural log of mean Charlson-Deyo index (CDI_{ht})	0.142 (0.227)
Natural log of case-mix index (CMI_{ht})	0.889** (0.445)
$\frac{1}{2}(\ln Y_{ht})^2$	-0.011 (0.087)
$\ln Y_{ht} \cdot Q_h$	0.082 (0.053)
$\ln Y_{ht} \cdot \ln CDI_{ht}$	-0.236 (0.194)
$\ln Y_{ht} \cdot \ln CMI_{ht}$	0.080 (0.352)
$\frac{1}{2} Q_h^2$	—
$Q_h \cdot \ln CDI_{ht}$	0.165 (0.138)
$Q_h \cdot \ln CMI_{ht}$	-0.563* (0.297)
$\frac{1}{2}(\ln CDI_{ht})^2$	-0.534 (0.537)
$\ln CDI_{ht} \cdot \ln CMI_{ht}$	0.286 (0.968)
$\frac{1}{2}(\ln CMI_{ht})^2$	0.296 (2.356)
Time (t)	0.053*** (0.009)
$\frac{1}{2} t^2$	-0.082*** (0.012)
$t \cdot \ln Y_{ht}$	0.012 (0.011)
$t \cdot Q_h$	-0.007 (0.008)
$t \cdot \ln CDI_{ht}$	0.065* (0.035)
$t \cdot \ln CMI_{ht}$	-0.103* (0.060)
Other Statistics	
R squared	0.824
R squared (within)	0.479
Model F test, *p* value	0.000
F test on hospital fixed effects, *p* value	0.000
Correlation between observables and fixed effects	0.083
Hausman test of fixed vs. random effects, *p* value	0.652
Number of hospital-years	612

Notes: Based on benchmark pneumonia choice analysis and benchmark pneumonia sample of hospitals. Benchmark analysis is a fixed-effects specification of cost model. Hospital fixed effect embodies revealed revealed quality, leaving quality-only terms unidentified. Standard errors are not corrected for first-stage sampling variability. * indicates statistical significance at the 10% level, ** at 5%, and *** at 1%.

Table A5: Analyses of Total Hospital Annual Costs Based on Negative Mortality Rate			
	Specification		
	Pooled regression on annual mortality		*Average mortality with fixed effects*
	OLS	IV	
Parameter Estimate (Standard Error)			
Constant	-0.121** 0.000	-0.131*** 0.000	-0.086* 0.000
Natural log of total annual stays (Y_{ht})	1.022*** (0.056)	1.007*** (0.059)	1.054*** (0.135)
Negative mortality rate, in % (Q_h)	0.005 (0.006)	0.019 (0.013)	—
Natural log of mean Charlson-Deyo index (CDI_{ht})	-0.113 (0.210)	-0.158 (0.234)	-0.076 (0.250)
Natural log of case-mix index (CMI_{ht})	1.433*** (0.313)	1.482*** (0.319)	1.143** (0.457)
$\frac{1}{2} (\ln Y_{ht})^2$	0.087 (0.075)	0.098 (0.069)	0.067 (0.078)
$\ln Y_{ht} \cdot Q_h$	—	—	—
$\ln Y_{ht} \cdot \ln CDI_{ht}$	0.123 (0.169)	0.088 (0.189)	-0.162 (0.202)
$\ln Y_{ht} \cdot \ln CMI_{ht}$	-0.331 (0.220)	-0.311 (0.231)	0.463 (0.322)
$\frac{1}{2} Q_h^2$	—	—	—
$Q_h \cdot \ln CDI_{ht}$	—	—	—
$Q_h \cdot \ln CMI_{ht}$	—	—	—
$\frac{1}{2} (\ln CDI_{ht})^2$	0.665 (0.712)	0.844 (0.847)	-0.236 (0.691)
$\ln CDI_{ht} \cdot \ln CMI_{ht}$	-0.993 (1.044)	-1.002 (1.073)	-0.306 (1.126)
$\frac{1}{2} (\ln CMI_{ht})^2$	2.813 (1.801)	2.276 (1.955)	1.356 (2.584)
Time (t)	0.043*** (0.011)	0.042*** (0.011)	0.054*** (0.009)
$\frac{1}{2} t^2$	-0.082*** (0.016)	-0.080*** (0.017)	-0.089*** (0.012)
$t \cdot \ln Y_{ht}$	0.005 (0.013)	0.016 (0.013)	0.018 (0.011)
$t \cdot Q_h$	—	—	—
$t \cdot \ln CDI_{ht}$	0.002 (0.050)	0.004 (0.050)	0.080** (0.038)
$t \cdot \ln CMI_{ht}$	-0.016 (0.085)	-0.034 (0.083)	-0.156** (0.066)
Other Statistics			
R squared	0.851	—	0.846
R squared (within)	—	—	0.498
Model F test, *p* value	0.000	0.000	0.000
F test on higher-order mortality terms, *p* value	0.502	0.787	0.865
F test on hospital fixed effects, *p* value	—	—	0.000
Correlation between observables and fixed effects	0.000	0.000	-0.113
Hausman test of fixed vs. random effects, *p* value	—	—	0.808
Number of hospital-years	533	522	553

Notes: Mortality is risk-adjusted 30-day mortality rate for community-acquired pneumonia, measured in percent; average is with respect to 2000-2004. The negative of mortality is analyzed, because lower mortality represents higher quality. Hospital fixed effect embodies revealed revealed quality, leaving quality-only terms unidentified. Pooled regressions cluster standard errors on the hospital. Instruments include lagged annual mortality and its interactions with hospital characteristics. Standard errors are not corrected for first-stage sampling variability. * indicates statistical significance at the 10% level, ** at 5%, and *** at 1%.

Table A6: First-Stage Revealed Quality Regression	
Parameter (Standard Error)	
Constant	-1.174*** (0.339)
Responsiveness of hospital demand to revealed pneumonia quality (Q^{IV})	0.018*** (0.005)
Other Statistics	
R squared	0.107
F statistic	14.84
N	126

Notes: Based on benchmark pneumonia choice analysis. Standard errors are not corrected for first-stage sampling variability. * indicates statistical significance at the 10% level, ** at 5%, and *** at 1%.

Table A7: First-Stage Pneumonia Mortality Regressions		
	Specification	
	Pooled regression	Fixed effect
Parameter (Standard Error)		
Constant	-5.766*** (0.506)	1.963** (0.782)
Lagged one-year mortality rate, in %	0.452*** (0.039)	—
Quality responsiveness (Q_h^{IV})	—	0.689*** (0.258)
Other Statistics		
R squared	0.202	0.060
F statistic	131.62	7.14
N	522	114

Notes: Mortality rate is risk-adjusted 30-day mortality rate for community-acquired pneumonia. Quality responsiveness is the derivative of hospital demand with respect to the average mortality rate. Standard errors are not corrected for first-stage sampling variability. * indicates statistical significance at the 10% level, ** at 5%, and *** at 1%.

Table A8: Decomposition of Average Pneumonia Mortality and Productivity

Specification	OLS	IV
Parameter (Standard Error)		
Constant	-0.001 (0.031)	-0.001 (0.031)
Negative average mortality rate, in %	0.009 (0.012)	0.021 (0.049)
Other Statistics		
R squared	0.006	—
N	114	
Hausman test of OLS vs. IV, *p* value	0.803	
Correlation between mortality and productivity	0.000	-0.093

Notes: Mortality is risk-adjusted 30-day mortality rate for community-acquired pneumonia, averaged over 2000-2004. The negative of mortality is analyzed, because lower mortality represents higher quality. Standard errors and p value are not corrected for first-stage sampling variability. * indicates statistical significance at the 10% level, ** at 5%, and *** at 1%.