Games Hospitals Play: Entry Deterrence in Hospital Procedure Markets

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Strategic investment models, though popular in the theoretical literature, have rarely been tested empirically. This paper develops a model of strategic investment in inpatient procedure markets, which are well-suited to empirical tests of this behavior. Potential entrants are easy to identify in such markets, enabling the researcher to accurately estimate the entry threat faced by different incumbents. I derive straightforward empirical tests of entry deterrence from a model of patient demand, procedure quality, and differentiated product competition. Using hospital data on electrophysiological studies, an invasive cardiac procedure, I find evidence of entry-deterring investment. These findings suggest that competitive motivations play a role in treatment decisions.

1. Introduction

The theory of strategic investment, in which an incumbent firm (the "first mover") adjusts its investment in period 1 because its choice affects play in period 2, originates in von Stackelberg (1934) and is extended by Spence (1977, 1979), Dixit (1979, 1980), and others. Although the theory has been embraced by practitioners (famously the Boston Consulting Group, 1968), it has received little attention from empirical economists. Empirically distinguishing between strategic entry deterrence and non-strategic investment decisions requires an accurate assessment of the *ex ante* threat of entry as well as assumptions regarding the investments

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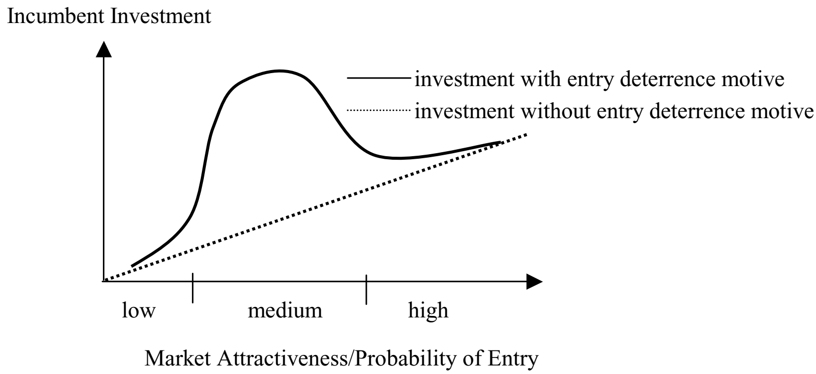

FIGURE 1. PREDICTED INCUMBENT INVESTMENT PATTERNS

that would have been made absent strategic motives. This paper develops a model of strategic entry deterrence in a setting where *ex ante* threats of entry, investment trends, and deviations from investment trends can be observed: inpatient surgical procedure markets.

Although inpatient surgical procedures are a primary output of the hospital industry, research on competition within surgical procedure markets—or even the concept of a surgical procedure market—is not well developed. In addition, the role of learning-by-doing in surgery, though well documented, has only been linked anecdotally to market structure. This paper formalizes these relationships by explicitly modeling the demand and supply for surgical procedures, incorporating the role of learning-by-doing into the production function, and positing a differentiated-products game that governs play among market participants. I use this model to illustrate the incentives to invest strategically in volume-increasing assets or activities, focusing on incumbents' ability to deter entry through this channel. To investigate whether the entry-deterrence motive affects investment decisions, I use an empirical test introduced by Ellison and Ellison (2000). The insight underlying this test is that investment by incumbents facing entry should increase monotonically with market potential (and the *ex ante* threat of entry) *unless* entry deterrence incentives are present. These incentives are strongest in markets of intermediate attractiveness, where potential entrants are "on the fence" and therefore most likely to be swayed by incumbents' actions. Thus a nonmonotonic relationship between investment and market attractiveness, as illustrated in Figure 1, constitutes evidence of a strong entry-deterrence motive.

Using nationwide data from MedPAR, the Medicare claims database, I investigate the relationship between volume growth (my measure of investment) and the probability of entry in local markets for electrophysiological studies, a procedure to identify and correct cardiac arrhythmias. I focus on incumbents' volume growth in 1988–1989, after the Medicare program announced a likely reimbursement increase, but before this increase took effect. I find the strongest growth among incumbent providers in markets facing intermediate *ex ante* threats of entry. This cross-sectional finding is confirmed in a panel analysis using data from 1985–1989. Controlling for volume trends that vary by the probability of entry, I find that volume growth between 1988 and 1989 is significantly larger for incumbents in intermediate markets than for incumbents in markets with low or high *ex ante* entry probabilities (48 and 44 percentage points larger, respectively). These point estimates imply a substantial impact of entry deterrence motives on hospital volumes for procedures characterized by a high degree of learning-by-doing.

In addition to providing evidence of strategic entry deterrence, this study complements and extends the literature on hospital competition. Although several researchers have investigated the reduced-form relationship between Herfindahl-type measures of hospital competition and service offerings (e.g., the "medical arms race" literature), few have offered a structural interpretation of this relationship or provided a model of competitive play.[1] The results I obtain suggest that hospitals engage in more sophisticated strategic decision making than has previously been documented. The welfare implications of this behavior are ambiguous, as heightened concentration produces a positive learning-by-doing benefit that must be balanced against the adverse effects of strategically motivated treatment decisions and reduced competition.

Section 2 describes prior research on strategic entry deterrence and the relationship between procedure volume and surgical quality, which features prominently in the model developed in Section 3. After deriving empirically testable predictions that discern between strategic and nonstrategic investment patterns, I test these predictions in Section 4 using hospital-level data on electrophysiological studies. Section 5 concludes.

2. Background

2.1. Strategic Entry Deterrence

The theoretical literature on entry deterrence is well developed (see Wilson (1992) in *The Handbook of Game Theory* for a good review). The

1. Exceptions include Chernew et al. (2002), who model entry into bypass surgery as a function of expected patient flows, and Vogt (1999), who considers preemption motives for acquisition of magnetic resonance imaging (MRI) machines in duopoly hospital markets.

critical insight from this research is that a sunk investment, be it in cost-cutting, capacity, advertising, or experience, credibly commits the incumbent to a particular course of action and therefore gives it an edge in strategic play. For example, an existing auto-assembly firm that builds a large new plant credibly commits to producing more vehicles in the event of entry (and perhaps in the absence of entry as well), thereby reducing the potential profits of an entrant and the likelihood of entry.

The empirical literature on entry deterrence is rather sparse, with most studies documenting competitive responses to investment decisions rather than identifying strategic motives for the investments. Examples of such papers include Lieberman (1987), who finds that incumbents in concentrated chemical processing industries reduce investment in response to expansions by rivals, Chevalier (1995), who finds that leveraged buyouts of supermarket chains are followed by softer product-market competition, and Scott Morton (2000), who finds that advertising does not deter generic entry following the expiration of pharmaceutical patents. These studies suggest that capacity, capital structure, and advertising are effective vehicles for strategic investment, but do not constitute prima facie evidence that such investment is taking place.

Two recent papers, Vogt (1999) and Ellison and Ellison (2000), construct tests for strategic entry deterrence. Vogt's test detects strategic behavior by comparing technology adoption times across duopoly markets with varying degrees of heterogeneity between the two players. Using data on adoption dates of magnetic resonance imaging (MRI) technology in 31 duopoly hospital markets, Vogt finds evidence of preemption through early adoption by a rival. Ellison and Ellison study the advertising, product presentation, and pricing behavior of pharmaceutical firms facing an immediate threat of generic entry due to patent expiration. Because the strategic incentive to deter entry is greatest in markets where entry is probable, as compared to markets where it is effectively blockaded (i.e., the drug has extremely small revenues) or extremely likely (e.g., Prozac), the authors look for investment behavior that is nonmonotonic in entry probability. They find evidence supportive of attempts to deter entry: incumbents in medium-sized markets are more likely than incumbents in small or large markets to decrease advertising and increase the variety of product presentations immediately prior to patent expiration. Both behaviors reduce the expected profits of an entrant, and should increase monotonically with market potential if entry deterrence motives are absent. This reasoning underlies the empirical tests I conduct in Section 4.

2.2. The Volume–Outcome Relationship in Surgery

Since the late 1970s, medical researchers have published hundreds of articles documenting a strong, positive correlation between procedure-specific hospital volume and outcomes for a wide range of procedures, including coronary artery bypass surgery (CABG), cardiac catheterization, prostatectomy, total hip replacement, resectioning of abdominal aortic aneurysms, and electrophysiological studies, to list only a few. This correlation is robust to detailed controls for patient risk factors, hospital characteristics, surgeon volume, and local sociodemographics.[2]

Although this evidence is suggestive of learning-by-doing in surgery, there are a number of limitations of the medical literature that render such a conclusion premature. First, the outcome measures used in most studies—inpatient mortality, length of stay, and postsurgery complications—are limited. Hospitals with low volumes are at greater risk for extremely high levels of these variables simply because of statistical chance. Second, although the studies attempt to control for patient risk factors, the potential for omitted variables is clearly problematic. Third, these studies cannot distinguish between two alternate hypotheses for the volume-outcome phenomenon: the "practice makes perfect" or learning-by-doing hypothesis, and the "selective referral" hypothesis, which maintains that hospitals with good outcomes generate high volumes, rather than vice versa.

The few studies that have attempted to separate these effects have found support for both. Simultaneous-equation estimates of the outcome–volume relation and the volume–outcome relation by Luft, Hunt, and Maerski (1987) reveal bilateral relationships for some procedures and unilateral relationships for others.[3] More recent work on cardiac surgery has found evidence of both learning-by-doing (Ho, 2002) and selective referral (Mukamel and Mushlin, 1998).

This paper does not attempt to enter the debate described above; rather, the model outlined in Section 3 incorporates both pathways. Cumulative volume is an input into hospital quality, which reflects

2. The evidence on the relationship between *surgeon* volumes and outcomes is less conclusive. There is consensus that a positive correlation is present for select procedures (e.g., carotid endarterectomy), and substantial evidence that very low-volume operators obtain extremely poor results across a range of surgical procedures (e.g., Hughes et al. 1987; Cebul et al. 1998). A recent study by Huckman and Pisano (2003) suggests that learning-by-doing on the part of surgeons is hospital-specific.

3. Note that Luft et al. (1987) use data gathered in 1972 for the Professional Activities Study by the Commission on Professional and Hospital Activities (CPHA), as do many of the studies described in this section. Thus, hospital choice was far less restricted during the period explored in this body of literature than is the case today.

the "practice makes perfect" hypothesis. Patient demand responds to quality, as per the "selective referral" hypothesis. Thus, if hospitals are aware that volume begets volume, they may consider strategies to increase volume for competitive effect. The prominence of procedure volume data in hospital marketing campaigns, together with volume requirements imposed by surgical accreditation boards and insurance programs, suggest that hospitals are indeed cognizant of this possibility.[4] Perhaps by creating a high-volume "center of excellence" in a given procedure market, a hospital can forestall new entrants, whose comparative lack of experience is unattractive to patients, physicians, and insurers alike.

3. A Model of Entry Deterrence

3.1. Assumptions

In hospital markets, supply and demand do not equilibrate contemporaneously via a price mechanism. The nation's largest insurer, Medicare, dictates a fixed price for each of roughly 500 Diagnosis Related Groups (DRGs), and private insurers negotiate reimbursement amounts with individual hospitals. Moreover, insured patients do not typically bear the marginal costs of treatment, as hospital stays generally exhaust deductibles and co-payment caps. Thus, price P is not considered a choice variable for hospitals in this model.[5] A hospital seeking to expand current production in one of its product lines (say, cardiac surgery) must attract patients through other means: improved outcomes, advertising, physician referral networks, amenities, new technology, and so forth.

I aggregate these choices into a variable called *quality*, denoted by L. Quantity demanded for a given procedure in hospital h at time t, denoted Q_t^h, is assumed to be an increasing function of hospital h's quality, L_t^h, and a decreasing function of the quality of its competitors, L_t^{-h}

$$Q_t^h = q\left(L_t^h, L_t^{-h}\right), \tag{1}$$

where $\frac{\partial q}{\partial L_t^h} > 0$ and $\frac{\partial q}{\partial L_t^{-h}} < 0$.

4. Examples of volume guidelines include Medicare's restriction of coverage for liver transplants to centers that have performed 12 or more procedures per year for 3 consecutive years, and the American College of Surgeons' recommendation that hospitals perform at least 200 open-heart surgeries per year in order to "function efficiently" and attain quality goals.

5. Note that the model is tested on Medicare data, and because Medicare beneficiaries face the same out-of-pocket price at all hospitals, a hospital cannot increase volume by lowering price.

Although I have omitted procedure subscripts, all variables are at the procedure level, so that L and Q refer to quality and quantity for a particular procedure, respectively.

The inputs into quality include current spending S_t^h, cumulative experience $\bar{Q}_t^h = \Sigma_{j=0}^{t-1} Q_j^h$, and the stock of purchased inputs, denoted K_{t-1}^h. This stock includes equipment as well as (potentially) long-lived investments such as advertising. Current spending includes nondurable items such as nursing staff salaries as well as durable contributions to the stock of purchased inputs. Thus, $K_t^h = \alpha S_t^h + \delta K_{t-1}^h$, where $0 < \alpha, \delta < 1$, α is the share of current spending on durables, and δ is a depreciation factor. Because the empirical tests will not be able to distinguish between these investment types, I assume hospitals select the optimal α based on exogenously determined rates of return. The production function for quality can therefore be summarized as

$$L_t^h = l\left(S_t^h, \bar{Q}_t^h, K_{t-1}^h\right), \tag{2}$$

where $\frac{\partial l}{\partial S_t^h} > 0$, $\frac{\partial l}{\partial \bar{Q}_t^h} > 0$ and $\frac{\partial l}{\partial K_{t-1}^h} > 0$.

To ensure a unique equilibrium, I also assume $\frac{\partial^2 l}{\partial S^2} < 0$ and $\frac{\partial^2 q}{(\partial L^h)^2} < 0$. The second argument in l captures the "practice makes perfect" or learning-by-doing effect discussed in Section 2. The "selective referral effect" is reflected in the function for quantity demanded, as a hospital acquires more patients if it offers higher quality. Thus, volume begets more volume. This implies that even nondurable spending that increases volume, such as providing free screening for prostate cancer in order to generate more surgical cases (a common practice), has a long-term impact on quality and, therefore, reduces the profits of a potential entrant. These short-run "quality" improvements are akin to low first-generation pricing by aircraft manufacturers trying to acquire experience. Henceforth, I will use the terms *spending* and *investment* interchangeably.

For simplicity, the cost per procedure is fixed at c. I assume the entrant incurs a cost E upon entry, where E is stochastic and its cumulative distribution function $F(E)$ is known to all parties.[6]

3.2. Model

I begin with a standard three-period strategic investment model, summarized in the following diagram.

6. Were E not stochastic, the model would be deterministic: the investment needed to deter entry would be known, and entry-deterring investment would either be successful or would not be undertaken at all.

$t = 1$	$t = 2$	$t = 3$
Incumbent monopolist chooses S_1^M and earns $\pi_1^M(S_1^M)$	Potential entrant observes $Q_1^M(S_1^M)$ and the realization of E and decides whether to enter	Monopoly payout $\pi_2^{*M}(S_1^M, S_2^{M*})$ or duopoly payouts $\pi_2^{*D_M}(S_1^M, S_2^{D_E^*}, S_2^{D_M^*})$ and $\pi_2^{*D_E}(S_1^M, S_2^{D_E^*}, S_2^{D_M^*})$

Here the superscript M refers to the monopolist when she is the sole supplier, and D_M and D_E to the former monopolist and the entrant, respectively, if entry occurs. Production occurs twice (in periods 1 and 3) and is denoted by the subscripts 1 and 2. The profit functions are assumed to be concave, and the payoffs in the event of entry result from a unique Nash equilibrium in the third-period game.

Assuming no discounting, the monopolist's maximization problem is simply

$$\max_{S_1^M, S_2^M, S_2^{D_M}} E(\pi) = \pi_1^M(S_1^M) + F\left(\pi_2^{D_E}\left(S_1^M, S_2^{D_E}, S_2^{D_M}\right)\right) \times \pi_2^{D_M}\left(S_1^M, S_2^{D_E}, S_2^{D_M}\right) + \left(1 - F\left(\pi_2^{D_E}\left(S_1^M, S_2^{D_E}, S_2^{D_M}\right)\right)\right)\pi_2^M(S_1^M, S_2^M) \tag{3}$$

The solution for S_2 is straightforward: the incumbent simply picks the optimal amount given the competitive environment, spending $S_2^{M^*}$ or $S_2^{D_M^*}$. The first-order condition for S_1^M is

$$-\frac{d\pi_1^M}{dS_1^M} = F\left(\pi_2^{D_E}\left(S_1^M, S_2^{D_E^*}, S_2^{D_M^*}\right)\right)\frac{\partial \pi_2^{D_M}}{\partial S_1^M} + \left(1 - F\left(\pi_2^{D_E}\left(S_1^M, S_2^{D_E^*}, S_2^{D_M^*}\right)\right)\right)\frac{\partial \pi_2^M}{\partial S_1^M} + F\left(\pi_2^{D_E}\left(S_1^M, S_2^{D_E^*}, S_2^{D_M^*}\right)\right)\frac{\partial \pi_2^{D_M}}{\partial S_2^{D_E}}\frac{dS_2^{D_E^*}}{dS_1^M} + \left(\pi_2^{D_M}\left(S_1^M, S_2^{D_E^*}, S_2^{D_M^*}\right) - \pi_2^M\left(S_1^M, S_2^{M^*}\right)\right) \times f\left(\pi_2^{D_E}\left(S_1^M, S_2^{D_E^*}, S_2^{D_M^*}\right)\right)\frac{d\pi_2^{D_E}}{dS_1^M}. \tag{4}$$

The term on the left hand side measures the cost associated with investment beyond the single-period optimum; because this investment pays off in future periods as well as in the current period, this term should be positive. The first two terms on the right-hand side constitute the "open loop" or nonstrategic first-order condition, in which the incumbent takes the entrant's behavior, including the probability of entry, as given. The third term is the "strategic entry accommodation" term, which incorporates the effect of the incumbent's expenditure in the first period on the entrant's choice of $S_2^{D_E}$. If it is greater (less) than zero, an incumbent that is accommodating entry in its market will overinvest (underinvest) in S_1^M relative to the open-loop optimum. My focus is on the fourth term, the "strategic entry deterrence" effect.

The magnitude of the entry deterrence effect increases in the difference between monopoly and duopoly profits in the second period, as well as in the probability mass of E at $\pi_2^{D_E}$. This means that the incentive to deter entry is greatest when substantial profits are at stake, and when the entrant is likely to be "on the fence" in terms of its entry decision. Under these circumstances, a bit of overinvestment (underinvestment if $\frac{d\pi_2^{D_E}}{dS_1^M} > 0$) has a large payoff.

3.3. Generating Testable Predictions

This section describes the two elements needed to create an empirical test for the presence of the entry-deterrence term in the hospital's optimization formula. First, I use a result derived in Ellison and Ellison (2000). The authors introduce a variable z into the profit and cost functions for the incumbent and the potential entrant, where z reflects market size or other characteristics associated with the probability of entry, and $\frac{d}{dz}\pi^{D_E^*}(S_1^M, S_2^{D_E}, S_2^{D_M}, z) > 0$. They illustrate that, under certain conditions, *the incumbent's investment is monotone increasing in z in the absence of the entry-deterrence effect*. (This situation would prevail, for example, if the incumbent's investment were not revealed to the entrant prior to the entry decision.)[7] The conditions under which this proposition holds are not demanding, and a more thorough discussion is presented in the appendix. Intuitively, this result simply means that in the absence of entry-deterrence motives, incumbents' investments will increase monotonically with market potential.

Having established monotonicity of investment in z when entry-deterrence objectives are absent, the authors then illustrate *nonmonotonicity when entry-deterrence objectives are present*. This follows intuitively from an examination of the entry-deterrence term, now

$$\left(\pi_2^{D_M}\big(S_1^M(z), S_2^{D_E^*}(z), S_2^{D_M^*}(z), z\big) - \pi_2^M\big(S_1^M(z), S_2^{M^*}(z), z\big)\right)$$
$$\times f\left(\pi_2^{D_E}\left(S_1^M(z), S_2^{D_E^*}(z), S_2^{D_M^*}(z), z\right)\right)\frac{d\pi_2^{D_E}}{dS_1^M}. \tag{5}$$

7. The first-order condition used to obtain $S_1^{M^*}$ in this case *does* incorporate the strategic entry accommodation term described above.

$f(\pi_2^{D_E})$, the probability density of entrants who are indifferent between entering and not entering the market, does not increase monotonically in market attractiveness. When the market is extremely attractive or unattractive, few entrants will be indifferent; $f(\pi_2^{D_E})$ will be largest when z has an intermediate value.[8] Because $f(\pi_2^{D_E})$ is multiplied by the difference between duopoly and monopoly profits, the strategic entry deterrence effect can be rather large, generating an investment curve that is nonmonotonic in z. In the surgical procedure setting, if the entry-deterrence motive is sufficiently strong, S_1^M will be greatest in markets where incumbents perceive entry to be possible, as compared to markets where entry is unlikely or likely.

The second component needed to transform the incumbent's first-order condition into a testable relationship concerns S_1^M. Although S_1^M is unobservable, the end product of the investment, first-period procedure volume (Q_1^M), *can* be measured. Thus, the change in procedure volume between $t = 1$ and $t = 2$, after controlling for covariates, can proxy for S_1^M. This result is a feature of the model sketched above; a profit-maximizing hospital would only spend money to boost quality if the quality improvement generated more business at the fixed price P.[9]

To see whether entry-deterrence incentives influence investment behavior, I will investigate whether incumbents in markets of intermediate attractiveness, where entry-deterring investment can have the greatest impact on the entry decision, exhibit the strongest volume growth in the face of shocks that increase industry profits.

4. Testing the Model: The Market for Electrophysiological Studies

4.1. Market Selection

To test these predictions empirically, I sought a surgical procedure that satisfies the key conditions dictated by the model: (1) a high degree of learning-by-doing; (2) a large fixed investment upon entry; (3) demand that is increasing in the quality of the procedure. I further restricted my search to procedures that experienced positive, anticipated profitability shocks. This provides a window of time during which incumbents have a particularly strong incentive to deter entry. Focusing on this window also enables me to conduct more rigorous tests of entry deterrence by controlling for differences in pre-shock growth trends across markets.

8. This is true provided that the mass of the distribution of entry costs is concentrated in the interior of the range $[0, \bar{E}]$, for example, the normal distribution.

9. The result would be unaffected if quality itself had a positive weight in the hospital's objective function.

Last, the procedure had to be well-represented among the elderly, as Medicare's inpatient database (MedPAR) is the only source of national longitudinal data with a sufficiently large sample size for my purposes. The procedure that best fulfills these criteria is electrophysiological study, or EP.[10]

Introduced in the early 1980s, EP is a highly specialized invasive procedure to identify and treat cardiac arrhythmias. The heart is stimulated at various rates and cadences, and electrode catheters placed within veins or arteries record the responses. Therapeutic ablation, in which tissue is destroyed using high-frequency currents, may also be performed.[11] The *Manual of Cardiovascular Medicine* stresses the importance of a highly experienced operator in obtaining a successful outcome (criterion 1). Residents must complete 8 years of training before being permitted to *assist* in an EP, and a 1992 survey by the North American Society of Pacing and Electrophysiology documents a positive relationship between hospital case volume and the rate of complications (Scheinman, 1994). EP is also performed in a specially equipped cardiac catheterization lab, which entails a large fixed entry cost (criterion 2). The cost to equip a catheterization lab with the required software and technology to perform EP is $1.5–2 million, on top of which an EP specialist and technicians must be recruited. Given operating income (net of depreciation) on the order of $2–3 million for a 200-bed hospital, EP represents a significant investment. Patients are referred to EP by cardiologists, who should be aware of quality differentials among area hospitals (criterion 3). The potential for hospitals to increase the volume of procedures performed is high: only 14% of newly eligible patients undergo EP each year (Ruskin et al. 2002). A recent report by The Advisory Board Company (2004), which provides best practices research and analysis to 2,100 health systems and medical centers, lists several practices hospitals can adopt to increase EP volume. These practices are summarized in Table I. Finally, the procedure is well represented in the Medicare population. Tabulations using California's census of hospital discharges (OSHPD) indicate that roughly half of EP procedures are performed on Medicare beneficiaries.

10. After identifying a comprehensive list of surgical procedures that experienced a sudden technological change or a large increase in Medicare reimbursement between 1984 and 1996, the period for which I have the MedPAR data, I reviewed medical literature and interviewed physicians to establish how well each procedure satisfies the technical criteria listed above. As a final screen, I used MedPAR data and data from California's state inpatient database to identify providers for each candidate procedure, rejecting those procedures that were performed in only a small number of markets during the pre-shock period (e.g., extracorporeal photopheresis, a cancer treatment in which a patient's blood is passed through an external device and exposed to ultraviolet light) or on a small number of Medicare patients (e.g., bone marrow transplants).

11. *The Miller-Keane Medical Dictionary; Manual of Cardiovascular Medicine* (2000).

Table I.
Strategies for Increasing EP Volume

Increase Patient Demand
- "Fully leverage heart failure hospitalizations" by screening this "captive audience" to determine suitability for EP
- Increase awareness among referring physicians by sending mailings and video clips
- Seek news media exposure by supplying local news outlets with highly-structured content on therapies

Increase Hospital Capacity
- Increase throughput by optimizing use of EP specialist's time
  - → Create team that includes general surgeons, interventional cardiologists, and nurse practitioners to perform tasks that do not require specialist's expertise
  - → Invest in transtelephonic systems to enable specialist to monitor devices without office visits
  - → Hire staff to ensure pre-procedure patient readiness and avoid costly cancellations/rescheduling
- Recruit an EP Specialist
  - → Offer financial incentives and "lavish" staff and facility upgrades, as these specialists are in short supply
- Add a dedicated EP lab

Source: Electrophysiology Excellence: Building a Financially Viable and Clinically Advanced Program, The Advisory Board Company, 2004.

Although EP is extremely costly (hospitals reported expenses of \$5,000 to \$21,000 in 1988 dollars), it did not affect DRG assignment for several years. Patients undergoing EP were typically placed in DRGs 138 and 139 for cardiac arrhythmias, with FY1988 reimbursements of roughly \$1,800 and \$2,700, respectively. HCFA responded to hospital complaints in its customary fashion: it announced a new procedure code to gather separate data on EP in order to determine the appropriate reimbursement amount. This announcement appeared in HCFA's annual publication of proposed changes on May 27, 1988. The new code was used during FY1989, and a substantial reimbursement increase was enacted for FY1990 and beyond. This was accomplished by designating EP as a "non-operating room procedure," enabling patients to be assigned to higher paying surgical DRGs (104, 106, 108, and 112) with reimbursements ranging between \$6,500 and \$26,700.[12] Thus, the attractiveness of entry increased dramatically in FY1990. (Hereafter all years refer to HCFA's fiscal years, which begin in October of the previous calendar year.)

12. Changes to the inpatient hospital payment system are proposed in a late May/early June publication and finalized in September. They are effective on October 1, the start of the next fiscal year. Dollar estimates were calculated by multiplying DRG weights by the standard hospital amount for large urban hospitals (sources: 53 FR 38476, 54 FR 19636, 54 FR 36452).

In the context of the three-period model, 1988 represents $t = 1$, 1989 is $t = 2$, and 1990 is $t = 3$. An incumbent's EP volume growth between 1988 and 1989 serves as a proxy for S_1^M. This is the period during which incumbents may have made entry-deterring investments for potential entrants to observe prior to making their entry decisions, as entrants would likely wait until the reimbursement increase was enacted. Of course, entry can and does occur in $t = 2$; this is a problem I address in the empirical analysis below.

4.2. Data

I obtain estimates of annual hospital EP volumes using a 20% sample of the 1985–1989 Medicare Provider Analysis and Review (MedPAR) files. This comprehensive data source contains information on all hospitalizations of Medicare enrollees, including surgical procedure codes and hospital identification numbers.[13] The 20% sample comprises 2.1 to 2.8 million individual records per year. After aggregating the procedure data to the hospital level, each hospital is matched to a record from the 1988 *Annual Survey of Hospitals* by the American Hospital Association (AHA). This survey provides detailed information on virtually all US hospitals, including service offerings and utilization statistics.

Table II presents descriptive statistics for incumbent providers, defined as hospitals performing EP in 1988 and 1989.[14] Average incumbent volume in 1988 is approximately 51 (recall that the data in Table II is a 20% sample of Medicare patients, who account for half of the EP caseload). The mean value for the dependent variable, ln (1989 volume) − ln (1988 volume), is 0.27, with substantial variation around this mean. Compared to the average US hospital, incumbent EP providers are more than twice as large and six times more likely to offer cardiac catheterization and open-heart surgery. The incumbents are distributed across 40 states plus the District of Columbia.[15]

The market definition I use is the Hospital Service Area (HSA), delineated by the Dartmouth Atlas of Health Care (Center for Evaluative Clinical Sciences, 1996). Each HSA comprises the smallest group of contiguous zipcodes containing the hospitals serving the majority of residents in those zipcodes. There are 3,436 HSAs in the United States, with population ranging between 866 (Hoven, South Dakota) and 2.7 million

13. Inpatient stays by HMO enrollees, who accounted for 5.2% of Medicare beneficiaries in 1990, are not included in the data.

14. Of the 252 incumbent providers, I exclude four that stopped performing EP in 1989, and one that could not be matched to a Hospital Service Area.

15. The states lacking an EP provider in 1988–1989 are Alaska, Delaware, Idaho, Maine, Mississippi, Montana, North Dakota, Nevada, South Dakota, and Wyoming.

Table II.
Descriptive Statistics, EP Incumbents ($N = 247$)

	Mean	Standard Deviation
Incumbent Characteristics		
1985 volume	1.56	(3.54)
1986 volume	2.01	(3.72)
1987 volume	2.91	(4.12)
1988 volume	5.11	(5.35)
1989 volume	6.99	(7.14)
ln (1989 volume) – ln (1988 volume)	0.27	(0.87)
Years of EP Experience by 1988	2.67	(1.21)
For Profit	0.05	(0.22)
Government-owned	0.13	(0.34)
Not-for-profit	0.82	(0.39)
Teaching Hospital	0.53	(0.50)
Cath Lab and Open-heart Surgery	0.87	(0.34)
Annual Surgical Operations	7852	(4458)
Beds	517	(250)
Market (HSA) Characteristics		
Number of Incumbents	2.47	(1.76)
Number of Potential Entrants	1.34	(1.70)
Entry in 1989	0.22	(0.42)
Entry in 1990	0.28	(0.45)
Entry in 1989 or 1990	0.43	(0.50)
Population	7.49	(6.24)
EP Penetration Rate	17.68	(23.07)
EP Access Rate	0.50	(0.48)

Notes:
(1) Markets are Health Service Areas (HSAs) as defined in the Dartmouth Atlas of Health Care (1996).
(2) Potential entrants are nonincumbent hospitals with catheterization labs and open-heart surgery facilities, located in the incumbent's HSA.
(3) Population is given for 1990 and measured in 100,000s.
(4) EP penetration rate = (number of 1988 procedures in the HSA in 20% MedPAR sample × 5)/population in 100,000s.
(5) EP access rate = number of incumbents in HSA/population in 100,000s.
Sources: 20% MedPAR sample 1985–1989, AHA *Survey of Hospitals* (1988), Dartmouth Atlas of Health Care (1996).

(Chicago); of these, 149 had EP incumbents in 1988. Approximately 69 percent of the US population in 1988 resided in an HSA with one or more EP incumbents. There were 96 HSAs with monopolist incumbents (therefore contributing 96 hospital-level observations), 28 with two incumbents (56 hospital-level observations), and 25 with three or more incumbents (95 hospital-level observations).

4.3. Empirical Analysis

4.3.1. Cross-sectional analysis

To investigate whether volume growth is nonmonotonic in market attractiveness, I begin with a cross-sectional analysis. I regress ln (1989

TABLE III.
EX ANTE AND *EX POST* ENTRY MEASURES,
ALL INCUMBENTS

Number of Potential Entrants	N	*Ex post* Probability of Entry
0	103	0.09
1	61	0.49
2	34	0.85
3	26	0.77
4+	23	0.78
All	247	0.43

Notes:
(1) The unit of observation is the hospital.
(2) *Ex post* entry probability is the mean value of an indicator for entry in the incumbent's HSA.

volume) − ln (1988 volume) for every incumbent on a measure of the market potential in the incumbent's market. For this measure, I use the number of hospitals in the incumbent's market that do not perform EP but do offer cardiac catheterization and open-heart surgery (i.e., the number of potential entrants). A catheterization lab (used to image the heart and/or perform therapeutic procedures) is a prerequisite to establishing an EP service, while open heart surgery is a complement and safety backup. There is substantial overlap between revascularization patients (who use the cath lab and open heart facilities) and EP candidates; indeed, one strategy for increasing EP volume is to screen such patients when they are hospitalized for these procedures. The number of potential entrants is, therefore, an excellent measure of the unmet or referrable EP demand in a market. Given this measure of z, the *ex ante* threat of entry should increase in z for two reasons: first, the profits upon entry increase in z; second, the first-order statistic for entry costs decreases in z, simply because the lowest E declines in the number of draws from the distribution of entry costs. Entry-deterring investment should have the biggest "bang for the buck" at middling levels of z, where the probability of entry is intermediate.

Table III reports descriptive statistics on the number of potential and actual entrants.[16] Out of 247 incumbent providers 103 are located in HSAs without any potential entrants (as defined above), and the *ex post*

16. Children's hospitals and federal government hospitals are excluded; none of the incumbents falls into these categories. Of the 423 providers that performed EP for the first time in 1989 or 1990, I exclude 5 due to missing data and 11 that exited in 1989. I also drop 91 providers that performed fewer than three procedures during the entire period for which I have the data, 1985–1996. This restriction minimizes the number of hospitals labeled as entrants solely due to coding errors.

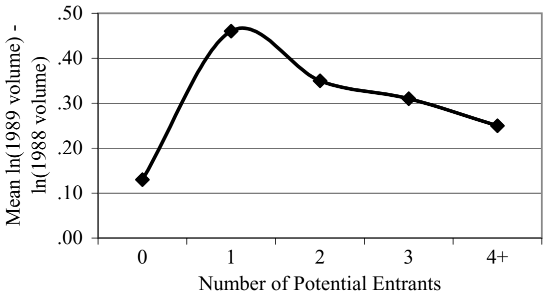

FIGURE 2. ACTUAL INCUMBENT VOLUME GROWTH, EP MARKET

probability of entry for hospitals in these markets is correspondingly low (9%). The *ex post* probability of entry reaches nearly one-half for hospitals facing one potential entrant, jumps to 85% for hospitals with two potential entrants, and declines slightly for hospitals in markets with three or more potential entrants. Thus, the measure of market attractiveness accords well with *ex post* entry, and if hospitals are behaving strategically, investment should peak in markets with one potential entrant. Indeed, Figure 2, which graphs unadjusted incumbent growth rates against the number of potential entrants, mirrors the theoretical pattern in Figure 1.

To control for other factors that may be contributing to this pattern, I estimate specifications of the following form:

$$\ln(1989\ \text{volume})_{mh} - \ln(1988\ \text{volume})_{mh} = \alpha + \sum_{i=1}^{4+} \beta_i I(\text{potential entrants} = i)_m + [\nu X_h + \varphi Z_m] + \varepsilon_{mh}. \quad (6)$$

The dependent variable is the continuous growth rate for hospital h in market m. Using the growth rate rather than the absolute change in volume accounts for differences in the size of individual hospitals' programs; an increase of five procedures represents a larger investment for a program initially performing 10 procedures per year than for a program performing 50. The independent variables of interest are the indicator variables for the number of potential entrants, with zero as the omitted category. Because these variables vary at the market level, all standard errors are corrected for correlation within markets. A finding of $\hat{\beta}_1 > \hat{\beta}_{4+}$ constitutes conclusive evidence of entry deterrence; as Figure 1 illustrates, such a result requires an extremely strong entry deterrence effect. If the underlying monotonic relationship between volume growth and entry probability is steep or convex, hospitals facing intermediate entry probabilities will not exhibit significantly higher growth than hospitals subject to high entry probabilities, even in the presence of entry-deterring investment. Because the omitted category represents a low entry probability, absent any controls all of the coefficients in $\hat{\beta}$ should be greater than zero.

Caution must be exercised when including additional controls, as these controls may be collinear with market attractiveness, precisely the factor the potential entrant indicators are meant to capture. Although the specification that accords best with the theory excludes controls, it is valuable to test the robustness of the findings by allowing for progressively richer specifications. Finding $\hat{\beta}_1 > \hat{\beta}_{4+}$ in spite of the inclusion of additional controls would help to rule out omitted variables as the underlying source of the results. For example, it is possible that growth rates are (nonstrategically) larger for teaching hospitals, whose skilled physicians may continually pioneer new applications of EP. If the proportion of incumbents that are teaching hospitals is highest in markets with one potential entrant, such an association could also produce a nonmonotonic pattern of coefficient estimates.

To control for such biases, I sequentially introduce X_h and Z_m into the base specification. X_h is a vector of incumbent controls, consisting of all of the variables reported in Table II: years of EP experience, ownership status, teaching status, indicator for catheterization lab and open-heart surgery facilities, annual number of surgical operations, and number of beds. Z_m is a vector of market-level controls, including population and its square, the EP penetration rate (=number of EP procedures/population), the EP "access rate" (=number of incumbents/population), and an indicator for entry in 1989 ($t = 2$). If a market experiences entry in 1989, incumbents did not have a full year to expand their programs prior to the entry decision, so their investment levels may be depressed relative to those of incumbents in markets that did not experience such entry. Because entry at any time is likeliest in markets with multiple potential entrants, the results could be biased in favor of nonmonotonicity in the absence of a control for such entry. All other control variables are measured as of 1988, with the exception of population, which is only available for 1990.

Column 1 of Table IV presents estimates of β from the base specification, which excludes all control variables. Column 2 adds incumbent controls, column 3 adds the indicator for entry in 1989, and column 4 adds all the remaining market control variables. In all four specifications, a nonmonotonic investment pattern is evident, with the largest coefficient on I(potential entrants = 1). Incumbents in these markets increased their procedure volumes approximately 35 percentage points ($=e^{0.3} - 1$) more than did incumbents in markets with no potential entrants, and

Table IV.
Cross-Sectional Results, All Incumbents

	Dependent Variable is ln (1989 volume) − ln (1988 volume)			
	(1)	(2)	(3)	(4)
Number of Potential Entrants				
1	0.330**	0.354**	0.299*	0.170
	(0.150)	(0.149)	(0.157)	(0.157)
2	0.218	0.138	0.038	−0.082
	(0.163)	(0.178)	(0.191)	(0.224)
3	0.173	0.176	0.062	−0.018
	(0.219)	(0.230)	(0.236)	(0.249)
4+	0.120	−0.006	−0.149	0.012
	(0.221)	(0.208)	(0.196)	(0.237)
Control Variables				
Incumbent Characteristics	N	Y	Y	Y
[F-test]		[0.00]	[0.00]	[0.02]
Market Characteristics	N	N	N	Y
[F-test]				[0.00]
Entry in 1989			0.288	0.152
			(0.168)	(0.159)
p-values from $H_0: \hat{\beta}_1 = \hat{\beta}_{4+}; H_1: \hat{\beta}_1 > \hat{\beta}_{4+}$	0.19	0.05	0.02	0.26
N	247	245	245	245

Notes:
(1) Results from estimation of equation (6) in the text, $\ln(1989\text{ volume})_{mh} - \ln(1988\text{ volume})_{mh} = \alpha + \sum_{i=1}^{4+} \beta_i I(\text{potential entrants} = i)_m + [\nu X_h + \varphi Z_m] + \varepsilon_{mh}$, where X_h and Z_m denote vectors of incumbent and market characteristics, respectively. Incumbent characteristics are ownership type, teaching status, cath lab/open-heart surgery dummy, number of beds, number of surgical operations, and years of EP experience (between 1985 and 1988). Market characteristics are population, population squared, EP penetration rate, and EP access rate. Coefficients on control variables are reported in Table AI.
(2) Robust standard errors corrected for correlation within markets are in parentheses.
(3) *signifies $p < 0.10$, **signifies $p < 0.05$, ***signifies $p < 0.01$.

26 to 49 percentage points more than incumbents in markets with 4 or more potential entrants. For a typical incumbent in a market with one potential entrant, a 35 percentage point increase translates into 10–11 additional procedures per year.

As predicted, all coefficients are positive in the first specification. $\hat{\beta}_1$ is statistically significant at $p < 0.05$ in columns 1 and 2, and $p < 0.10$ in column 3. The coefficient on entry in 1989 is positive rather than negative, implying that early entry does not bias the results in favor of nonmonotonicity. Although the incumbent controls have little impact on $\hat{\beta}$, the full set of market controls reduces the magnitude of these estimates, and in particular the magnitude of $\hat{\beta}_1 - \hat{\beta}_{4+}$. Because the potential entrant indicators vary at the market level, the market controls are likely collinear with these regressors. Nevertheless, the general nonmonotonic pattern of the point estimates is robust to this full set of controls.[17]

Overall, the results in Table IV are suggestive of entry deterrence, with $\hat{\beta}_1 > \hat{\beta}_4$ in all specifications. However, the coefficient estimates are too imprecise to reject $\hat{\beta}_1 = \hat{\beta}_{4+}$ at conventional levels of significance for 2 of the 4 specifications. In addition, a primary concern is the possibility that omitted factors are driving the results. These concerns are mitigated in this setting because the omitted factors would have to vary nonmonotonically with market attractiveness or volume growth in order to produce a bias. Nevertheless, the possibility remains that markets with one potential entrant experience rapid growth for reasons other than entry-deterring investment. To address this possibility, I reformulate the regression specification to control for different growth trends across market types (where "type" refers to the number of potential entrants) prior to the profitability shock in 1989.

4.3.2. Panel Analysis

To control for pre-existing differences in growth rates across market types, I assemble a panel dataset of EP volumes for each incumbent hospital between 1985 and 1989, and estimate

$$\begin{aligned}\ln(\text{volume})_{mht} = \alpha + \delta_h + \tau_t + \sum_{i=1}^{4+} \mu_i I(\text{potential entrants} = i)_m \times \text{year}_t \\ + \sum_{i=1}^{4+} \gamma_i I(\text{potential entrants} = i)_m \times I(1989)_t \\ + \rho I(\text{entrant})_{mt} + [\theta X_h \times \text{year}_t + \varsigma Z_m \times \text{year}_t] + \varepsilon_{mht},\end{aligned} \tag{7}$$

where δ_h is a set of hospital dummies, τ_t is a set of year dummies, $\sum_{i=1}^{4} \mu_i I(\text{potentialentrants} = i)_m \times \text{year}_t$ is a set of trends for each market type, $I(1989)_t$ is an indicator variable for the "treatment" year, 1989, and $I(\text{ entrant})_{mt}$ is an indicator variable for entry in an incumbent's

17. The results are not affected by inclusion of individual state dummies, county-level managed care penetration, and additional hospital controls such as the share of patients that are insured by Medicare. To further test the robustness of the results, I also estimated the cross-sectional model in two stages, as in Ellison and Ellison (2000). The first stage is a probit model of *ex post* entry, with the number of potential entrants, the number of potential entrants squared, and the hospital and market controls as explanatory variables. I then use the predicted entry probabilities from this equation to designate the threat of entry as low ($\widehat{\textit{entry probability}} < 0.25$), medium ($0.25 < \widehat{\textit{entry probability}} < 0.75$), or high ($\widehat{\textit{entry probability}} > 0.75$). The second stage and variations thereof are exactly as presented in the text, replacing the number of potential entrants indicators with the medium and high indicators. The results are quite similar, although the estimates of $\beta_{med} - \beta_{high}$ are slightly smaller than the estimates of $\beta_1 - \beta_{4+}$.

Table V.
Panel Results, All Incumbents, 1985–1989

	Dependent Variable is ln (volume)		
	(1)	(2)	(3)
Number of Potential Entrants × I(1989)			
1	0.483**	0.455**	0.437**
	(0.201)	(0.199)	(0.196)
2	0.248	0.272	0.275
	(0.221)	(0.224)	(0.220)
3	0.208	0.281	0.274
	(0.320)	(0.326)	(0.327)
4+	0.047	0.048	0.043
	(0.323)	(0.306)	(0.300)
Control Variables			
Year Fixed Effects	Y	Y	Y
Incumbent Fixed Effects	Y	Y	Y
Number of Potential Entrant Trends	Y	Y	Y
Incumbent Characteristic Trends	N	Y	Y
[F-test]		[0.02]	[0.01]
Market Characteristic Trends	N	N	Y
[F-test]			[0.10]
Entry dummy	0.031	0.034	0.016
	(0.068)	(0.067)	(0.065)
p-values from $H_0: \hat{\gamma}_1 = \hat{\gamma}_{4+}$; $H_1: \hat{\gamma}_1 > \hat{\gamma}_{4+}$	0.10	0.11	0.11
N	856	849	856

Notes:
(1) Results from estimation of equation (7) in the text, $\ln(\text{volume})_{mht} = \alpha + \delta_h + \tau_t + \sum_{i=1}^{4+} \mu_i I(\text{potential entrants} = i)_m \times \text{year}_t + \sum_{i=1}^{4+} \gamma_i I(\text{potential entrants} = i)_m \times I(1989)_t + \rho I(\text{entrant})_{mt} + [\theta X_h \times \text{year}_t + \varsigma Z_m \times \text{year}_t] + \varepsilon_{mht}$, where δ_h is a set of incumbent fixed effects, τ_t is a set of year fixed effects, and $X_h \times \text{year}_t$ and $Z_m \times \text{year}_t$ are vectors of trends that vary by hospital and market characteristics, respectively. Incumbent characteristics are ownership type, teaching status, cath lab/open-heart surgery dummy, number of beds, number of surgical operations, and years of EP experience (between 1985 and 1988). Market characteristics are population, population squared, EP penetration rate, and EP access rate. Coefficients on control variables are reported in Table AII.
(2) Robust standard errors corrected for correlation within markets are in parentheses.
(3) *signifies $p < 0.10$, **signifies $p < 0.05$, ***signifies $p < 0.01$.

market in year t. (Note hospital fixed effects obviate the need for market fixed effects, as the latter consist of groups of the former.) γ captures the extra growth in 1989 by market type, controlling for pre-existing trends by market type, year dummies, and any shock associated with a new entrant. Column 1 of Table V presents the estimates of γ from this base specification. The specification in column 2 allows growth trends to differ by incumbent characteristics, and column 3 adds growth trends by market characteristics.

The coefficient estimates in Table V imply that incumbents in markets with a single potential entrant increased their volume 55–62 percentage points more between 1988 and 1989 than did incumbents

Table VI.
Ex Ante and *Ex Post* Entry Measures,
Monopolist Incumbents

Number of Potential Entrants	N	*Ex post* Probability of Entry
0	58	0.09
1	22	0.36
2+	16	0.94
All	96	0.29

Notes:
(1) The unit of observation is the hospital, which is the same as the HSA in this case.
(2) *Ex post* entry probability is the mean value of an indicator for entry in the incumbent's HSA.

in markets with four or more potential entrants, *after* controlling for differences in growth trends across market types. This finding is robust to the inclusion of trends for hospital and market characteristics.[18] In all the specifications, $\hat{\gamma}_1 = \hat{\gamma}_{4+}$ can be rejected in favor of $\hat{\gamma}_1 > \hat{\gamma}_{4+}$ at the $\alpha < 0.11$ level. These results constitute strong evidence of entry deterrence: even controlling for pre-1989 differences in market growth rates, hospitals in markets with intermediate entry probabilities boosted their procedure volumes following the reimbursement announcement more than did hospitals of any other market type.

4.3.3. Monopolist Incumbents

The analyses presented thus far include all incumbents, regardless of market structure. The results are likely to be stronger if the sample is restricted to monopolist incumbents, because monopolists stand to lose more rents if entry occurs than do incumbent duopolists or oligopolists (the efficiency effect).[19] Table VI contains descriptive statistics on the number of potential and actual entrants in these markets. Tables VII and VIII present the cross-sectional and panel analyses, respectively, for the 96 monopolist incumbents.

The point estimates suggest that the entry deterrence motive is indeed stronger for monopolist incumbents. For each specification, $\hat{\beta}_1$

18. The results are also robust to the inclusion of individual state trends, as well as trends that vary by the extent of managed care penetration and the share of the incumbent's patients that are Medicare insured.

19. Because the profit differential is multiplied by two additional terms (see equation [5]), the prediction regarding the relative overinvestment of monopolists versus oligopolists is technically ambiguous absent additional assumptions on competitive play in oligopoly markets. Another departure from the model in Section 3 is the presence of multiple potential entrants in attractive markets. Because incumbents in these markets will overinvest in order to discourage the second and third potential entrants, and so forth, my empirical test is biased against finding evidence of entry-deterring investment (relative to the single entrant model).

TABLE VII.
CROSS-SECTIONAL RESULTS, MONOPOLIST INCUMBENTS

	Dependent Variable is ln (1989 volume) − ln (1988 volume)			
	(1)	(2)	(3)	(4)
Number of Potential Entrants				
1	0.421*	0.542**	0.518**	0.210
	(0.237)	(0.256)	(0.258)	(0.287)
2+	0.302	0.350	0.120	−0.394
	(0.209)	(0.233)	(0.225)	(0.376)
Control Variables				
Incumbent Characteristics	N	Y	Y	Y
[F-test]		[0.07]	[0.02]	[0.03]
Market Characteristics	N	N	N	Y
[F-test]				[0.00]
Entry in 1989			0.531**	0.359
			(0.255)	(0.234)
p-values from $H_0: \hat{\beta}_1 = \hat{\beta}_{2+}$; $H_1: \hat{\beta}_1 > \hat{\beta}_{2+}$	0.33	0.24	0.06	0.01
N	96	95	95	95

Notes:
(1) Results from estimation of the following equation, using only the sample of monopolist incumbents: $\ln(1989\ \text{volume})_{mh} - \ln(1988\ \text{volume})_{mh} = \alpha + \Sigma_{i=1}^{2+} \beta_i \text{I}(\text{potential entrants} = i)_m + [\nu X_h + \varphi Z_m] + \varepsilon_{mh}$, where X_h and Z_m denote vectors of incumbent and market characteristics, respectively. Incumbent characteristics are ownership type, teaching status, cath lab/open-heart surgery dummy, number of beds, number of surgical operations, and years of EP experience (between 1985 and 1988). Market characteristics are population, population squared, EP penetration rate, and EP access rate. Coefficients on control variables are available upon request.
(2) Robust standard errors corrected for correlation within markets are in parentheses.
(3) *signifies $p < 0.10$, **signifies $p < 0.05$, ***signifies $p < 0.01$.

or $\hat{\gamma}_1$ is larger in this sample than in the sample of all incumbents. Direct comparisons between estimates of $\beta_1 - \beta_{4+}$ or $\gamma_1 - \gamma_{4+}$ cannot be made because the small number of monopolist markets with multiple potential entrants necessitates a single category (2+), but the estimates of $\beta_1 - \beta_{2+}$ and $\gamma_1 - \gamma_{2+}$ are consistently large and positive.

4.3.4. ALTERNATIVE EXPLANATIONS

The panel specification ruled out the possibility that incumbents in markets with one potential entrant were simply on faster growth tracks than incumbents in markets with lower or higher probabilities of entry. Thus the identifying assumption in the panel model is that no omitted, time-varying factor particular to markets with one potential entrant caused an off-trend growth spurt in 1989. However, if incumbents were traveling along nonlinear paths, it is possible that the 1989 growth pattern was due to these pre-existing trajectories. For example, suppose that procedure diffusion in a market is described by an S-curve: a new procedure is used infrequently until it hits critical mass, after which it

TABLE VIII.
PANEL RESULTS, MONOPOLIST INCUMBENTS, 1985–1989

	Dependent Variable is ln (volume)		
	(1)	(2)	(3)
Number of Potential Entrants × I(1989)			
1	0.627*	0.660**	0.594*
	(0.330)	(0.329)	(0.314)
2+	0.275	0.356	0.380
	(0.289)	(0.304)	(0.315)
Control variables			
Year Fixed Effects	Y	Y	Y
Incumbent Fixed Effects	Y	Y	Y
Number of Potential Entrant Trends	Y	Y	Y
Incumbent Characteristic Trends	N	Y	Y
[F-test]		[.47]	[0.17]
Market Characteristic Trends	N	N	Y
[F-test]			[0.00]
Entry dummy	0.080	0.048	−0.002
	(0.151)	(0.158)	(0.162)
p-values from $H_0: \hat{\gamma}_1 = \hat{\gamma}_{2+}$; $H_1: \hat{\gamma}_1 > \hat{\gamma}_{2+}$	0.17	0.20	0.28
N	331	326	326

Notes:
(1) Results from estimation of the following equation, using only the sample of monopolist incumbents: $\ln(\text{volume})_{mht} = \alpha + \delta_h + \tau_t\ \Sigma_{i=1}^{2+} \mu_i \text{I(potential entrants} = i)_m \times \text{year}_t + \Sigma_{i=1}^{2+}\ \gamma_i \text{I(potential entrants} = i)_m \times \text{I}(1989)_t + \rho \text{I(entrant)}_{mt} + [\theta X_h \times \text{year}_t + \varsigma Z_m \times \text{year}_t] + \varepsilon_{mht}$, where δ_h is a set of incumbent fixed effects, τ_t is a set of your fixed effects, and $X_h \times \text{year}_t$ and $Z_m \times \text{year}_t$ are vectors of trends that vary by hospital and market characteristics, respectively. Incumbent characteristics are ownership type, teaching status, cath lab/open-heart surgery dummy, number of beds, number of surgical operations, and years of EP experience (between 1985 and 1988). Market characteristics are population, population squared, EP penetration rate, and EP access rate. Coefficients on control variables are available upon request.
(2) Robust standard errors corrected for correlation within markets are in parentheses.
(3) *signifies $p < 0.10$, **signifies $p < 0.05$, ***signifies $p < 0.01$.

grows rapidly until a "ceiling" is reached. Further suppose that new procedures diffuse first to the most attractive markets, next to markets of intermediate attractiveness, and last to the least attractive markets. Then, it is possible that diffusion in the attractive markets was near complete in 1989, intermediate markets were just hitting the steep slope of the S-curve, and diffusion was just beginning in the least attractive markets.

To account for this possibility, I follow Griliches (1957) and estimate a logistic growth curve (the S-curve) for hospitals in each market type using the entire period available to me, 1985–1996. The linear transform of the logistic is simply $\ln[P_t/(C - P_t)] = a + bt$, where C is the "ceiling" or maximum volume of procedures for hospitals of each market type and P_t is the volume achieved in year t. For each market, I set C equal to the 95th percentile of provider volumes in 1996, in order to minimize the influence of outliers. As in Griliches, I estimate the logistic curves for each market type using observations satisfying $0.05 \leq P_t \leq 0.95$. The coefficients from these models are then used to predict annual volumes for hospitals of each market type. Finally, I subtract these predictions from the actual volumes and use the residuals to estimate the basic panel specification in column 1 of Table V, now excluding the linear potential entrant trends and year fixed effects. The results suggest the diffusion story cannot explain the nonmonotonic growth pattern between 1988 and 1989. The estimate of $\gamma_1 - \gamma_{4+}$ declines to 0.29 as compared to 0.44 in Table V, but $\hat{\gamma}_1 = \hat{\gamma}_{4+}$ can still be rejected in favor of $\hat{\gamma}_1 > \hat{\gamma}_{4+}$ at the $\alpha < 0.10$ level.[20]

The failure of the diffusion correction to eliminate the nonmonotonic pattern is easily explained upon examination of the fitted S-curves, which are practically linear. This finding is consistent with other attempts to model diffusion in health care technologies, which have not found evidence of convergence in use across different locations (e.g., Skinner and Staiger 2003). Skinner and Staiger suggest that the absence of a national market for health care may help to explain this phenomenon.

To further rule out omitted variables bias, it would also be helpful to assess whether the investments made by incumbents actually succeeded in deterring entry. Although this is not necessary for the investments to have been optimal *ex ante* , evidence of this kind would vindicate the strategy. Unfortunately, there is no exogenous and sufficiently precise measure of the *ex ante* threat of entry that can be compared with the *ex post* result.

5. Conclusion

This paper develops a model of strategic investment in a setting that is conducive to a test of this behavior: the inpatient surgical procedure market. By combining simple models of patient demand, quality production, and differentiated product market competition, I am able to generate clear theoretical predictions regarding entry deterrence through volume-increasing investments. The main result is that procedure growth rates should increase monotonically in market attractiveness unless hospitals engage in entry-deterring investment. Such investment should be largest where entry deterrence is likeliest to impact entry decisions: in markets of intermediate attractiveness.

Using hospital-level data on electrophysiological studies (EP), an invasive cardiac procedure developed in the 1980s, I find evidence of

20. Results available upon request. Note the results are similar for all three panel specifications.

investment for the purpose of entry deterrence: incumbents in moderately attractive markets generated the strongest volume growth in the year following an announced reimbursement increase for EP. This increase cannot be attributed to time-invariant omitted variables, as it is present even after controlling for hospital fixed effects, nor to pre-existing differences in growth trends, as it is robust to the inclusion of linear or S-shaped trends for each market type. Even after controlling for these trends, the post-announcement volume growth in moderately attractive markets is statistically significantly greater than that in unattractive or very attractive markets.

These results offer empirical support for theoretical models of strategic investment and suggest that hospitals could use experience to deter entry. The recent proliferation of self-proclaimed "centers of excellence" in specific diagnoses may be a manifestation of this strategy. An important step for future research is to discern between investments in learning-by-doing versus other volume-increasing alternatives.

This paper also contributes to the mounting evidence that the Hippocratic oath does not suffice to protect patients from undergoing unnecessary but profitable treatments. One mitigating factor is that successful entry deterrence will result in greater specialization across hospitals and superior outcomes for patients, *ceteris paribus*. More generally, stronger competition in quality will reduce the need for regulatory interventions such as "certificates of need," which are designed to constrain the number of providers of a given service in order to improve quality and reduce duplicative costs. However, these benefits must be weighed against the adverse consequences of aggressive procedure use and the increased market power of the remaining providers.

Appendix

This section summarizes the monotonicity result presented in Ellison and Ellison (2000), as applied to the model outlined in Section 3. A more precise exposition can be found in the original source.

Without entry-deterrence motives, the first-order condition for $S_1^{M*}(z)$ is

$$-\frac{d\pi_1^M}{dS_1^M} = F\left(\pi_2^{D_E^*}\left(S_1^M(z), z\right)\right)\frac{\partial \pi_2^{D_M^*}}{\partial S_1^M} + \left(1 - F\left(\pi_2^{D_E^*}\left(S_1^M(z), z\right)\right)\right)\frac{\partial \pi_2^{M^*}}{\partial S_1^M}.$$

The strategic entry accommodation effect is already incorporated in the choice of $S_1^M(z)$ (compare with the first-order condition in Section 3.2, where $\frac{\partial \pi_2^{D_M}}{\partial S_1^M}$ and $\frac{\partial \pi_2^M}{\partial S_1^M}$ are used). Differentiating this expression with respect to z yields

Table AI.
Full Cross-Sectional Results, All Incumbents

	Dependent Variable is ln (1989 volume) − ln (1988 volume)			
	(1)	(2)	(3)	(4)
Number of Potential Entrants				
1	0.330**	0.354**	0.299*	0.170
	(0.150)	(0.149)	(0.157)	(0.157)
2	0.218	0.138	0.038	−0.082
	(0.163)	(0.178)	(0.191)	(0.224)
3	0.173	0.176	0.062	−0.018
	(0.219)	(0.230)	(0.236)	(0.249)
4+	0.120	−0.006	−0.149	0.012
	(0.221)	(0.208)	(0.196)	(0.237)
Incumbent Characteristics				
Years of EP Experience		−0.105**	−0.109**	−0.120***
		(0.044)	(0.044)	(0.042)
For Profit		0.031	−0.038	0.077
		(0.294)	(0.289)	(.278)
Government Owned		0.168	0.222	0.159
		(0.155)	(0.163)	(0.159)
Teaching Hospital		0.186	0.166	0.160
		(0.133)	(0.133)	(0.131)
Cath Lab and Open-heart Surgery		−0.278	−0.290	−0.206
		(0.198)	(0.202)	(0.187)
No. of Beds		0.009	0.019	0.011
		(0.043)	(0.043)	(0.042)
No. of Surgeries per Year		0.026	0.024	0.015
		(0.025)	(0.025)	(0.026)
Market Characteristics				
Population				0.049
				(0.034)
Population Squared				−0.002**
				(0.001)
EP Penetration Rate				0.014***
				(0.004)
EP Access Rate				−0.571***
				(0.157)
Entry in 1989			0.288*	0.152
			(0.168)	(0.159)
N	247	245	245	245

Notes:
(1) Results from estimation of equation (6) in the text, $\ln(1989\ \text{volume})_{mh} - \ln(1988\ \text{volume})_{mh} = \alpha + \sum_{i=1}^{4+} \beta_i I(\text{potential entrants} = i)_m + [\nu X_h + \varphi Z_m] + \varepsilon_{mh}$, where X_h and Z_m denote vectors of incumbent and market characteristics, respectively.
(2) Robust standard errors corrected for correlation within markets are in parentheses.
(3) *signifies $p < 0.10$, **signifies $p < 0.05$, ***signifies $p < 0.01$.

TABLE AII.
FULL PANEL RESULTS, ALL INCUMBENTS, 1985–1989

	Dependent Variable is ln (volume)		
	(1)	(2)	(3)
Number of Potential Entrants × I(1989)			
1	0.483**	0.455**	0.437**
	(0.201)	(0.199)	(0.196)
2	0.248	0.272	0.275
	(0.221)	(0.224)	(0.220)
3	0.208	0.281	0.274
	(0.320)	(0.326)	(0.327)
4+	0.047	0.048	0.043
	(0.323)	(0.306)	(0.300)
Year Fixed Effects			
1986	0.058	0.499**	0.524**
	(0.114)	(0.213)	(0.232)
1987	0.335**	1.113***	1.171***
	(0.152)	(0.377)	(0.424)
1988	0.619***	1.683***	1.775***
	(0.179)	(0.522)	(0.593)
1989	0.755***	2.007***	2.132***
	(0.206)	(0.649)	(0.740)
Number of Potential Entrant Trends			
1	−0.118	−0.092	−0.104
	(0.087)	(0.083)	(0.079)
2	−0.041	−0.050	−0.080
	(0.074)	(0.075)	(0.080)
3	−0.025	−0.007	−0.011
	(0.096)	(0.093)	(0.103)
4+	−0.008	−0.024	0.008
	(0.106)	(0.102)	(0.122)
Incumbent Characteristic Trends			
Years of EP Experience		−0.122***	−0.129***
		(0.038)	(0.037)
For Profit		0.016	0.040
		(0.114)	(0.122)
Government Owned		−0.016	−0.029
		(0.057)	(0.059)
Teaching Hospital		−0.054	−0.065
		(0.053)	(0.053)
Cath Lab and Open-heart Surgery		0.074	0.100
		(0.121)	(0.115)
No. of Beds		−0.011	−0.009
		(0.016)	(0.016)
No. of Surgeries per Year		0.019**	0.016*
		(0.009)	(0.009)

Continued

Table AII.
Continued

	Dependent Variable is ln (volume)		
	(1)	(2)	(3)
Market Characteristic Trends			
Population			0.005
			(0.013)
Population Squared			0.000
			(0.000)
EP Penetration Rate			0.004**
			(0.002)
EP Access Rate			−0.167
			0.101
Incumbent Fixed Effects	Y	Y	Y
Entry Dummy	0.031	0.034	0.016
	(0.068)	(0.067)	(0.065)
N	856	849	856

Notes:
(1) Results from estimation of equation (7) in the text, $\ln(\text{volume})_{mht} = \alpha + \delta_h + \tau_t + \sum_{i=1}^{4+} \mu_i I(\text{potential entrants} = i)_m \times \text{year}_t + \sum_{i=1}^{4+} \gamma_i I(\text{potential entrants} = i)_m \times I(1989)_t + \rho I(\text{entrant})_{mt} + [\theta X_h \times \text{year}_t + \varsigma Z_m \times \text{year}_t] + \varepsilon_{mht}$, where δ_h is a set of incumbent fixed effects, τ_t is a set of year fixed effects, and $X_h \times \text{year}_t$ and $Z_m \times \text{year}_t$ are vectors of trends that vary by hospital and market characteristics, respectively.
(2) Robust standard errors corrected for correlation within markets are in parentheses.
(3) *signifies $p < 0.10$, **signifies $p < 0.05$, ***signifies $p < 0.01$.

$$-\frac{d^2\pi_1^M}{dz\,dS_1^M} - \frac{d^2\pi_1^M}{d\left(S_1^M\right)^2}\frac{dS_1^{M*}}{dz} = F\left(\pi_2^{D_E^*}\right)\left(\frac{\partial^2\pi_2^{D_M^*}}{\partial\left(S_1^M\right)^2}\frac{dS_1^{M*}}{dz} + \frac{\partial^2\pi_2^{D_M^*}}{\partial z\partial S_1^M}\right) + \left(1 - F\left(\pi_2^{D_E^*}\right)\right)\left(\frac{\partial^2\pi_2^{M*}}{\partial\left(S_1^M\right)^2}\frac{dS_1^{M*}}{dz} + \frac{\partial^2\pi_2^{M*}}{\partial z\partial S_1^M}\right) + f\left(\pi_2^{D_E^*}\right)\frac{d\pi_2^{D_E^*}}{dz}\left(\frac{\partial\pi_2^{D_M^*}}{\partial S_1^M} - \frac{\partial\pi_2^{M*}}{\partial S_1^M}\right).$$

Solving for $\frac{dS_1^{M*}}{dz}$ produces

$$\frac{dS_1^{M*}}{dz} = \frac{\left[F\left(\pi_2^{D_E^*}\right)\left(\frac{\partial^2\pi_2^{D_M^*}}{\partial z\partial S_1^M}\right) + \left(1 - F\left(\pi_2^{D_E^*}\right)\right)\left(\frac{\partial^2\pi_2^{M*}}{\partial z\partial S_1^M}\right) + \frac{d^2\pi_1^M}{dz\,dS_1^M}\right] + f\left(\pi_2^{D_E^*}\right)\frac{d\pi_2^{D_E^*}}{dz}\left[\frac{\partial\pi_2^{D_M^*}}{\partial S_1^M} - \frac{\partial\pi_2^{M*}}{\partial S_1^M}\right]}{-\frac{d^2\pi_1^M}{d\left(S_1^M\right)^2} - F\left(\pi_2^{D_E^*}\right)\frac{\partial^2\pi_2^{D_M^*}}{\partial\left(S_1^M\right)^2} - \left(1 - F\left(\pi_2^{D_E^*}\right)\right)\frac{\partial^2\pi_2^{M*}}{\partial\left(S_1^M\right)^2}}.$$

Because of the concavity assumptions for the profit functions, the denominator of this expression is always positive. Given the earlier assumption of $\frac{d\pi_2^{D_E^*}}{dz} > 0$, $S_1^{M*}(z)$ is monotone nondecreasing (nonincreasing) in z if both bracketed terms in the numerator are nonnegative (nonpositive). Ellison and Ellison label the first term the "direct effect" of z on $S_1^{M^*}$; it is positive so long as increasing z raises marginal profits more than it raises marginal investment costs. The second bracketed term is the "competition effect," which is nonnegative provided the marginal duopoly profits associated with an additional unit of $S_1^{M^*}$ exceed or equal the marginal monopoly profits. Note that if demand is separable in L^i and L^{-i}, the competition effect drops out.

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