The Utilization of Competing Technologies Within the Firm: Evidence from Cardiac Procedures

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This paper examines the role of technological status in determining the rates at which competing techniques are used within a firm. Consistent with prior studies, technological status is measured on the basis of an actor's prior contributions to the body of knowledge concerning a given technique. The empirical analysis considers two treatments for coronary artery disease (CAD), each of which is associated with a distinct professional group within a hospital. These two groups are often characterized as engaging in a "turf war" for patients. After controlling for several factors that might explain technological choice—the clinical severity of patients, the relative quality of the two procedures at a given facility, firm-level financial performance, and other firm-level characteristics—I find that the technological status of the group associated with each technique affects the relative rate at which it is used within a given hospital. Moreover, this effect is strongest for patients at the margin between the two techniques. These results suggest that viewing the choice between competing innovations as a single, firm-level decision may not always capture the true dynamics underlying such a situation.
(*Technological Choice; Competing Innovation; Technological Status; Intrafirm Groups*)

1. Introduction

Prior studies investigate the determinants of technological adoption and diffusion at several levels. One group considers the underlying characteristics of a *technology* itself, such as its effect on productivity or profitability (Griliches 1957, Mansfield 1963). A second examines the structural characteristics (e.g., size) of *firms* that use a technology (Oster 1982, Karlson 1986, Rose and Joskow 1990, Levin et al. 1992). A third group focuses on the characteristics of the *market* in which a technology diffuses (Romeo 1975, Reinganum 1981, Nelson and Winter 1982, Hannan and McDowell 1984). Finally, a fourth group addresses the *interactions* between two or more of the factors mentioned above, such as a firm's ability or willingness to embrace a given technology (Abernathy and Clark 1985, Tushman and Anderson 1986, Cohen and Levinthal 1990, Henderson and Clark 1990, Christensen 1997, Pisano et al. 2001).

Building off this final category of work, this study examines how the characteristics of the *individual* of a given technology affect its adoption and diffusion within a firm. Paramount among these characteristics is the "technological status" of an actor, which Podolny and Stuart (1995, p. 1232) define as "the perceived quality or importance of that actor's previous contributions to the advancement of technological knowledge."[1] Using data on semiconductor patents, they find that those patents held by high-status actors—based on the number of prior citations

[1] Stuart et al. (1999, p. 327) describe a related concept of "technological prominence." They note that "technologically prominent organizations are those that have developed many influential ... innovations."

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they have received—or connected with other high-status actors (through citations) tend to be more likely to serve as the basis for future innovations.

This paper investigates the impact of technological status in an empirical setting—the treatment of coronary artery disease (CAD)—where two techniques explicitly compete for share of a hospital's patients. While many prior studies have considered *several* sets of competing technologies, I focus on a *single* pair of techniques and examine them in great detail. As such, this analysis does not require controls for differences in the intensity of competition between innovations, which could affect citation rates in studies with multiple sets of competing technologies.[2] In short, the competition between the technologies studied here is clear and significant. Further, it occurs to a large degree within the boundaries of individual firms. In this sense, this study differs from much of the previous literature, which assumes the firm represents a single decision maker with respect to competing technologies.

The setting for this study is one where technological choice may emerge from competition or conflict between groups within the firm (March 1962, Cyert and March 1963). Perrow (1986) links the intraorganizational conflict described by Cyert and March (1963) to technological choice. He asks, "Why can one generally assume that even within departments there is a good chance of conflict between representatives of different product lines, different treatment technologies (such as social workers and psychiatrists), or different disciplines, such as the social sciences and engineering (Perrow 1986, p. 132)?" He begins to answer this question by suggesting that groups within the firm struggle for certain values and rewards, such as security, power, survival, discretion, and autonomy.

In the CAD setting, the firms are individual hospitals and the two technologies are coronary artery bypass surgery (CABG), also known as open-heart surgery, and percutaneous transluminal coronary angioplasty (PTCA). The former was introduced in the late 1960s and the latter in the late 1970s. All firms in the sample have adopted both techniques, though they are used in varying proportions across organizations. Each of these procedures is performed by a different type of physician—CABG by cardiac surgeons and PTCA by invasive cardiologists—and there is little, if any, evidence of physicians switching between these two specialties during their careers. As a result, CABG and PTCA can be viewed as substitutes at the level of the hospital, but not at that of the individual physician.

For patients with either very severe or very mild CAD, the choice between the two technologies is relatively consistent across organizations. Historically, those with very severe CAD (e.g., three or more blocked vessels) tended to receive CABG regardless of the hospital at which they sought treatment. Similarly, those with relatively mild (e.g., single vessel disease) were likely to receive PTCA (Hillis and Rutherford 1994). Patients with medium-severity disease thus have driven much of the interhospital variation in the relative use of the two procedures. While PTCA's initial use was primarily limited to patients with mild disease, the degree of substitutability between the procedures has increased over time as learning and technological advancement have improved PTCA's outcomes for more severe patients. As a result, there remains substantial debate in the clinical literature regarding the relative effectiveness of CABG and PTCA for patients with medium-severity CAD (CABRI Trial Participants 1995, Pocock et al. 1995, Taggart 1996).

The distinct constituencies involved with each of these technologies and the increasing degree of substitution between them has led to a "turf war" for CAD patients within many hospitals. Even as early as the mid-1980s, the president of Mt. Sinai Hospital in Hartford, Connecticut, noted, "Surgeons are not the best friends of angioplasts" (Hamilton 1986, p. 14). A newspaper article on the introduction of PTCA at Mt. Sinai referred to the hospital's then-chief of medicine: "Dr. Ferguson said that where the open-heart alternative is available, the number of angioplasty procedures performed is usually small, and the hospitals make no effort to recruit (physicians) who are skilled in angioplasty" (Hamilton 1986,

[2] Podolny and Stuart (1995) control for these differences in the intensity of competition—which they refer to as "attributes of niche structure"—using data on the ties between patents.

p. 14).[3] This turf war within hospitals is consistent with March's (1962) conception of the firm as a conflict system in itself rather than simply a unit within a larger conflict system, such as a market or industry.

In many hospitals, the conflict between surgeons and cardiologists may not be "overt" in the sense defined by Rotemberg and Saloner (1995). Rather this conflict may appear as a more subtle competition between groups for resources that are either controlled by the firm (e.g., capital or managerial attention[4]) or by parties outside of the firm (e.g., access to business from a fixed pool of external referral sources). This tension raises the question of whether it is possible for the older technology—CABG—to become "entrenched" in organizations within which those individuals associated with CABG (e.g., cardiac surgeons) have traditionally held high levels of technological status.[5,6] In medicine, where the delayed or accelerated diffusion of an innovation may have direct consequences for patient outcomes and costs (Baker 2001), status-related technological entrenchment could have a substantial impact on productivity.[7]

Using patient-level data for all CABG and PTCA procedures performed in New York State from 1993–1995, I test whether hospitals with high technological status for CABG relative to PTCA are characterized by a greater long-run[8] propensity to use CABG. I proxy for a hospital's technological status with respect to each procedure using the number of relevant citations in academic publications that have been attributed to that institution. This measure is analogous to previous ones based on patent citations (Trajtenberg 1990, Podolny and Stuart 1995, Podolny et al. 1996).[9] The rationale behind my choice of proxies is that individuals who author important papers may gain a degree of status within broad professional communities and—either directly or indirectly—within the hospitals in which they work. It is possible that such status will enable them to be more successful in competing with other groups within the firm. After controlling for factors such as patient severity, procedure quality, and hospital-level demographic and financial characteristics, I find that facilities with greater CABG status have higher rates of CABG as a percentage of total revascularizations (i.e., CABG plus PTCA procedures).[10] Further, this effect is particularly strong among patients whose severity places them at the "margin" between the two therapies. I perform several extensions to consider the robustness of these results and address potential concerns about residual endogeneity in the proxies for technological status.

Beyond the well-defined competition between them, CABG and PTCA serve as the basis of this study for several reasons. First, there is a wide clinical literature on the use of both CABG and PTCA. As

[3] Parentheses are placed around "physicians" in the above quote because it replaces the word "surgeons" that inaccurately appeared in the news article. This word was changed to avoid confusion over terminology.

[4] See Simon (1947) and Ocasio (1997) for discussions of how the attention of decision makers is focused within organizations. Milgrom and Roberts (1988) refer to the attempts of various groups to affect organizational decisions as "influence activities." Cockburn et al. (1999) link attention within the organization to technological choice by suggesting that the "internal structure of power and attention" within a firm may be responsible for variation in the diffusion of science-driven discovery in pharmaceutical research.

[5] Throughout the paper, references to the "technological status of CABG (PTCA)" should be considered synonymous with those to the "technological status of the CABG (PTCA) group."

[6] This situation could be considered a less extreme form of technological "lock-in" (e.g., David 1985, Arthur 1989) in which both of the competing technologies are adopted by a firm, but one technology appears to benefit from barriers to the diffusion of the other.

[7] With respect to CABG and PTCA, several papers in the clinical literature find evidence of a positive relationship between the volume of procedures performed by a given provider and the quality of that provider's outcomes (Showstack et al. 1987, Hannan et al. 1991, Hannan et al. 1997). In their study of minimally invasive cardiac surgery, Pisano et al. (2001) find a substantial *firm-specific* component of learning. The above evidence of learning suggests that potential delays or accelerations in the use of these procedures may have implications for cost and quality.

[8] I use the term "long-run" to refer the utilization rates during the period from 1993–1995 because 27 of the 31 hospitals offering PTCA in 1993 had adopted it by 1986 and 30 had adopted it by 1990.

[9] Trajtenberg (1990) finds a positive relationship between patent citation counts and independent measures of the social value of innovations in computed tomography (CT).

[10] This result is consistent with prior studies that have suggested the importance of physician characteristics in the prescription of drug therapies (Hellerstein 1998, Stern and Trajtenberg 1998).

such, it is easy to develop bibliometric measures of technological status with respect to each procedure at a given hospital. Second, roughly 75% of the hospitals that offered CABG and PTCA in New York during the sample period are teaching hospitals. Given the incentives for academic publication in such settings, one can assume that bibliometric measures reflect status within, as well as outside of, a given hospital. Third, there are objective measures of the severity of patients' conditions and *actual* procedural quality for each technology at each hospital. Using these measures as controls helps isolate the impact of *perceived* quality—the key component of technological status—from that of *actual* quality.

2. Background on Cardiac Procedures

A Brief Description of CABG and PTCA[11]

Developed in the late 1960s, CABG is an invasive surgical procedure that involves taking a section of vein (from the leg) or artery (from the chest) and grafting it to create a bypass of blockage in the coronary artery. It requires opening the patient's chest and relies on a heart-lung bypass machine to perform the functions of the heart during the grafting process. PTCA involves the threading of a balloon catheter through the artery to the point of blockage. The balloon is then inflated to expand the artery and restore blood flow. This procedure, which was first performed in 1977, is less traumatic than surgery, as patients avoid the substantial chest incision and arterial reconstruction that are integral to CABG. PTCA patients, however, run the risk of restenosis, or the return of blockage to the artery. During the late 1980s, PTCA—which had previously been reserved for patients with only mild CAD—began to be used more widely in cases of multivessel disease (Hillis and Rutherford 1994). The increased use of PTCA on more severe patients may be attributable either to learning or technological improvement, such as the use of stents—small braces that are used to prop open an artery and maintain blood flow after PTCA.

[11] Additional discussion of the clinical and economic characteristics of CABG and PTCA procedures appears in Huckman (2003).

The differences between these two procedures extend to their economic impact for the hospitals at which they are performed. On both an average and marginal basis, cardiac surgery is more profitable for hospitals than PTCA (Advisory Board Company 1997, Huckman 2003, Seinfeld and Mas 2000). Nevertheless, both procedures remain very profitable for hospitals relative to their other lines of business.

The cost structure for each technology includes a substantial fixed component. CABG typically occurs in an operating room that is outfitted with specialized equipment (e.g., a heart-lung bypass machine) and dedicated technicians. CABG programs also require the availability of a diagnostic catheterization laboratory, which is equipped with specialized radiological equipment and dedicated technical staff. At some point prior to receiving surgery, each CABG patient undergoes a diagnostic catheterization to determine the extent and location of any blockage. To perform PTCA, a hospital must supplement a basic diagnostic catheterization lab with additional equipment and staff. The hospital must also recruit cardiologists with the specialized training required for this procedure.

One unique feature of the relationship between CABG and PTCA is that hospitals typically must have the former service in place before offering the latter.[12] This requirement ensures that surgical back-up will be available in case an attempted PTCA procedure is unsuccessful. Because of the need for surgical back-up, the incremental fixed costs of adopting PTCA thus depend on whether a facility already has CABG in place. If a hospital offers CABG, then only the above enhancements to the catheterization laboratory would be necessary to introduce PTCA. Otherwise, it would need to make a sizeable investment to obtain the equipment, dedicated staff, and surgeons necessary to launch a CABG program.[13]

[12] Recently, hospitals in some states have begun to offer PTCA without CABG back-up. During the period studied, only one facility in New York State provided PTCA without CABG back-up at the same facility. That hospital, which received CABG back-up from an adjacent facility, has been excluded from this analysis.

[13] One cardiologist at a major teaching hospital in the United States estimated this additional cost to be on the order of $10 million for a basic program.

Table 1 Growth in Cardiac Case Volume in New York State, 1982–1998

	1982	1990	1998	CAGR, 1982–1998
AMI and IHD discharges	92,120	124,651	135,030	2%
CABG discharges	7,688	14,717	21,477	7%
PTCA discharges	505	9,505	31,455	29%

Source. SPARCS, 1982–1998.

Cardiac Procedures in New York State, 1982–1998

By 1998, 33 hospitals in New York State had adopted both CABG and PTCA.[14] Within this group, 80% of the CABG adoptions—but only 33% of the PTCA adoptions—had occurred by 1982, the first year for which hospital-level data on CABG and PTCA volumes are available from New York State. Though initially limited, the adoption of PTCA occurred relatively quickly; as of 1986, all 27 of the hospitals that were "at risk" for adopting PTCA (i.e., those that already offered CABG) had begun providing PTCA. The few facilities that adopted PTCA after 1986 all did so within one year of adopting CABG.

Table 1 illustrates the relative growth in CABG and PTCA cases in New York State from 1982–1998. The top line of the table shows the growth in the main candidate population for either CABG or PTCA—patients with a primary diagnosis of either acute myocardial infarction (AMI) or ischemic heart disease (IHD).[15] During this 17-year period, the number of AMI and IHD discharges increased at a 2% compound annual growth rate (CAGR). CABG and PTCA grew at annual rates of 7% and 29%, respectively, over the same period.

3. Quality, Technological Status, and Technological Choice

Interhospital variation in the use of CABG and PTCA may be explained by several factors. As suggested earlier, the severity of a patient's CAD is a clear determinant of treatment choice. In addition, the location of a hospital, its overall size, and the demographic characteristics of its patient base may also affect the relative use of CABG and PTCA. For example, a hospital in an urban area with a large number of academic medical centers (e.g., New York City), may tend to use an innovation more frequently because of its proximity to other hospitals on the "frontier" of medical practice. After controlling for the above variables, one must consider two additional hospital characteristics that may affect CABG rates. These two factors—discussed in greater detail below—are the objective quality of CABG and PTCA outcomes and the technological status of cardiac surgeons relative to cardiologists at a given hospital.

Relative Quality of CABG and PTCA

If cardiac surgeons at a particular hospital achieve significantly better outcomes with CABG than cardiologists do with PTCA, one would expect that facility to have a higher CABG rate ceteris paribus. Any analysis of hospital quality, however, is complicated by the fact that, for many forms of medical care, outcomes are multidimensional and difficult to measure (McClellan and Staiger 1999). CABG fares well in addressing these issues. First, the literature has approached consensus concerning the appropriate metric of quality for this procedure—the risk-adjusted mortality rate (RAMR). Second, mortality is easily measured and occurs with relatively high frequency for CABG patients.[16] Finally, detailed clinical data, such as that available from New York State, enables researchers to risk-adjust these outcomes based on the severity of a patient's preprocedure condition. The resulting variation in this measure across hospitals thus provides a relevant basis for interfirm comparisons of quality.[17]

[14] For the purposes of this study, the date of CABG (PTCA) adoption for a hospital is defined as the first year in which at least ten CABG (PTCA) procedures were performed at that facility.

[15] These two diagnoses accounted for roughly 93% of all CABG and PTCA discharges in New York State during the seven-year period from 1992–1998.

[16] The average in-hospital mortality rate for CABG was 2.65% throughout New York State for the period from 1991–1996.

[17] The use of in-hospital mortality has been criticized because of the possibility that hospitals concerned about their reported outcomes may attempt to discharge patients quickly to decrease the probability of registering an in-hospital death. Unfortunately, most studies are not able to identify easily whether non-Medicare patients die after leaving the hospital, as this requires the linkage of discharge data to mortality records at the patient level.

Differentiating hospitals in terms of PTCA quality is more difficult than for CABG, as in-hospital mortality following PTCA is very rare. Between 1993 and 1995, only 0.9% of PTCA patients in New York State died in the hospital; this rate is only one-third the size of that for CABG patients during the same period. As such, in-hospital death represents a relatively noisy measure of PTCA quality. An adverse outcome that is more common for PTCA patients is the use of CABG on an emergency basis immediately after an attempted PTCA. Nevertheless, the average rate of emergency bypass in the New York State sample is still relatively low at roughly 1.6%.[18] Given the limitations described above, I make the simplifying assumption that PTCA quality does not vary across hospitals in any measurable manner. As a result, the RAMR for CABG at a given hospital serves as a sufficient measure of the quality of CABG *relative to PTCA* at that facility. Later, I relax this assumption by including both the CABG RAMR and the risk-adjusted emergency CABG rate for PTCA patients as separate independent variables.

To the extent that outcomes are influenced by illness severity, researchers aim to risk-adjust them using observable characteristics of a patient prior to treatment. If performed accurately, such risk adjustment allows one to distinguish between hospitals with truly low quality and those that have low observed (but high risk-adjusted) quality simply because of the high severity of their average patient. A common approach to risk adjustment is to use discharge-level *administrative* data that includes information about patient age, gender, ethnicity, diagnoses, and procedures performed. The primary benefit of such data is that it is readily available in most states. Nevertheless, some studies suggest that administrative data may be inferior to clinical data for the purposes of risk adjustment (e.g., Hannan et al. 1992). Because of a reliance on established codes that are often quite broad, administrative data may not capture within-diagnosis or within-procedure heterogeneity in severity. In addition, many diagnostic codes may reflect conditions that were not present at the time of admission, but rather emerged during the course of treatment. As a result, risk adjustment using only administrative data may be incomplete.

[18] In addition, the New York State Department of Health cautions that the complication of emergency bypass may be underreported by hospitals. Further, the term "emergency" may be interpreted subjectively by hospitals.

To address the above limitation, this study relies on detailed *clinical* data at the patient level. These data are collected for every CABG and PTCA patient in New York State and include information about roughly 40 preprocedure risk factors, such as the extent and location of coronary blockage and whether a patient has a history of diabetes, stroke, or renal failure. Section 4 provides more detail concerning these data.

Technological Status

Beyond patient severity and the relative quality of outcomes for CABG and PTCA, the choice of revascularization method at a given hospital may also depend on the technological status of CABG versus PTCA at that facility. As previously mentioned, learning and technological improvement increasingly have enabled PTCA to serve as a substitute for CABG at severe levels of CAD. The dramatic effect of this substitution is highlighted by the concurrence of a 12% increase and a 4% *decline* in the absolute number of PTCAs and CABGs, respectively, in New York State from 1997–1998. Several previous studies (Dranove 1988, McGuire and Pauly 1991, Yip 1998) note that physicians may seek to offset income losses because of lower per-unit revenue by increasing the units of care they provide. Given that surgeons are not trained to provide PTCA, a downward shock in CABG demand may create an analogous income effect and might encourage surgeons to be more aggressive (on the margin) about seeking out potential CABG patients. It is also possible that a similar incentive operates for cardiologists with respect to PTCA.

In this sense, the technological status of CABG or PTCA at a given hospital may be related to the influence that surgeons and cardiologists have among referring physicians (e.g., primary care doctors) and hospital administrators. Strong relationships with referring physicians serve to increase volume in a direct manner, as these doctors are typically making treatment decisions as agents for patients. The importance of a surgeon or cardioloigst's influence with respect to hospital administrators, however, is not obvious. While it is unrealistic to assume that hospital administrators play a direct role in the choice of revascularization method for individual patients, they may provide preferential support to either the CABG or PTCA group in terms of managerial attention (Simon 1947, Ocasio 1997) or financial commitments for physician recruitment, capital improvements, or marketing. As such, hospital administrators may play an indirect role in determining the relative frequency with which these two procedures are used.

Much of the previous literature involving bibliometric measures of technological status or quality has used patent data and focused on citation counts (e.g., Podolny and Stuart 1995, Trajtenberg 1990). Similarly, I proxy for technological status using citation counts in the academic medical literature. Several studies have noted a positive relationship between publication citations and measures of perceived research quality or researcher recognition (Cole and Cole 1967, Keen et al. 1998).[19] Given the complex nature of both CABG and PTCA, they tend to be performed at relatively large, academic medical centers. In fact, over 75% of the hospitals offering these procedures in New York State are listed as teaching hospitals with the American Hospital Association. Because of the value placed on academic publications in such environments, citation-based measures should provide particularly good measures of technological status.[20]

I develop separate measures for each procedure—CABG and PTCA—at each hospital. For a given hospital h, this measure, $CITE_h$, is simply

$$CITE_h = \sum_{i=1}^{p_h} C_i, \tag{1}$$

where i indexes relevant publications that list hospital h in the address field for at least one author and p_h represents the total number of such publications for hospital h during a given time period. C_i is the total number of citations (divided by 100 for ease of presentation) for publication i through the year 2001. Because the number of citations for an article can only increase with time, this measure will tend to attach higher levels of status to older articles, holding the underlying quality of the article constant. Prior studies adjust citation counts for the length of time that particular publications have been "at risk" of citation. While Trajtenberg (1990) notes that there is evidence of some bias created by "missing" citations to recent CT patents, he notes that this bias is small and would not systematically affect his findings based on citation counts. Here, I am not as concerned with controlling for the age of a publication, as one could argue that those who published earlier may likely be rewarded with higher status (i.e., they are more likely to be pioneers in a given field).[21]

As described in §5, the bibliometric measures for CABG and PTCA enter as separate independent variables in regressions where the dependent variable is the CABG rate adjusted for patient severity. These models also incorporate lagged measures of actual CABG—and in some versions, PTCA—quality at a given hospital. The coefficient on the CABG measure thus captures the impact of technological status with respect to CABG holding constant the PTCA status of a given hospital and the actual quality of care it provides. To the extent that CABG becomes an entrenched technology due to the technological status of it or its users, one would expect those hospitals with more CABG citations to experience higher use of CABG relative to PTCA ceteris paribus. A potential concern with this approach is that the CABG and PTCA citation measures may be highly collinear,

[19] In their conclusion, Podolny et al. (1996) suggest that their work using patent citations as measures of status could be replicated using journal citations.

[20] An anonymous referee suggested interacting citations with the teaching status of the hospitals under the assumption that the impact of citations should be larger for teaching hospitals, as physicians have particularly strong incentives to publish in such settings. Given the relatively low number of nonteaching hospitals offering CABG and PTCA—as well as the fact that four of the seven nonteaching hospitals have no CABG or PTCA publications—identification of such interactions is difficult. Nevertheless, re-estimating the regressions on a sample that includes only teaching hospitals reveals that the results are robust to this restriction of the sample.

[21] The appendix to Podolny's (1993) study of status in the investment banking industry discusses the significance of using historical measures to capture perceived quality.

thereby preventing the identification of independent effects for each variable. Despite this concern, the simple correlation between the two measures is only 0.12, suggesting a substantial degree of independence between them.

4. Data

The data used in this study are from three main sources. The New York State Department of Health provides discharge-level data on all CABG and PTCA patients in the state through the Cardiac Surgery Reporting System (CSRS) and Coronary Angioplasty Reporting System (CARS), respectively.[22] For each patient, these data provide clinical detail on preprocedure risk factors as well as post-procedure outcomes including in-hospital mortality.[23] I use this information to estimate a risk-adjusted CABG rate at each hospital for each year from 1993–1995. The denominator for this rate is the number of revascularizations at a given hospital in a particular year.[24] Given the fact that 27 of the 31 hospitals adopting PTCA by 1993 had done so by 1986, I consider CABG rates in the 1993–1995 period to be long-run use rates. I focus on these three years because they are the only ones for which both CABG and PTCA data were available as of the beginning of this study. CABG data, however, was available from 1991–1996, and I use all of this information to estimate the CABG RAMR for each hospital.

The second source of data is New York's Statewide Planning and Resource Cooperative System (SPARCS). SPARCS provides discharge-level administrative information—patient demographics, type of insurance, diagnoses, and procedures performed—for all inpatient hospital stays. Using these data, I form hospital-level observations for each year from 1993–1995. Each observation includes the total number of inpatient discharges as well as measures that capture the distribution of a hospital's patients across several payer categories—Medicare, Medicaid, HMO, and Medicaid HMO—in a given year.

Finally, the proxies for technological status are created using data from the Science Citation Index (SCI) and Social Science Citation Index (SSCI). These databases provide the number of times that individual articles are cited in the academic literature. The status measure for CABG includes any publications that: (1) appear in SCI or SSCI between 1969 and 1992, (2) have a given hospital listed in the corresponding address of at least one of the authors, and (3) have one of several surgery-specific terms in the title.

The status measures for PTCA meet both of the first two criteria above and include one of several PTCA-specific terms in the title.[25] The 1969–1992 period was selected because it spans the period from the first CABG or PTCA publication for a New York hospital through 1993—the beginning of the three-year window in which technological use is observed in this study. This timing avoids concerns about the direction of causality with respect to the status variables and the CABG rate. While limited only to those articles published between 1969 and 1992, the status proxies include all citations for those articles through the end of 2001.

As a preface to multivariate analysis, it is useful to consider the data in summary form. Modifying

[22] The CABG data covers only "isolated" procedures (i.e., those performed on patients who do not receive any other major heart surgeries, such as valve procedures, during the same admission (New York State Department of Health 1998)). The annual number of CABG procedures in the state ranges from a low of 14,944 in 1991 to a high of 20,078 in 1996; for PTCA, these figures vary from 16,804 in 1993 to 21,707 in 1995.

[23] Examples of the preprocedure risk factors include: number of diseased vessels and percent blockage, measures of ventricular function (e.g., ejection fraction), and indicators for previous myocardial infarction, peripheral vascular disease, previous cardiac procedures, diabetes, and renal failure. A more extensive listing of the available covariates appears in Huckman (2002).

[24] The PTCA rate thus equals one minus the CABG rate.

[25] For the CABG measure, these terms are: *cardiac surgery, bypass surgery, bypass graft, valve surgery, heart surgery*, or *CABG*. For the PTCA measure, these terms are: *coronary angioplasty, coronary stent*, or *PTCA*. Given the fact that some physicians may have moved among hospitals during the period from 1969–1992, one might want to measure the publications at a given hospital as the total publications for the surgeons or cardiologists who were practicing at the hospital in 1993. The names of the cardiologists at each facility, however, are not available in either the CSRS data or public reports. As such, the above measures based on hospital name must be used for this analysis.

Table 2 Adjusted CABG Rates by Severity Level (Weighted Hospital-Level Observations)

		Adjusted CABG rate = CABG/(CABG + PTCA)			
	Obs*	Mean	Standard deviation	25th percentile	75th percentile
Low severity (one vessel)	29	0.048	0.032	0.030	0.063
Medium severity (two vessels or one vessel in LAD)	29	0.359	0.107	0.274	0.434
High severity (3 + vessels or any blockage in LMT)	29	0.847	0.043	0.815	0.869

Notes. The means and standard deviations are weighted by the total number of revascularization cases at the given severity level for the three-year period from 1993–1995.

*Sample excludes one hospital that offered only PTCA during the sample period and another hospital whose PTCA program was placed on probation by New York State for some portion of the sample period. Twenty-eight of the 29 hospitals had adopted PTCA by 1990 and 25 had adopted as of 1986.

Source. CSRS, 1993–1995 and CARS, 1993–1995.

an index use in a study based at Duke University (Mark et al. 1994), I divide patients into three severity categories: low, medium, and high.[26] This categorization provides a rough control for the effects of any changes in the average severity of the population receiving revascularization. Table 2 provides data on the risk-adjusted CABG rate by severity level for the entire 1993–1995 period. As expected, the CABG rate is highest for the most severe and lowest for the least severe patients. On average, over 84% of severe patients received CABG as the initial mode of treatment, while the same was true for only 4.8% of low-severity cases. In addition, the dispersion in CABG rates across hospitals is quite low for both extreme categories, with only 5.4 and 3.3 percentage points separating the 25th and 75th percentile hospitals for the high and low groups, respectively. The middle category, however, is not characterized by the unanimity in treatment choice that appears in the two extremes. On average, CABG and PTCA both account for a sizeable portion of cases. This result is consistent with the claim that patients in this group constitute the "margin" between CABG and PTCA. Furthermore, the dispersion across hospitals is the largest of any of the three categories with 16 percentage points separating hospitals at the 25th and 75th percentiles, thus implying a fair degree of interhospital heterogeneity in the exact location of this margin.

5. Empirical Specification and Results

Splitting the population of revascularization candidates into three severity categories provides only a crude control for a patient's actual level of illness. Within a given category, there may still be a substantial degree of heterogeneity along dimensions that affect the choice of revascularization method. To control for this possibility, I use a multistage estimation procedure that first creates risk-adjusted CABG rates for each hospital year from 1993–1995. In the second stage, I regress these adjusted rates on the proxies for technological status and other controls.

To determine the risk-adjusted CABG rate for hospital h in year t, I estimate a logistic regression using patient-level observations for all revascularization procedures in New York State during the years from 1993–1995. These models are run separately for each of the three severity levels. The dependent variable is an indicator equal to one if the patient received CABG as the initial treatment and zero if PTCA was used.[27] The right-hand side of this equation includes a broad range of patient-specific variables, such as the patient's age, height, weight, and gender, as well as a host of clinical characteristics.[28] Averaging the predicted values of this regression over all patients at hospital h in year t yields an expected CABG rate,

[26] This categorization of CAD severity modifies the classification presented in Mark et al. (1994). A vessel is considered "diseased" if it is at least 70% blocked and a given patient may have between zero and four diseased vessels. "Severe" patients are those with blockage of the left main trunk (LMT) or at least three diseased vessels; "medium" patients have either two diseased vessels or single-vessel disease in the left anterior descending (LAD) artery; and "mild" patients have single-vessel disease in areas other than the LMT or LAD.

[27] Patients who received PTCA followed by an emergency bypass thus receive a value of zero for the CABG variable.

[28] The results of this first-stage regression are available from the author.

ECR_{ht}. For each severity level, the risk-adjusted CABG rate, $RACR_{ht}$, for hospital h in year t is calculated according to the following formula:

$$RACR_{z,\,ht} = \left[\frac{OCR_{z,\,ht}}{ECR_{z,\,ht}}\right] * \overline{OCR}_{z,\,93-95}, \qquad (2)$$

where $z \in \{1, 2, 3\}$ indexes the three severity levels: low, medium, and high. $OCR_{z,\,ht}$ is the observed CABG rate at severity level z for hospital h during period t and $\overline{OCR}_{z,\,93-95}$ is the average observed CABG rate across all patients of severity level z in New York State for the period from 1993–1995.[29]

A similar methodology is used to estimate the RAMR for CABG patients. In particular, I perform a logistic regression on individual observations for all CABG patients in New York State from 1991–1996. The dependent variable is equal to one if a CABG patient died in the hospital after receiving the procedure and zero otherwise. The resulting ratio of observed-to-expected mortality for each hospital is then normalized by the observed mortality rate for the entire state from 1991–1996. As previously noted, in-hospital mortality is very rare for PTCA patients, so calculating a RAMR may not be very meaningful. Nevertheless, the same methods are used to calculate a risk-adjusted emergency CABG rate (RAECR) for PTCA patients. Because of the limited availability of patient-level PTCA data, these estimates are based only on observations for the period from 1993–1995.

In the second stage, the following equation is estimated separately for each of the three severity levels:

$$\begin{aligned} RACR_{h,\,t} = {} & \delta_t + \beta_1 CABCITE_h + \beta_2 PTCCITE_h \\ & + \beta_3 ROS_{h,\,t-2} + \beta_4 RAMR_{h,\,t-2} \\ & + \beta_5 z_{h,\,t} + e_{h,\,t}. \end{aligned} \qquad (3)$$

Each of the observations used to estimate (3) represents one of the 29 hospitals in one of the three years covered in the sample.[30] δ_t represents a fixed effect for year and controls for any residual time trend in the RACR that remains after the first-stage estimation. $CABCITE_h$ and $PTCCITE_h$ are the citation counts for CABG and PTCA, respectively, at hospital h.[31]

$RAMR_{h,\,t-2}$ is the risk-adjusted mortality rate for CABG at hospital h during the two calendar years prior to year t. Including *RACR* and a *current-year* value of *RAMR* in the same regression would create problems in terms of causality, as a hospital that performs CABG more frequently may have higher quality due to potential volume-outcome effects. To avoid such endogeneity, this regression uses only lagged quality information. Given the relatively low frequency of in-hospital mortality, I use the 24-month average value of the RAMR with the goal of reducing the noise associated with this measure. In accordance with the base assumption that PTCA quality does not differ in a measurable manner across hospitals, the specification in (3) does not include the PTCA RAECR. Later extensions of the basic model relax this assumption by incorporating a measure of PTCA quality.

$ROS_{h,\,t-2}$ is the return on sales at hospital h over the two-year period ending in year t. It is defined as the ratio of net income to net patient revenue (after discounts), where both the numerator and denominator are obtained from a hospital's Medicare Cost Report. It is included to control for the possibility that, given the higher margin for CABG relative to PTCA, a less

[29] The New York State Department of Health (n.d.) provides the following caveat with respect to the use of the indicator for chronic obstructive pulmonary disease (COPD) for risk adjustment: "Prior to 1993, the definition used for COPD was considered subjective, and irregular frequency distributions across institutions were noted. The definition was changed in 1993 to include documentation of objective clinical criteria. However, the wide range in COPD rates reported across hospitals remains, presumably due to practice patterns among various providers with regard to utilizing objective testing for COPD."

[30] The 29 hospitals represented in the sample exclude two facilities—one that offered only PTCA during the sample period and another whose PTCA program was placed on probation by New York State for some portion of the sample period. There are only 86, rather than 87, observations in the sample because one hospital's CABG program shifted from a predecessor facility to its current location in 1992. As a result, the lagged CABG mortality variable ($RAMR_{h,\,t-2}$) is missing for this facility in 1993 and that observation is dropped from the sample.

[31] As noted in Table 4, each observation is weighted by the total number of revascularization cases (i.e., CABG plus PTCA) for a given hospital-year to account for differences in the total number of procedures appearing in the denominator of each hospital's rate. The results of the unweighted version of the model are very similar to those in Table 4.

Table 3 Descriptive Statistics for Key Independent Variables

Independent variable	Obs	Mean	Standard deviation	Min	Max
CABG citations/100, 1969–1992	86	1.99	2.59	0	10.2
PTCA citations/100, 1969–1992	86	0.72	1.61	0	7.1
Return on sales (prior 2 years)	86	0.6%	2.8%	−8.2%	9.3%
CABG observed mortality rate (prior 2 years)	86	2.9%	0.8%	1.0%	4.8%
CABG RAMR (prior 2 years)	86	2.9%	1.1%	1.3%	6.6%
PTCA RAECR (prior 1 year)	58	1.8%	0.8%	0.4%	4.1%
ln(total annual discharges)	86	10.02	0.42	9.27	10.7
Teaching hospital	86	79.1%	40.9%	0	1
Population density (000s/square mile)	86	22.4	23.2	0.3	53.6
Medicaid (as % of total discharges)	86	20.4%	14.9%	1.3%	65.6%
Medicare (as % of total discharges)	86	30.0%	9.6%	11.2%	58.6%
HMO (as % of total discharges)	86	11.2%	10.9%	0.0%	39.4%
Medicaid HMO (as % of total discharges)	86	0.5%	1.0%	0.0%	4.8%

profitable hospital might face incentives for the more aggressive use of surgery.

The vector $z_{h,t}$ introduces several controls for the demographic and organizational characteristics of each hospital. These include the percentage of all inpatients insured by Medicaid, Medicare, an HMO, or a Medicaid HMO, respectively, as well as controls for the size of the hospital (measured by the log of annual total discharges) and the size of the hospital's cardiac program (measured by the log of annual AMI and IHD discharges). In addition, $z_{h,t}$ contains the population density—measured in thousands of residents per square mile—of the county in which a hospital is located. This variable accounts for the possibility that the relative rates of CABG and PTCA may depend on the speed at which information is transmitted across providers and that this speed should increase with population density. Finally, $z_{h,t}$ includes an indicator for teaching hospitals, which are defined as those facilities that are listed as members of the Council of Teaching Hospitals (COTH) in annual surveys conducted by the American Hospital Association (AHA).[32] This variable captures the degree to which innovations (in general) and cardiac innovations (in particular) diffuse faster or slower at teaching hospitals. Table 3 provides descriptive statistics for all key independent variables.

[32] This indicator is based on AHA data from 1994 and 1995 and is assumed to have a constant value for the period from 1993–1995.

The Impact of Key Independent Variables

Technological Status. Table 4 presents estimates of (3) by severity level. The results provide strong support for the hypothesis that hospitals with higher technological status for CABG are more likely, ceteris paribus, to use to CABG relative to PTCA. For all three severity levels, this result is illustrated by the positive and significant coefficients on CABG citations. While negative for both medium- and high-severity patients, the coefficient on PTCA citations is statistically significant at conventional levels only for the high-severity group.[33] As is the case in all remaining tables of this paper, the standard errors in Table 4 are clustered by hospital to address the potential lack of independence among annual observations for a particular facility.

For ease of interpretation, the lower portion of the table provides the weighted-average value of the dependent variable as well as the impact of increasing each of status proxies by one standard deviation. Of

[33] Adding quadratic terms somewhat improves the explanatory power of the regression for medium-severity patients, but reduces the adjusted R^2 for the low- and high-severity groups. The coefficients on both the linear and quadratic terms for CABG citations are positive for all severity levels. While the individual coefficients are not significant at conventional levels, F-tests suggest that the linear and quadratic terms for CABG are jointly significant at the 1% level. For PTCA citations, the linear term is negative and the quadratic term is positive for all specifications. These effects are jointly significant at the 5% level for low- and medium-severity patients.

Table 4 Regression of RACR on Citation Measures and Controls

	Dependent variable: RACR Severity level		
	Low (1)	Medium (2)	High (3)
CABG citations/100, 1969–1992	0.0047*	0.0199***	0.0092***
	(0.0023)	(0.0064)	(0.0025)
PTCA citations/100, 1969–1992	0.0029	−0.0048	−0.0055**
	(0.0024)	(0.0115)	(0.0025)
Return on sales (prior 2 years)	−0.0061***	−0.0122***	−0.0038*
	(0.0018)	(0.0039)	(0.0020)
Year = 1993?	−0.0002	0.0106	0.0276*
	(0.0082)	(0.0230)	(0.0144)
Year = 1994?	0.0000	0.0051	0.0231***
	(0.0058)	(0.0148)	(0.0087)
CABG RAMR (prior 2 years)	0.0068	0.0158	0.0045
	(0.0062)	(0.0153)	(0.0051)
ln(AMI/IHD discharges)	0.0315	0.0837	0.0250
	(0.0293)	(0.0610)	(0.0188)
ln(total annual discharges)	−0.0398	−0.1623**	−0.0340
	(0.0238)	(0.0736)	(0.0254)
Teaching hospital?	0.0092	0.0235	0.0094
	(0.0079)	(0.0300)	(0.0183)
Population density (000s/sq. mile)	−0.0009***	−0.0026**	−0.0008*
	(0.0003)	(0.0011)	(0.0004)
Medicaid (as % of total discharges)	0.0005	0.0027	0.0012
	(0.0006)	(0.0021)	(0.0007)
Medicare (as % of total discharges)	−0.0007	−0.0024	0.0004
	(0.0010)	(0.0034)	(0.0012)
HMO (as % of total discharges)	0.0004	0.0018*	0.0011
	(0.0004)	(0.0010)	(0.0008)
Medicaid HMO (as % of total discharges)	−0.0013	0.0044	0.0033
	(0.0044)	(0.0192)	(0.0091)
Constant	0.2084	1.3315*	0.9220***
	(0.2009)	(0.7017)	(0.2348)
Weighted average value of dependent variable	0.048	0.360	0.847
Impact of 1 SD increase in CABG citations	0.012	0.052	0.024
Impact of 1 SD increase in PTCA citations	0.005	−0.008	−0.009
Observations	86	86	86
R^2	0.36	0.52	0.50
Adjusted R^2	0.23	0.43	0.40

Notes. Standard errors (in parentheses) are heteroskedasticity robust and clustered by hospital. All observations are weighted by the number of revascularization cases (i.e., CABG plus PTCA) for the relevant severity level. The impact of increasing various independent variables by one standard deviation captures the effect of relevant coefficients regardless of their statistical significance.

*, **, ***Denote statistical significance at the 10%, 5%, and 1% levels, respectively.

particular interest is how the effect of status proxies on RACR varies across the three severity levels. The coefficient for the middle group is more than twice that for the high group and over four times that for the low group. The incremental effects suggest that an increase of one standard deviation in CABG citations raises the RACR by 5.2 percentage points for medium-severity patients; for high-severity patients, this effect is only 2.4 percentage points. This difference is striking when one considers that the mean RACR for medium-severity patients is 36%, less than one-half the rate of 85% for high-severity individuals. Thus, one standard deviation change in CABG citations increases the adjusted CABG rate for medium-severity patients by 14% relative to the mean value; for the high group, this increase is less than 3%. By comparison, the effect of changes in PTCA citations is relatively small in magnitude across all specifications. The difference in the magnitude of effects for CABG and PTCA publications may stem from the fact that the former measure presents a more continuous distribution than the latter. Specifically, the CABG citation variable has a nonzero value for 22 of the 29 hospitals in the sample; for the PTCA variable, only 15 hospitals have nonzero values.

While small in absolute magnitude, the incremental effect for low-severity patients is very large relative to the weighted, average RACR. Nevertheless, the regressions for the low-severity group must be interpreted with caution, as the average severity of patients in the low group may differ across hospitals depending on the frequency with which low-severity patients are referred for *any* revascularization. For example, cardiologists at Hospital A may choose to recommend neither CABG nor PTCA for patients with single-vessel disease, while those at Hospital B refer such patients routinely for PTCA. In such a case, the CABG (PTCA) rate at Hospital A would be greater (less) than that at Hospital B, even though both hospitals might use PTCA at similar rates *conditional on patient severity*. For the medium and high categories, this selection is less concerning, because more severe patients are likely to receive some form of revascularization regardless of hospital-specific practice patterns.

Overall, the effect of technological status is largest for middle-severity patients. This finding is consistent with the fact that the margin between CABG and PTCA appears to fall within this portion of the severity distribution. As suggested by Table 2, there is a fair degree of consistency across hospitals with respect to the choice of CABG over PTCA for patients at the extremes of the severity continuum (i.e., the low and high groups). Thus, one would not expect nonclinical factors, such as technological status, to affect treatment patterns as substantially for these patients as for those with medium-severity CAD.

Actual Procedure Quality. Perhaps surprisingly, the coefficient on CABG RAMR is positive in all specifications in Table 4, though it is not significant in any model. Lower average CABG quality at a given hospital thus does not appear to reduce future use of the procedure at that facility. There are several potential explanations for the nonnegative relationship between RAMR and RACR.[34] The most likely—and the only one that I can test using these data—is that it may simply reflect incomplete risk adjustment. Even with the extensive clinical information used in this study, there may remain some heterogeneity among patients that is observed by physicians but not reflected in the data. To the extent that referring cardiologists send patients who are more severe along these unobserved dimensions to hospitals that are known to be more intensive users of CABG, one would predict a positive coefficient on RAMR. If true, this explanation would suggest that the positive correlation between RAMR and RACR reflects the sorting of high-risk cases to hospitals that perform CABG more frequently independent of issues concerning technological status.[35]

To test for the presence of incomplete risk adjustment, I reestimate the basic regression replacing

[34] A second story would attribute the nonnegative coefficient on RAMR to an income effect on the part of surgeons who lose revascularization volume due to low quality in prior years. A third explanation of the quality result is the "high-risk rejection" story—that physicians or hospitals experiencing low reported quality in a given year will attempt to improve their outcomes by operating on a less severe mix of patients (Leventis 1998). Such an explanation may have been relevant in New York State during the mid-1990s, as the state began to publicly report CABG outcomes by hospital in 1990 and by physician in 1992 (Chassin et al. 1996).

[35] If hospitals that perform CABG more frequently are better equipped to handle high-risk patients, this sorting would improve patient welfare (Dranove et al. 2002).

RAMR with the *observed* mortality rate (OMR). The hypothesis of incomplete risk adjustment would predict that the coefficients on OMR should be positive and of greater magnitude than those on the RAMR variable. This is because OMR is equivalent to the RAMR in the case where *all* heterogeneity is unobserved. Table 5 shows that the coefficient on OMR is *smaller* than that on RAMR—and is actually insignificantly negative—across all severity levels. The use of observed CABG quality (as opposed to risk-adjusted CABG quality) also has relatively little impact on the relationship between the status proxies and RACR.[36]

Hospital Profitability. Across all severity levels in Table 4, the coefficient on lagged profitability is negative and significant at least at the 10% level. The fact that lower profitability is correlated with higher rates of CABG relative to PTCA could be due to several factors. Again, it is possible that the negative coefficient on profitability simply reflects unobserved heterogeneity across hospitals. Nevertheless, one would imagine that the broad array of hospital-level variables included in the regressions (i.e., teaching status, payer mix, overall size, location in New York State) should mitigate concerns about bias. An alternative explanation is that hospitals might view increased CABG intensity as a means of boosting financial performance. As is the case with the measures of technological status, the impact of profitability is greatest for patients with medium-severity CAD. This result again suggests that the effect of nonclinical factors on treatment choice appears to be most substantial for patients near the severity margin between CABG and PTCA. Further analysis is required to make definitive statements concerning the link between hospital profitability and technological choice.

Robustness and Extension of Basic Findings

Models with CABG and PTCA Quality Measures. Interpretation of the CABG RAMR coefficient in the initial regressions is complicated by the fact that CABG and PTCA quality may be correlated to varying degrees across hospitals.[37] To address this concern, I relax the assumptions of the basic regression and reestimate (3) with separate measures of CABG and PTCA quality. The sample size in this final specification is reduced by one third, however, because the lagged quality measure for PTCA is only available for two years—1994 and 1995. In addition, because of limited data availability, the PTCA RAECR is the average for only *one* year prior to year t. Columns 1 through 3 of Table 6 illustrate that, with respect to the citation measures, the results from the basic regression with CABG RAMR alone are quite robust to the addition of the PTCA RAECR. One notable change in the controls is that the coefficients for CABG RAMR—which are still positive—are now significantly different from zero for low- and medium-severity patients. The impact of the PTCA RAECR is positive in all models—suggesting that lower PTCA quality is correlated with reduced PTCA use—though is not significant for any level of severity. Again, these results should be interpreted with caution, as the PTCA RAECR may represent a fairly weak measure of PTCA quality.

Addressing Potential Endogeneity. Despite the large number of patient- and hospital-level controls incorporated into the analysis thus far, one might still be concerned that the coefficients on CABG and PTCA citations are biased by residual endogeneity because of unobservable factors that are correlated with both the citation measures and the error term in (3). For example, patients likely do not arrive at hospitals randomly; a hospital that has a lot of CABG citations may be viewed by doctors or patients as a "CABG-intensive" institution and may be selected by patients who have unobserved preferences for CABG over PTCA. While this may be due to technological status, it may also be caused by other factors. To address this issue, I estimate a version of (3) using patients who arrive at hospitals roughly exogenously—AMI patients admitted through the emergency room. These individuals typically do not choose a particular hospital, but are rather transported to the nearest facility with an emergency room.

[36] Exclusion of CABG quality altogether yields results that are very similar to those using either observed or risk-adjusted CABG quality.

[37] The correlation between the two-year lagged average of RAMR and the one-year lagged average of RAECR is 0.20.

Table 5 Sensitivity of the Basic Model to Using Observed Measures of Procedure Quality

	Dependent variable: RACR Severity level		
	Low (1)	Medium (2)	High (3)
CABG citations/100, 1969–1992	0.0050**	0.0217***	0.0102***
	(0.0022)	(0.0064)	(0.0025)
PTCA citations/100, 1969–1992	0.0044	−0.0003	−0.0037
	(0.0028)	(0.0118)	(0.0025)
Return on sales (prior 2 years)	−0.0059***	−0.0116**	−0.0033
	(0.0021)	(0.0047)	(0.0021)
Year = 1993?	0.0061	0.0287	0.0349***
	(0.0079)	(0.0227)	(0.0130)
Year = 1994?	0.0015	0.0105	0.0256***
	(0.0057)	(0.0157)	(0.0089)
CABG observed mortality rate (prior 2 years)	−0.0052	−0.0204	−0.0106
	(0.0044)	(0.0188)	(0.0094)
ln(AMI/IHD discharges)	0.0233	0.0658	0.0199
	(0.0283)	(0.0602)	(0.0174)
ln(total annual discharges)	−0.0406	−0.1699**	−0.0380
	(0.0245)	(0.0758)	(0.0257)
Teaching hospital?	0.0127	0.0380	0.0169
	(0.0080)	(0.0315)	(0.0226)
Population density (000s/sq. mile)	−0.0009**	−0.0028**	−0.0009*
	(0.0004)	(0.0012)	(0.0004)
Medicaid (as % of total discharges)	0.0005	0.0028	0.0013*
	(0.0006)	(0.0021)	(0.0007)
Medicare (as % of total discharges)	−0.0007	−0.0026	0.0003
	(0.0010)	(0.0036)	(0.0012)
HMO (as % of total discharges)	0.0005	0.0023*	0.0013*
	(0.0004)	(0.0012)	(0.0007)
Medicaid HMO (as % of total discharges)	−0.0015	0.0041	0.0036
	(0.0042)	(0.0174)	(0.0081)
Constant	0.3045	1.6209**	1.0312***
	(0.1942)	(0.7386)	(0.2453)
Weighted average value of dependent variable	0.048	0.360	0.847
Impact of 1 SD increase in CABG citations	0.013	0.056	0.026
Impact of 1 SD increase in PTCA citations	0.007	0.000	−0.006
Observations	86	86	86
R^2	0.34	0.52	0.51
Adjusted R^2	0.21	0.43	0.41

Notes. Standard errors (in parentheses) are heteroskedasticity robust and clustered by hospital. All observations are weighted by the number of revascularization cases (i.e., CABG plus PTCA) for the relevant severity level. The impact of increasing various independent variables by one standard deviation captures the effect of relevant coefficients regardless of their statistical significance.

*, **, ***Denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 6 Robustness of the Basic Model

	Dependent variable: RACR			
	Severity level			Emergency AMI
	Low (1)	Medium (2)	High (3)	(4)
CABG citations/100, 1969–1992	0.0027	0.0154**	0.0104***	0.0081***
	(0.0021)	(0.0069)	(0.0028)	(0.0028)
PTCA citations/100, 1969–1992	−0.0015	−0.0194	−0.0090**	0.0010
	(0.0034)	(0.0160)	(0.0040)	(0.0052)
Return on sales (prior 2 years)	−0.0057***	−0.0103**	−0.0044*	−0.0021
	(0.0016)	(0.0049)	(0.0024)	(0.0022)
Year = 1993?				0.0283**
				(0.0131)
Year = 1994?	−0.0050	−0.0063	0.0181*	0.0103
	(0.0072)	(0.0192)	(0.0096)	(0.0080)
CABG RAMR (prior 2 years)	0.0182**	0.0514**	0.0060	0.0039
	(0.0082)	(0.0201)	(0.0091)	(0.0065)
PTCA RAECR (prior 1 year)	0.0077	0.0206	0.0095	
	(0.0048)	(0.0191)	(0.0062)	
ln(AMI/IHD discharges)	0.0275	0.0864	0.0392***	0.0761***
	(0.0197)	(0.0526)	(0.0144)	(0.0260)
ln(total annual discharges)	−0.0283	−0.1538**	−0.0519**	−0.1083***
	(0.0250)	(0.0763)	(0.0242)	(0.0323)
Teaching hospital?	−0.0086	−0.0180	0.0007	0.0016
	(0.0107)	(0.0325)	(0.0186)	(0.0215)
Population density (000s/sq. mile)	−0.0003	−0.0008	−0.0008	0.0002
	(0.0003)	(0.0015)	(0.0005)	(0.0006)
Medicaid (as % of total discharges)	−0.0003	0.0013	0.0016**	0.0009
	(0.0005)	(0.0023)	(0.0008)	(0.0009)
Medicare (as % of total discharges)	−0.0016	−0.0043	−0.0006	−0.0024
	(0.0010)	(0.0035)	(0.0011)	(0.0014)
HMO (as % of total discharges)	−0.0001	0.0011	0.0010	0.0009
	(0.0003)	(0.0010)	(0.0008)	(0.0008)
Medicaid HMO (as % of total discharges)	−0.0025	−0.0012	0.0007	0.0014
	(0.0041)	(0.0225)	(0.0096)	(0.0096)
Constant	0.1405	1.2144*	1.0128***	1.4483***
	(0.2240)	(0.6847)	(0.2285)	(0.3096)
Weighted average value of dependent variable	0.047	0.354	0.843	0.934
Impact of 1 SD increase in CABG citations	0.007	0.040	0.027	0.021
Impact of 1 SD increase in PTCA citations	−0.002	−0.031	−0.014	0.002
Observations	58	58	58	86
R^2	0.46	0.59	0.63	0.31
Adjusted R^2	0.28	0.45	0.51	0.18

Notes. Standard errors (in parentheses) are heteroskedasticity robust and clustered by hospital. All observations are weighted by the number of revascularization cases (i.e., CABG plus PTCA) for the relevant severity level. The impact of increasing various independent variables by one standard deviation captures the effect of relevant coefficients regardless of their statistical significance.

*, **, ***Denote statistical significance at the 10%, 5%, and 1% levels, respectively.

The CSRS and CARS data do not identify a patient's source of admission and cannot be used for the AMI analysis. As a result, I use the SPARCS database to select all patients who are admitted to the hospital via the emergency room with a primary diagnosis of AMI and receive either CABG or PTCA during that admission.[38] I repeat the process used to calculate the RACR from (2) on these data, though the covariates for use in risk adjustment are limited to a patient's age, age-squared, and gender. Further, without access to the detailed covariates present in the CSRS and CARS data, these patients cannot be assigned to the three separate severity groups. Nevertheless, the fact that over 90% of these patients receive CABG rather than PTCA suggests that they tend to be of homogenously high severity, thereby reducing the need for additional risk adjustment.

Column 4 of Table 6 shows the results of estimating (3) using the RACR for AMI patients admitted through the emergency room. The results are similar to those presented in Table 4. The coefficient on CABG citations is positive and significant at the 1% level, while that for PTCA citations is positive, but insignificant. Based on the severity of these patients' conditions, it is not surprising that the magnitude of this effect is similar to that identified for high-severity patients in Table 4.

The above findings suggest that unobserved factors that might cause patients to pick particular hospitals do not appear to bias the results from the initial specification in Table 4. Nevertheless, there may still be other sources of endogeneity in these regressions. For example, a given hospital may simply value the work of its surgeons more than that of its cardiologists (or vice-versa). The regressions control for many of the key factors that might drive this difference in the way in which the work of the two groups is valued (e.g., differences in the actual quality for each procedure, hospital demographics, hospital financial condition, hospital teaching status). Despite the above evidence suggesting that several obvious sources of bias do not appear to affect the basic findings, one cannot dismiss the possibility of some degree of residual endogeneity.[39]

[38] Using the SPARCS data, I am able to estimate this logistic regression using all patients from 1992–1998, rather than just 1993–1995.

6. Conclusion

This paper examines the impact of the technological status on the use of competing technologies within the firm. The two technologies—CABG and PTCA—are partial substitutes, each of which requires a distinct set of physical and human assets. As such, opportunities for substitution occur only at the level of the hospital, not at that of the individual physician. The "turf war"—whether explicit or implicit—between these techniques within many hospitals is well documented.

The technologies considered in this paper are suited to the development of bibliometric proxies for status using data on academic citations. The impact of these proxies on technological choice is examined in the presence of controls for the severity of patients, the actual quality of the two procedures at a given facility, and several hospital-level characteristics. After accounting for the impact of these controls, I find evidence of higher CABG rates in hospitals where CABG enjoys relatively high technological status compared to PTCA. This effect is robust to multiple specifications and is particularly strong for patients with medium-severity CAD, who likely are near the severity margin between CABG and PTCA.[40]

[39] I consider one other potential explanation for the observed positive correlation between the relative technological status of CABG and CABG use. Given that PTCA diffused among hospitals significantly later than CABG, it is possible that this result is driven by later adoption of PTCA at hospitals with high levels of CABG status. As a result, one might argue that high CABG rates at these later adopters may simply be due to the transition to equilibrium levels of PTCA use. At first glance, this seems unlikely given the previously noted fact that 26 of the 29 hospitals in the sample had adopted PTCA by 1986 (i.e., seven years before the beginning of the sample period for this analysis). Nevertheless, I reestimate the basic regression including both linear and quadratic terms for the number of years since PTCA had been introduced at a given hospital. The basic results are robust, in terms of both magnitude and significance, to the inclusion of this variable.

[40] As a cautionary note, I emphasize that the welfare implications of entrenched CABG utilization are not clear and require further study. To the extent that outcomes for CABG and PTCA are sim-

While this study considers a particular medical application, it provides insight into what may be a more general process surrounding competing innovation that can be tested in other settings (e.g., selection of information or production technologies). Further, whereas many previous studies view technological choice as a single decision made at the firm level, this paper suggests that the degree to which competing technologies are used by a firm in equilibrium may actually result from a competition between technological groups, or constituencies, within the firm. This competition may be resolved on the basis of several "objective" criteria, such as the characteristics of customers or the actual quality of the products produced by each technology. To this list, this study adds the importance of more subjective criteria such as the status that each technology—and the group of users associated with it—holds within a given organization.

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ilar, the welfare impact of using one technology more frequently than the other depends on a comparison of costs. If outcomes differ, then one should consider the *cost per unit of long-run benefit*. Completing this analysis thus will require a clearer consensus with respect to the long-run (i.e., post-discharge) benefits and costs of CABG versus PTCA for patients with medium-severity CAD.

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