The Diffusion of Abandonment Decisions:
An application to pulmonary artery catheters

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I. BACKGROUND

This paper studies the abandonment of technology in reaction to information shocks. While the diffusion of new technologies has been widely researched, the reverse is less well understood. The deficient knowledge of the factors driving abandonment is particularly problematic in the health care sector, where curbing overuse of redundant or dangerous technologies is a high priority. Using the abandonment of pulmonary artery (PA) catheters as an empirical application, this paper aims to understand patterns of human behavior when information becomes available that suggests that a technology is ineffective. This study is the first of its kind to propose a mechanism for characterizing abandonment based on peer to peer information transfer.

II. LITERATURE

II.1. Abandonment

The economics literature contains little theory on behavioral patterns of abandonment. The most significant contributions come from the field of agricultural economics but findings have not been generalized. These studies focus on the adoption and subsequent abandonment of farming technologies or processes. Walton (2008) constructs a model in which a farmer faces an initial discrete choice to adopt a technology based on a preliminary estimates of cost versus profit and a successive choice to abandon after realizing true costs and profits. Uematsu et al (2010) expand on this by estimating the probability of adoption, retention, and abandonment at a given point in time. Läpple (2010) uses a hazard function to model the likelihood of abandoning organic farming given the length of survival time since adopting and a set of parameters to account for differential characteristics. Each of these papers treats abandonment as a one-time decision that is not reversible. This limits the applicability to health care settings where physicians often taper use of a procedure overtime rather than instantaneously.

More relevant to the application explored in this paper is the growing literature on abandonment of technologies by physicians. These aim to understand the characteristics of hospitals or physicians that change their behavior in response to new research findings suggesting that a technology is ineffective. Empirical analyses by Duffy and Farley (1992) and Howard (2011, 2012, 2013) demonstrate that high profile clinical trials and recommendations can lead to abandonment and cost savings but that abandonment is not uniform.[1] Howard et al (forthcoming) applied the theory of supplier induced demand to show that providers at physician-owned surgery centers abandoned a common knee surgery at a lesser rate than peers practicing in hospitals after a trial indicated ineffectiveness. While focusing on peer-to-peer interactions rather than supplier induced demand, our paper aims to contribute to the health care abandonment literature in a way that is generalizable to the wider economics literature.

II.2. Adoption

The literature on adoption after diffusion of new information is highly saturated and has many potential applications to abandonment. The decision to abandon a technology given the spread of new information conceptually mirrors the decision to adopt a technology under new information. Diffusion of innovation is typically modeled in the literature as an s-shaped curve (Rogers 1962). The s-curve is simply the cumulative distribution function of adopters overtime if individuals' propensity to adopt is characterized by a normal distribution. Most of the literature that follows models some derivation of the s-curve.

The most relevant adoption models to our application are those characterizing diffusion in social networks. Herding models are the most basic theories in this category. Banerjee (1992) describes a

[1] Duffy and Farley (1992) show that ownership, teaching status, location, payer mix, and volume all influence a physician's probability of abandoning intermittent positive pressure breathing. Howard (2011) finds that teaching status, ownership, and make-up of a health system do not influence relative rates of abandonment in the case of percutaneous coronary intervention (PCI) after the COURAGE trial. Howard (2012) shows a 47% decline in arthroscopic debridement and lavage surgical treatments after a negative trial results were published in the New England Journal of Medicine. Howard (2013) shows a 7.9% decline in prostate testing rates among men ages 75+ after the US Preventative Services Task Force recommended against screening.

herding model as a game with two empty restaurants. If a person randomly chooses to eat at restaurant one and the second person to walk by has no prior information, he will also eat at restaurant one because it is busier. If the third person to walk by has private information that restaurant two is better, he may choose to ignore this information in order to follow the herd. Thus herding causes agents to ignore information, causing convergence towards inefficient equilibria.

While herding is a real occurrence, in many instances individuals incorporate their own experiences with the experiences of those in their networks. Bala and Goyal (1998) model a network in which agents are aware of the payoffs of their own actions as well as the payoffs of the actions of others. Assuming each action is chosen enough times by some agent, the true payoffs of each action will be revealed overtime and society will converge to an efficient equilibrium. Golub and Jackson (2010) describe a similar network, except information is aggregated through discrete communication using the DeGroot (1974) model of consensus. By the DeGroot model, an individual's beliefs in period two is the weighted average his and his neighbors' period one beliefs. Golub and Jackson assume that agents' initial beliefs are based on noise around a correct mean. Thus, updating information overtime will lead to a network equilibrium that converges to the true mean.

II.3. Application to Abandonment

Young (2009) examines three theories of diffusion—contagion, social influence, and social learning—in a manner that is concretely applicable to abandonment decisions. In a contagion model, adoption spreads much like an epidemic. An individual adopts simply because he comes into contact with someone who has adopted. In social influence models, individuals adopt once the number of adopters around them has crossed a certain threshold. Social learning models take social influence models one step further: agents now adopt once they believe the benefit of the innovation has crossed a certain threshold based on observations of the experience of early adopters. Bala's and Goyal's model is an example of social learning.

Of Young's models, social learning model is the most closely adaptable to an abandonment model. Young begins by defining $r(t)$ as a cumulative measure of the information generated by adopters at a given time, t:

$$r(t) \ = \int_0^t p(s)ds$$

$r(t)$ will grow overtime as more adopters contribute information about the value of the innovation. While this is the sum all information known to society, the portion of this information an individual differs based on a measure of social connectivity, B_i. Each agent has a response function $\phi_i(r)$ denotes the probability that an agent will adopt given the cumulative information of the experience of the adopters, $r(t)$. The response function is related to an individual's information threshold r_i:

$$r_i \ = \frac{\tau_i(c_i - \mu_{i0})}{B_i(\mu - c_i)}$$

The information threshold depends on five parameters. Young defines μ as the average payoff from using the innovation as compared to the status quo technology and μ_{i0} as each agents' initial beliefs about the value of the technology. These beliefs are somewhat arbitrary given that, by definition, neither the agent nor the agent's peers has used the technology when μ_{i0} is established. The cost of the innovation to each individual is given as c_i. Thus $c_i - \mu_{i0}$ is the initial perceived cost of adoption to the individual and $\mu - c_i$ is the actual benefit of adoption. If the ratio of these two measures is high (ie, there is high perceived cost and low actual benefit), the individual will have a high information threshold for adoption. This ratio is further influenced by two measures. Individuals become more likely to adopt if τ_i, a measure of flexibility, is low. Agents with low τ_i will change their behavior based on a small amount of information. Finally, individuals with a high B_i, the aforementioned measure of social connectedness, are more likely to adopt. Agents with a higher B_i will have more interactions with adopters and will thus have more information with which to update their prior beliefs. When the cumulatively generated information, $r(t)$, exceeds the information threshold, r_i, an agent will be more likely to adopt. The actual point at which the agent adopts is a function of $\phi_i(r)$. Plotting the sum of $\phi_i(r)$ for all i over r yields an s-shaped curved typical of diffusion theory.

While these models of diffusion were designed to simulate adoption patterns, there exists great potential to adapt them to abandonment by reinterpreting a few parameters. Given that agents have prior experience using the technology in the abandonment scenario, μ_{i0} will be based on prior experience with the old technology rather than a random perception of a new technology. The parameter, $r(t)$, will be the cumulative information on the effects of abandonment based on academic literature and experiences of those who have already abandoned. As in Young's adoption model, $r(t)$ is the cumulative experience for *all* society, but only a portion of this information may have reached any given physician.

The following empirical analysis will be most concerned with the parameter measuring social connectivity, B_i. Agents who use a technology can be characterized by varying levels of social connectivity based on the community to which they belong. Communities with a high B_i would be the first to learn new information and would be more likely to be aware of early abandoners. In our application to PA catheters, physicians practicing at a teaching hospital might have a high initial B_i. As shown in Young's model, agents with a high B_i will have a lower information threshold, r_i, and will likely be among the earliest group to abandon. Agents with a lower initial B_i will be less aware of the cumulative information on abandonment available in society and have a higher information threshold to reach before abandoning. For instance, these could be physicians at remote rural hospitals.

This paper contends that a sudden shock that increases B_i will cause agents with an initially high information threshold, r_i, to abandon a previously used technology. In our empirical analysis, this sudden increase in social connectivity occurs when a physician who is aware of current best-practices regarded the use of a technology enters a hospital where physicians were previously less aware.

III. EMPERICAL ANALYSIS

III.1. Application

To study the importance of changes in team composition on abandonment and its pace, our analysis focuses on the abandonment of pulmonary artery (PA) catheters for use during Coronary Artery Bypass Graft (CABG) surgery over the past twenty years. A PA catheter (also known as Swan-Ganz or right heart catheter) is a catheter inserted into the right side of the heart in order to measure hemodynamic data for critically ill patients. PA catheters were designed to provide physicians with cardiac output and additional information in order to monitor at risk patients and ultimately decrease mortality. As the functionality of PA catheters is conceptually appealing, they were rapidly adopted upon becoming available in the 1970s. Robin (1985) was the first article to question the use of the technology, citing the rapid adoption of the procedure without randomized control trials (RCTs). However, RCTs could not be conducted at that time of Robin's article because physicians considered it unethical to deprive randomly selected patients of a potentially life-saving intervention. In 1996, Connors et. al. published a retrospective observational study using matched cohorts that found a significant increase in mortality and increase in cost among patients who received a pulmonary artery catheter. This was accompanied by an influential letter in the Journal of the American Medical Association (JAMA) calling for an immediate clinical trial or removal of pulmonary artery catheters from hospitals altogether (Dalen 1996). This information shock is considered in the literature as a turning point for the use of PA catheters. An analysis by Wiener and Welch (2007) shows a 65% decline in pulmonary artery catheter use for surgical patients between 1993 and 2004.[2] As the use of PA catheters became disputed, five RCTs were performed in rapid

[2] Wiener and Welch (2007) use joinpoint regression analysis to isolate 1996 as the year when a statistically significant change in PA catheter usage trend first occurs, consistent with the release of Connors' article. However, they mention that lesser abandonment trends are visible prior to 1996 and hypothesize that Connors' findings began to disseminate in 1994 when he presented the abstract at the American Thoracic Society conference.

succession. All five RCTs showed that the use of PA catheters yielded no benefit for patients (Rubenfeld 2007).[3]

There are a number of reasons why PA catheters are an ideal application for studying the mechanisms underlying the abandonment of medical technology. First, abandonment was triggered by a well-documented information shock, as described in previous literature. Because the shock occurred early on in the data, we are able to measure the decline over an extended period of time. Second, it is reasonable to assume that a thoracic surgeon's hiring is orthogonal to his or her rate of PA catheter use. If, for instance, hospitals hired surgeons who matched their hospital rate of PA catheter use, there would be little or no room to have entry influence incumbent surgeons' behavior. Put differently, entry is unlikely to be endogenous to the entrant's rate of PA catheter use. PA catheter use, unlike CABG, is not an intervention upon which hospitals built their reputation. The third reason to study the abandonment of PA catheters is that reimbursement rates were not affected by the information warning against PA catheter use. Changes in reimbursement by public and commercial insurers may affect centralized decision making. In particular, reduction or elimination of reimbursement may lead hospitals to make PA catheters less accessible to their physicians. As reimbursement was not affected and its revenue was negligible in comparison to the reimbursement for a CABG surgery, the decision to abandon its use was left to the individual physician. This in part can explain the considerable variation across surgeons within hospitals and over time in PA catheter use. For these reasons, the abandonment of PA catheters allows for credibly identifying the impact of surgeons' hiring as a mechanism for both information dissemination and the altering of practice style by veteran surgeons.

III.2. Data

This analysis uses Florida hospital inpatient discharge data for the years 1992 to 2011. The data come from the Florida Agency for Healthcare Administration (AHCA) and contain 100 percent of inpatient discharges for that time period. Current Procedural Terminology (CPT) codes were used to

[3] For clinical trials, see Richard (2003), Sandham (2003), Binanay (2005), Harvey (2005), and Wheeler (2006).

identify all CABG surgeries performed in the data. For each CABG surgery, we indicate whether or not a patient received a PA catheter. Our data was then linked to the Florida Department of Health's Health Care Practitioner data to identify location and timing of each physician's medical training. The data allows for tracking physicians and hospitals overtime using Florida provider license numbers and CMS Certification Numbers respectively.

The data contains 427,690 hospital admissions involving a CABG surgery, performed by 398 different physicians between 1992 and 2011. Of these, 48,874 patients (11.4 percent) received a PA catheter during surgery. To be included in the study sample, a physician needs to have performed five or more annual CABG surgeries in at least one year of the data and have reported a fellowship in thoracic surgery in the Florida AHCA database. For physicians who completed a fellowship in general surgery only, a minimum of 20 CABG surgeries in at least one year of the data were performed to have the physician included in the data. This inclusion criteria resulted in omitting 9% of CABG surgeries, performed by 4,114 low volume physicians (91.2% of all physicians with at least a single CABG surgery during our study period). .

In addition, we split our sample into physicians who were present prior to 1998, and new graduates who entered our Florida sample after 1998. The year 1998 is chosen as it nearly evenly splits our sample of physicians into the two groups. In particular, the sample of pre-1998 physicians, henceforth referred to as "veteran physicians," include 206 surgeons (51.8%) practicing in 57 hospitals. They performed a total of 194,722 CABG surgeries between 1998 and 2011, with 10 percent of patients received a PA catheter during their CABG surgery.

Figure 1 displays the trend in abandonment of PA catheters overtime in Florida from 1992 to 2011 for the full sample of physicians and the veteran sample of physicians. In 1998, the same set of physicians comprise both samples. Between 1992 and 1997, the full sample includes physicians who no longer practiced in Florida by 1998 and are not included in the veteran sample. After 1998, the full sample includes all veteran physicians plus all physicians who joined a hospital after 1998—whether directly from medical school or from a hospital outside of Florida.

The full and veteran samples show similar abandonment patterns. For the full sample, the use of PA catheters peaked in 1995 at a rate of 21 percent. After Connors' article (1996), PA catheter use declineed rapidly, falling below 10 percent by 2001 leveling at 5 percent by 2006. The veteran and full sample PA catheter usage was nearly identical prior to 1998. This indicates that the veteran sample is a representative sample of all physicians practicing prior to abandonment. From 1999 to 2008, the veteran PA catheter usage rate was slightly higher than the rate of the full sample, suggesting that the entering physicians used marginally fewer PA catheters on average than the veteran physicians. By 2009, this effect was no longer apparent.

Table 1 shows a preliminary breakdown of patients who do or do not receive a PA catheter for all physicians in the data set from 1992 to 2011 and for veteran physicians from 1998 to 2011. Patient characteristics are divided into two categories: demographics and high risk indicators. Available patient demographic information includes age, gender, and race. The six high risk indicators—having an emergency admission, heart failure, acute myocardial infarction, a prior heart valve replacement, a bypass of three coronary arteries, or a bypass of four or more coronary arteries—represent characteristics that may lead to more challenging CABG surgeries. These criteria are selected based on the American Society of Anesthesiologists' *Choosing Wisely* guidelines as well as physician input.

Table 1 shows significant differences in all categories between patients who did or did not receive a PA catheter using two sample t-tests or Pearson chi square tests. In terms of demographics, the populations look similar with Black patients being slightly less likely to receive a PA catheter in the 1992-2011 full sample and White Hispanic patients slightly more likely to receive a PA catheter in the 1998-2011 veteran sample. The high risk indicators suggest that patients with more complicated cases are slightly more likely to receive a PA catheter. In both samples, patients receive PA catheters at higher rates if they have heart failure or acute myocardial infarction or if they have a bypass of more than three vessels while patients receive fewer PA catheters if they have had a prior heart valve replacement. Patients who are admitted through the emergency room are less likely to receive a PA catheter in the full sample but more likely to receive one in the veteran sample. It is important to note that the significant differences in Table 1 may be driven by large sample size and are not necessarily meaningful. The following regression analysis will address this possibility.

We use a linear probability function to demonstrate that time trends remain consistent in both samples after controlling for patient characteristics and hospital and physician fixed effects. The model identifies the likelihood that a physician uses a PA catheter, $\boldsymbol{PAC_{ihjt}}$, given patient *i*, hospital *h*, physician *j*, and time *t*. The regressions are run using three specifications for each sample. In each, the variables of interest are $\boldsymbol{Y_t}$, a vector of dummy variables for years 1993 to 2011, with 1992 as the omitted year. Heteroskedasticity robust standard errors are calculated for each coefficient. Equation 1 shows the most saturated specification:

$$(1) \qquad \boldsymbol{PAC_{ihjt}} = \boldsymbol{\beta_0} + \boldsymbol{\beta_1} \boldsymbol{Y}_t + \boldsymbol{\beta_2 D_{it}} + \boldsymbol{\beta_3 R_{it}} + \boldsymbol{\beta_4 CM_{it}} + \boldsymbol{\mu_h} + \boldsymbol{\phi_j} + \varepsilon_{ihjt}$$

The additional variables are:

1. $\boldsymbol{D_{it}}$: A vector of patient demographic variables described in Table 1. These are included to account for the possibility that demographic characteristics of patients is driving the decision to use a PA catheter.
2. $\boldsymbol{R_{it}}$: A vector of patient high risk variables described in Table 1. These are included to account for the possibility that differential protocols for PA catheter use exist for patients displaying these specific attributes.
3. $\boldsymbol{CM_{it}}$: A vector of 30 dummy variables for Elixhauser comorbidities. Elixhauser comorbidities are a standard list of comorbidities published in *Medical Care* (1998) and used to control for patient severity across the healthcare literature. Examples are diabetes, stroke, and drug abuse.
4. $\boldsymbol{\mu_h}$: Hospital fixed effects. These are included to isolate time trends of PA catheter usage within hospitals.
5. $\boldsymbol{\phi_j}$**:** Physician fixed effects. These are included to isolate time trends of PA catheter usage for a given physician.

The results of these regressions are displayed in Table 2. Specifications 1a and 1b show the likelihood that a physician uses a PA catheter in comparison to a physician practicing in 1992 in the full and veteran samples. Given that no other variables are included in these specifications, these should model the same trends visually displayed in Figure 1. Specifications 2a and 2b add patient demographics, high risk factors, and Elixhauser comorbidities. The aim is to determine whether accounting for these impact the time trend. For instance, if patients were becoming less sick overtime and PA catheters were selectively used on high risk patients, this would cause the abandonment trend to be overstated. Specifications 3a and 3b add hospital and physician fixed effects. These specifications consider whether a given physician in a given hospital uses fewer PA catheters overtime. This accounts for the possibility that physicians who use a high number of PA catheters are leaving the sample and being replaced by physicians who use few PA catheters without any individual physician changing his or her behavior.

The results in Table 2 demonstrate that in both samples, abandonment trends remain stable over all specifications. In comparison to 1992, the likelihood that a physician uses a PA catheter rises between the years 1993 and 1995 in all specifications. For the years 1996 and 1997, the likelihood is not significantly different than in 1992 at the p=0.05 level for any specification except for the full sample in 1996. This indicates that there was a decline in usage between 1995 and 1996 as shown in Figure 1. After 1997, all specifications suggest a decline in PA catheter use comparable to the trend displayed in Figure 1. The high correlation between the covariates in specifications 1 and 2 (both a and b) show that accounting for patient characteristics has little impact on predicted PA catheter usage rates. While Table 1 does show significant differences in patient characteristics between patients who do and do not receive PA catheters, these do not influence time trends. Adding hospital and physician fixed effects in specifications 3a and 3b causes the abandonment to reach a steady state slightly earlier, but generally preserves the same time trend. Overall, Table 2 shows that the abandonment trends displayed in Figure 1 are indeed stable.

To further characterize the physician sample, we decompose declining PA catheter rates into year and cohort effects. This demonstrates whether physicians who trained earlier are slower to change their behavior than those who trained later. In order to examine this phenomenon, we divide physicians into five cohorts based on year of education completion. Year of education completion is specified as the final year of a physician's fellowship in thoracic surgery.[4] The five cohorts are physicians who graduated before 1986, between 1986 and 1995, between 1996 and 2000, between 2001 and 2005, and between 2006 and 2011. These will henceforth be referred to as Cohorts 1 through 5 with Cohort 1 as the earliest

[4] Final year of education prior to joining the practice is used if no fellowship in thoracic surgery is indicated by the physician but they still qualified for our sample.

cohort. The first cutoff date corresponds with Robin's 1985 article questioning the use of PA catheters and the second with Connors' 1996 JAMA study. The years following 1996 are evenly divided into three cohorts to capture the rapidly changing practices over that time period.

Figure 2 shows the abandonment of PA catheters broken down by cohort. Due to small initial numbers, cohort lines are not graphed until the entire cohort has joined the workforce (ie, the line for the cohort who completed their education between 1996 and 2000 begins in 2001). Cohort 5, the 2006 to 2011 cohort, is thus omitted from Figure 2 but is still included in the sample for subsequent analysis.

An initial look at Figure 3 indicates that physicians in earlier cohorts experienced a lag before abandoning. Even while abandoning at a steady rate, the earliest cohort displayed a higher use of PA catheters than all later cohorts through 2008. Additionally, the latest cohort pictured – 2001 to 2005 – used a consistently lower rate of PA catheters than peers at all points after entering the data. This suggests that these physicians were trained to avoid inserting PA catheters in the majority of circumstances.

To account for patient and hospital characteristics, the impact of cohort on likelihood of using a PA catheter is predicted using a linear probability function similar to Equation 1. The regression is estimated with the full sample of data from 1992 to 2011 using five different specifications. In each, the variables of interest are $\boldsymbol{C_j}$, a set of dummy indicators representing Cohorts 2 through 5, with Cohort 1 omitted. Equation 2 shows the most saturated specification:

(2) $$\boldsymbol{PAC_{ihjt}} = \boldsymbol{\beta_0} + \boldsymbol{\beta_1 C_j} + \boldsymbol{\beta_2 Y}_t + \boldsymbol{\beta_3 D_{it}} + \boldsymbol{\beta_4 R_{it}} + \boldsymbol{\beta_5 CM_{it}} + \boldsymbol{\mu_h} + \varepsilon_{ihjt}$$

The additional variables in the regression have equivalent interpretations to those in Equation 1. Of the five specifications, the first includes a constant, cohorts ($\boldsymbol{C_j}$), and years ($\boldsymbol{Y_t}$) as regressors. The following specifications add patient demographics, patient high risk factors, patient comorbidities, and hospital fixed effects sequentially. Physician fixed effects are excluded from all specifications because cohort does not vary by physician overtime.

Table 3 shows the results of the five specifications of the regression. The coefficients on the cohort regressors, $\boldsymbol{C_j}$, can be interpreted as the likelihood that a physician in Cohorts 2 through 5 uses a PA catheter in comparison to the likelihood that a physician in Cohort 1 uses one. If education cohort retards abandonment, coefficients on each $\boldsymbol{C_j}$ will be negative and become progressively more negative for each cohort. In specification 1, which controls only for year, all cohorts except Cohort 5 demonstrate this retarding effect. In a given year, physicians in Cohort 2 are 5.7 percent less likely to use a PA catheter than physicians in Cohort 1. Physicians in Cohort 3 and 4 are 7.0 and 8.7 percent less likely to use a PA catheter than those in Cohort 1 respectively. Although physicians in Cohort 5 are 5.7 percent less likely to use a PA catheter than physicians in Cohort 1, they are equally likely to use a PA catheter are physicians in Cohort 2 and more likely than physicians in Cohorts 3 and 4. This is counter to the notion that the most recently trained cohort will be the least common users because they were trained not to use PA catheters. Nearly identical results hold for specifications 2 through 4 when patient characteristics are added.

Given that there is wide variation in PA catheter usage between hospitals, it is important to look within a hospital to see if a discrepancy in use between cohorts exists. After accounting for this by adding physician fixed effects in specification 5, cohort effects become less apparent. Within a hospital, physicians in Cohort 2 and 3 are 1.6 and 2.0 percent less likely to use a PA catheter than physicians in Cohort 1 respectively. However physicians in Cohort 4 are 1.4 percent more likely than physicians in Cohort 1 to use a PA catheter and Cohort 5 shows no difference at the p=0.05 level. These results indicate that within a hospital, physicians who are trained prior to 2000 are less likely to use a PA catheter in a given instance than physicians who are trained before 1986 or after 2000. We, therefore, cannot assume that all physicians who were trained later in the data will use fewer PA catheters than physicians who appear early on in the data.

III.3. Methods

Having established that differential patterns of abandonment across physicians is not driven primarily by patient case mix or physician cohort, we now explore the hypothesis that veteran physicians in a hospital will update their practices in response to new physicians who join their team. In order to test this hypothesis, we look at the change in PA catheter usage of veteran physicians who were present prior to 1998 in response to new graduates who entered in or after 1998. Our specific focus is the change in PA catheter use in response to entrants who came directly from a fellowship in thoracic surgery.

This sample of entrants, henceforth referred to as "newly-trained entrants," is comprised of physicians who graduated from a fellowship in thoracic surgery up to one year prior to joining the practice or practices to which they are attributed. While this excludes entrant physicians who are mid-career hires, the intent is to capture the effect of knowledge being transmitted directly from fellowship programs. Between 1998 and 2011, there were 55 newly-trained entrants (37.2% of total entrants during that time period).

Figure 3 compares PA catheter usage rates between the sample of veteran physicians and the sample of newly-trained entrants. The boxplots display median, twenty-fifth, and seventy-fifth percentile usage rates by physician. Extreme values are cut at the fifth and ninety-fifth percentiles to exclude outliers. The leftmost plot shows the distribution of PA catheter usage among veteran physicians prior to 1998. The center plots compare veteran and newly-trained entrants are between 1998 and 2004, and the rightmost plots compare the same groups between 2005 and 2011.

Figure 3 shows that veteran and newly-trained entrant physicians in aggregate do not display significantly different practice styles. While there was a wider distribution of usage rates for veteran physicians versus entrants in both time periods, median rates were very similar. The median PA catheter usage rate was 1.71 percent for veterans versus 1.40 percent for newly-trained entrants from 1998 to 2004, and 1.15 percent for veterans versus 1.54 percent for entrants from 2005 to 2011. This corroborate our earlier finding that entrants do not necessarily practice with fewer PA catheters than veteran physicians—this time using only our sample of newly-trained physicians.

To account for the possibility that not all newly-trained entrants are alike, we categorize physicians into three groups: low, medium, and high PA catheter volume entrants. These categories are defined in relation to the usage of the veteran physicians at the hospital that the entrant joined. For each newly-trained entrant, we calculate the proportion of PA catheters used by the entrant in his or her first year practicing at the hospital he or she enters. Two years rather than one are used in this calculation to account for physicians who entered later in a calendar year and had not performed sufficient CABGs in their first year appearing in the data. We then calculate the proportion of PA catheters used by veteran physicians in the hospital that the entrant joined. In this case, only one year of observations is used in order to minimize the possibility that the entrant physician had already influenced the practice style of veteran physicians. Newly-trained entrants are classified as low PA catheter volume entrants if their PA catheter rate in the first two years was at least 15 percent less than veteran peers. Entrants with 15 percent greater usage are categorized as high PA catheter volume entrants and the remaining entrants are named medium PA catheter volume entrants.

Table 4 shows the number of hospitals that have zero, one, or at least two newly-trained entrants broken down by entrant type. There are 101 unique physician-hospital entrant pairs, made up of 60 low, 19 medium, and 22 high PA catheter volume entrants.[5] The data contain hospitals with up to four low volume entrants, up to three medium volume entrants, and up to two high volume entrants. However, very few hospitals have more than two entrants in any category so these categories are collapsed into two or more entrants.

In the same manner as the cohort regressions, we use linear probability functions to model the impact of a newly-trained entrant on the likelihood that a veteran physician uses a PA catheter Of five specifications, the most saturated is as follows:

$$(3)\quad \boldsymbol{PAC_{ihjt}} = \boldsymbol{\beta_0} + \boldsymbol{\beta_1 EL}_{ht} + \boldsymbol{\beta_2 EM_{ht}} + \boldsymbol{\beta_3 EH_{ht}} + \boldsymbol{\beta_4 Y}_t + \boldsymbol{\beta_5 D_{it}} + \boldsymbol{\beta_6 R_{it}} + \boldsymbol{\beta_7 CM_{it}} + \boldsymbol{\mu_h} + \boldsymbol{\phi_j} + \varepsilon_{ihjt}$$

[5] There are only 55 unique newly-trained entrants in total because many thoracic surgeons practice in multiple Florida hospitals at once. A newly-trained entrant can join multiple hospitals in the same initial post-fellowship year. Thus, there are 101 unique physician-hospital pairs.

The covariates of interest are vectors of high, medium, and low PA catheter volume entrants: $\boldsymbol{EL}_{ht}$, $\boldsymbol{EM}_{ht}$, and $\boldsymbol{EH}_{ht}$. These binary indicators equal one if a hospital has seen at least that many newly-trained physicians in that category enter at the time of the CABG surgery. For example, if a hospital has a low volume entrant join in 1998 and 2000, a CABG observation from 2001 will show both $\boldsymbol{EL}_{1ht}$ and $\boldsymbol{EL}_{2ht}$ equal to 1.[6] The coefficients can be interpreted as the marginal effect of each additional entrant on a veteran physician's likelihood of using a PA catheter. In the example above, the coefficient on $\boldsymbol{EL}_{2ht}$ would signify the additional impact of the second low volume entrant given the effect already attributed to the first low volume entrant. As shown in Table 4, we only indicate the first two entrants of each type in this analysis to avoid including categories that include very few data points.

All five specifications of the linear probability model include indicators for low, medium, and high volume entrants, for year, and for hospital fixed effects. The second specification adds physician fixed effects and the third through fifth add patient demographics, high risk factors, and Elixhauser comorbidities successively. All regressions include hospital fixed effects because we are most interested in the differential effects of low, medium, and high volume entrants within a hospital. Adding physician fixed effects in the second through fifth specification presents a tradeoff. On the one hand, restricting variation to within physician-hospital pairs limits the variation in PA catheter usage that the regression can capture. On the other, hospital-physician fixed effects to accounts for the issue of physician turnover in the veteran sample. For instance, if a high volume veteran physician leaves a hospital just as a low volume entrant joins a hospital, a regression without physician fixed effects would show a decline in likelihood of PA catheter use associated with the arrival of the low volume entrant. However, the true reason for the decline would be the departure of the veteran physician. Adding hospital and physician fixed effects removes this problem because the regression now shows the change in behavior for an individual physician at a specific hospital in response to the arrival of the low volume entrant.

[6] This method of specifying the variables is chosen rather than dummies indicating the total number of entrants at a hospital at a given time for ease of interpretation. The coefficients on $\boldsymbol{EL}_{ht}$, $\boldsymbol{EM}_{ht}$, and $\boldsymbol{EH}_{ht}$ will be a linear transformation of the coefficients if the dummy method had been used.

III.4. Results

Table 5 shows the results of the fixed effects regressions. Specification 1 shows the impact of low, medium, and high volume entrants on PA catheter usage of veteran physicians after adjusting for year and hospital fixed effects. Specifications 2 through 5 adjust for physician fixed effects, patient demographics, high risk factors, and Elixhauser comorbidities added successively. The first aspect to note is that the coefficients are very similar for specification 1 (hospital fixed effects) and specification 2 (hospital and physician fixed effects). This indicates that the impact of an entrant physician manifests at the hospital level rather than the physician level. Stated differently, veteran physicians within a practice tend to react to entrants' practice styles as a group. Specifications 3 through 5 remain nearly unchanged from specification 2, confirming that patient characteristics have very little impact on a physician's likelihood of using a PA catheter in comparison to other factors included.

Given the similarities between all specifications, we will henceforth focus on the most saturated one. Specification 5 shows that the first low volume entrant has no significant effect on the likelihood of a veteran physician using a PA catheter in either direction. However, the second low volume entrant reduces the likelihood of using a PA catheter by 2.5 percent. This indicates that some type of reinforcement is necessary for veteran physicians to change their behavior. The same holds true in the opposite direction for high volume PA catheter entrants. There is no effect at the 5 percent significance level associated with the first high volume entrant, but there is an increase in likelihood of a veteran physician using a PA catheter of 5.8 percent associated with the second high volume entrant. This indicates that newly-trained entrants can influence veteran physicians in either direction. The medium volume entrants also have a significant effect, first in a negative direction and then in a positive direction. We would expect entrants who initially use similar volumes of PA catheters as veterans to have no impact on veteran physicians' PA catheter usage. Further analysis is necessary to understand the effect that these covariates are capturing. Overall, these findings show that newly-trained entrants do have a significant effect of the practice styles of veteran physicians practicing at the hospitals that they join.

IV. DISCUSSION

This paper draws on economic theory of adoption and diffusion to propose a mechanism for characterizing abandonment based on peer to peer information transfer. Based on Young's social learning model of adoption (2009), we hypothesize that physicians will abandon a previously used technology once information that it is ineffective reaches a physician. We propose that newly-trained peer physicians are a mechanism by which this information can travel.

Findings suggest that information that movement of peer physicians does ultimately contributes to abandonment decisions. However, in the example of PA catheters, the decision to abandon does not always appear to be a discreet choice triggered by the arrival of new information. Physicians who had previously been high PA catheter users appear to lower their usage rates in response to peers who transmit information about ineffectiveness, but may also raise rates in response to new peers who are still high frequency users. Ultimately, it appears that veteran physicians adjust their practice styles in response to newly-trained peers, but this may not move them towards a style that conforms to current best-practices.

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TABLE 1: Characteristics of Patients Receiving or Not Receiving PA Catheters

	1992-2011 Physician Average			1998-2011 "Veteran" Physician Average		
	PA Catheter (n=48,874)	**No PA Catheter** (n=378,816)	**P-Value**	**PA Catheter** (n=19,433)	**No PA Catheter** (n=175,289)	**P-Value**
Year	1998.9	2001.4	<0.0001	2001.5	2002.8	<0.0001
Patient Demographics						
Mean Age	67.1	67.3	0.0006	67.0	67.6	<0.0001
Female--%	27.9	28.8	0.0001	28.0	28.7	0.0438
Race—%			<0.0001			<0.0001
White Non-Hispanic	84.1	83.8		79.5	83.9	
White Hispanic	6.7	6.8		9.8	6.5	
Black	3.9	4.6		4.5	4.5	
Other	5.3	4.9		6.3	5.0	
High Risk Indicators						
Emergency Admission--%	25.3	25.9	0.0029	24.8	23.6	0.0003
Heart Failure -- %	24.4	21.0	<0.0001	22.3	21.5	0.0035
Acute Myocardial Infarction --%	24.6	24.1	0.0105	24.7	23.5	0.0002
Heart Valve Replacement -- %	8.9	10.5	<0.0001	10.3	11.9	<0.0001
Three Vessels--%	31.8	30.2	<0.0001	31.2	29.3	<0.0001
Four+ Vessels--%	19.1	15.6	<0.0001	16.6	15.9	0.0142

P-values from two sample t-test or Pearson chi square test

TABLE 2: PA Catheter Abandonment Overtime

	1992-2011 All Physicians			1992-2011 "Veteran" Physicians		
	(1a)	(2a)	(3a)	(1b)	(2b)	(3b)
	PAC	PAC	PAC	PAC	PAC	PAC
Year (1992 omitted)						
1993	0.018***	0.017***	0.029***	0.025***	0.024***	0.036***
	[0.004]	[0.004]	[0.004]	[0.005]	[0.005]	[0.004]
1994	0.039***	0.038***	0.026***	0.050***	0.049***	0.036***
	[0.004]	[0.004]	[0.004]	[0.005]	[0.005]	[0.004]
1995	0.041***	0.040***	0.031***	0.047***	0.045***	0.037***
	[0.004]	[0.004]	[0.004]	[0.005]	[0.005]	[0.004]
1996	-0.005	-0.007*	-0.008**	-0.004	-0.007	-0.002
	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]
1997	0.006	0.002	-0.005	0.007*	0.003	0.000
	[0.004]	[0.004]	[0.003]	[0.004]	[0.004]	[0.004]
1998	-0.014***	-0.017***	-0.028***	-0.009**	-0.013***	-0.021***
	[0.004]	[0.004]	[0.003]	[0.004]	[0.004]	[0.004]
1999	-0.041***	-0.044***	-0.052***	-0.032***	-0.035***	-0.045***
	[0.004]	[0.004]	[0.003]	[0.004]	[0.004]	[0.004]
2000	-0.063***	-0.064***	-0.075***	-0.051***	-0.054***	-0.068***
	[0.004]	[0.004]	[0.003]	[0.004]	[0.004]	[0.004]
2001	-0.085***	-0.086***	-0.097***	-0.071***	-0.073***	-0.092***
	[0.004]	[0.004]	[0.003]	[0.004]	[0.004]	[0.004]
2002	-0.079***	-0.080***	-0.092***	-0.063***	-0.065***	-0.087***
	[0.004]	[0.004]	[0.003]	[0.004]	[0.004]	[0.004]
2003	-0.085***	-0.086***	-0.102***	-0.069***	-0.071***	-0.098***
	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]
2004	-0.088***	-0.089***	-0.110***	-0.075***	-0.077***	-0.110***
	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]
2005	-0.098***	-0.098***	-0.118***	-0.085***	-0.086***	-0.118***
	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]
2006	-0.109***	-0.109***	-0.129***	-0.095***	-0.095***	-0.131***
	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]
2007	-0.108***	-0.107***	-0.128***	-0.092***	-0.091***	-0.128***
	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]
2008	-0.105***	-0.102***	-0.121***	-0.087***	-0.084***	-0.121***
	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]
2009	-0.113***	-0.109***	-0.123***	-0.095***	-0.090***	-0.118***
	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]
2010	-0.118***	-0.113***	-0.127***	-0.099***	-0.093***	-0.125***
	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]
2011	-0.118***	-0.113***	-0.128***	-0.097***	-0.092***	-0.128***
	[0.004]	[0.004]	[0.004]	[0.005]	[0.005]	[0.004]
Full Sample	✓	✓	✓			
Veteran Sample				✓	✓	✓
Patient Demographics		✓	✓		✓	✓
Patient High Risk Factors		✓	✓		✓	✓
Patient Elixhauser Comorbidities		✓	✓		✓	✓
Hospital Fixed Effects			✓			✓
Physician Fixed Effects			✓			✓
Observations	427,690	427,690	427,690	340,538	340,538	340,538
R-squared	0.027	0.032	0.397	0.020	0.026	0.402

Robust standard errors in brackets; *** p<0.01, ** p<0.05, * p<0.1

TABLE 3: PA Catheter Abandonment by Education

	(1)	(2)	(3)	(4)	(5)

	PAC	PAC	PAC	PAC	PAC
Cohort (Cohort 1: pre-85 omitted)					
Cohort 2: 1986-1995	-0.057***	-0.057***	-0.057***	-0.056***	-0.016***
	[0.001]	[0.001]	[0.001]	[0.001]	[0.001]
Cohort 3: 1996-2000	-0.070***	-0.071***	-0.071***	-0.071***	-0.020***
	[0.001]	[0.001]	[0.001]	[0.001]	[0.001]
Cohort 4: 2001-2005	-0.087***	-0.088***	-0.088***	-0.088***	0.014***
	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]
Cohort 5: 2006-2011	-0.057***	-0.058***	-0.057***	-0.056***	0.008*
	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]
Year (1992 omitted)					
1993	0.022***	0.022***	0.023***	0.021***	0.019***
	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]
1994	0.044***	0.044***	0.045***	0.043***	0.021***
	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]
1995	0.048***	0.048***	0.048***	0.046***	0.028***
	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]
1996	0.004	0.004	0.005	0.002	-0.010***
	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]
1997	0.016***	0.016***	0.017***	0.013***	-0.001
	[0.004]	[0.004]	[0.004]	[0.004]	[0.003]
1998	-0.001	-0.001	0.000	-0.004	-0.022***
	[0.004]	[0.004]	[0.004]	[0.004]	[0.003]
1999	-0.024***	-0.024***	-0.023***	-0.027***	-0.047***
	[0.004]	[0.004]	[0.004]	[0.004]	[0.003]
2000	-0.044***	-0.044***	-0.042***	-0.046***	-0.069***
	[0.004]	[0.004]	[0.004]	[0.004]	[0.003]
2001	-0.064***	-0.064***	-0.063***	-0.066***	-0.088***
	[0.004]	[0.004]	[0.004]	[0.004]	[0.003]
2002	-0.056***	-0.056***	-0.055***	-0.058***	-0.083***
	[0.004]	[0.004]	[0.004]	[0.004]	[0.003]
2003	-0.060***	-0.060***	-0.059***	-0.061***	-0.092***
	[0.004]	[0.004]	[0.004]	[0.004]	[0.003]
2004	-0.061***	-0.062***	-0.061***	-0.063***	-0.095***
	[0.004]	[0.004]	[0.004]	[0.004]	[0.003]
2005	-0.069***	-0.070***	-0.068***	-0.070***	-0.103***
	[0.004]	[0.004]	[0.004]	[0.004]	[0.003]
2006	-0.078***	-0.079***	-0.078***	-0.079***	-0.114***
	[0.004]	[0.004]	[0.004]	[0.004]	[0.003]
2007	-0.076***	-0.077***	-0.075***	-0.077***	-0.112***
	[0.004]	[0.004]	[0.004]	[0.004]	[0.003]
2008	-0.072***	-0.073***	-0.070***	-0.070***	-0.110***
	[0.004]	[0.004]	[0.004]	[0.004]	[0.003]
2009	-0.079***	-0.079***	-0.076***	-0.075***	-0.111***
	[0.004]	[0.004]	[0.004]	[0.004]	[0.003]
2010	-0.083***	-0.083***	-0.080***	-0.079***	-0.118***
	[0.004]	[0.004]	[0.004]	[0.004]	[0.003]
2011	-0.081***	-0.082***	-0.079***	-0.077***	-0.118***
	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]
Patient Demographics		✓	✓	✓	✓
Patient High Risk Factors			✓	✓	✓
Patient Elixhauser Comorbidities				✓	✓
Hospital Fixed Effects					✓
Observations	427,690	427,690	427,690	427,690	427,690
R-squared	0.036	0.036	0.037	0.040	0.361

Robust standard errors in brackets; *** p<0.01, ** p<0.05, * p<0.1

TABLE 4: Breakdown of Entrants by Hospital and Entrant Type

Number of Entrants per Hospital	Low PAC Volume Entrants Hosp N (%)	Medium PAC Volume Entrants Hosp N (%)	High PAC Volume Entrants Hosp N (%)
0	19 (33)	43 (75)	41 (72)
1	23 (40)	10 (18)	10 (18)

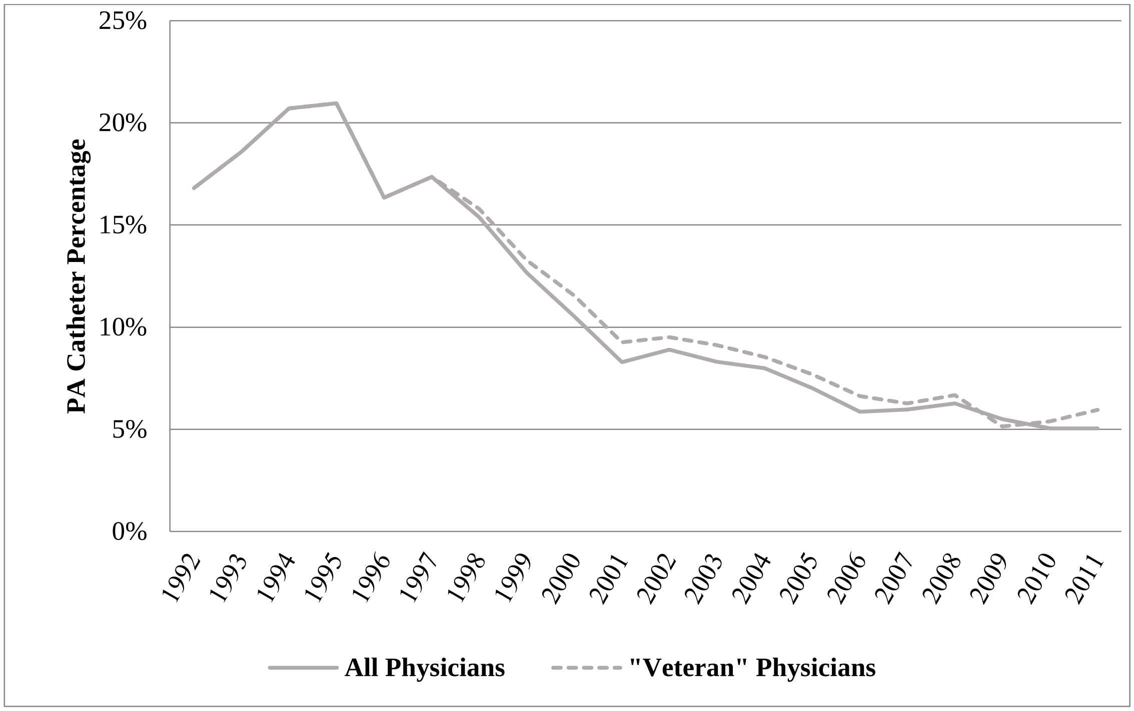
2+	15 (26)	4 (7)	6 (11)
Total Entrants	**60**	**19**	**22**

TABLE 5: Veteran PA Catheter Abandonment after Newly-Trained Entrant

	(1) PAC	(2) PAC	(3) PAC	(4) PAC	(5) PAC
Low PAC Volume Entrants					
Low Entrant 1	0.003	0.001	0.001	0.001	0.001
	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]
Low Entrant 2	-0.022***	-0.025***	-0.025***	-0.025***	-0.025***
	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]
Medium PAC Volume Entrants					
Mid Entrant 1	-0.023***	-0.025***	-0.025***	-0.025***	-0.025***
	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]
Mid Entrant 2	0.075***	0.072***	0.072***	0.072***	0.072***
	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]
High PAC Volume Entrants					
High Entrant 1	0.007*	0.007*	0.007*	0.007*	0.008*
	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]
High Entrant 2	0.059***	0.058***	0.058***	0.057***	0.058***
	[0.004]	[0.004]	[0.004]	[0.004]	[0.004]
Year					
1999	-0.024***	-0.024***	-0.024***	-0.024***	-0.024***
	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]
2000	-0.042***	-0.043***	-0.043***	-0.043***	-0.042***
	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]
2001	-0.064***	-0.066***	-0.066***	-0.066***	-0.065***
	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]
2002	-0.059***	-0.060***	-0.060***	-0.060***	-0.059***
	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]
2003	-0.067***	-0.069***	-0.069***	-0.069***	-0.068***
	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]
2004	-0.084***	-0.086***	-0.086***	-0.086***	-0.084***
	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]
2005	-0.093***	-0.094***	-0.094***	-0.094***	-0.093***
	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]
2006	-0.105***	-0.108***	-0.107***	-0.107***	-0.106***
	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]
2007	-0.099***	-0.102***	-0.102***	-0.101***	-0.100***
	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]
2008	-0.089***	-0.090***	-0.090***	-0.089***	-0.089***
	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]
2009	-0.082***	-0.083***	-0.083***	-0.082***	-0.082***
	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]
2010	-0.084***	-0.085***	-0.085***	-0.084***	-0.084***
	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]
2011	-0.080***	-0.080***	-0.080***	-0.079***	-0.079***
	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]
Hospital Fixed Effects	✓	✓	✓	✓	✓
Physician Fixed Effects		✓	✓	✓	✓
Patient Demographics			✓	✓	✓
Patient High Risk Factors				✓	✓
Patient Elixhauser Comorbidities					✓
Observations	194,722	194,722	194,722	194,722	194,722
R-squared	0.411	0.421	0.421	0.422	0.422

Robust standard errors in brackets; *** p<0.01, ** p<0.05, * p<0.1

FIGURE 1: Trend in PA Catheter Usage Overtime



25%
20%
15%
10%
5%
0%
PA Catheter Percentage
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
All Physicians
"Veteran" Physicians

FIGURE 2: Trend in PA Catheter Usage by Physician Education Cohort

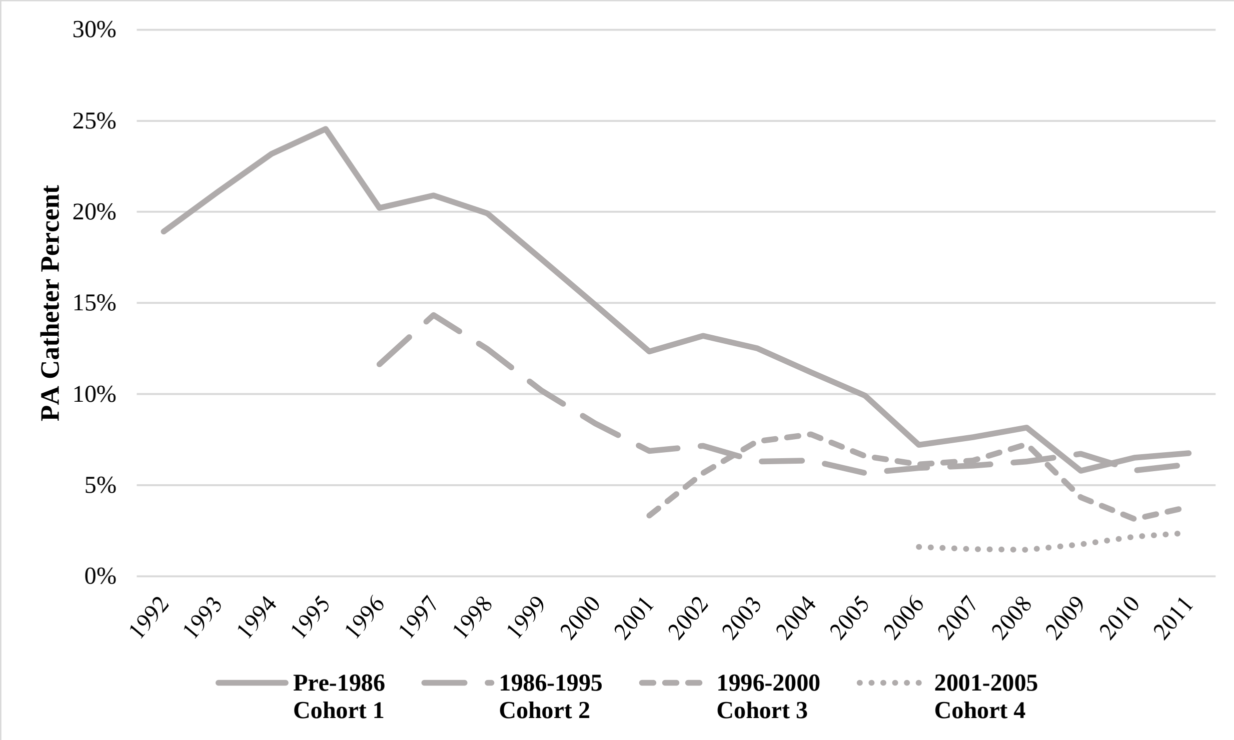


FIGURE 3: PA Catheter Usage Differentials between Veteran and Entrant Physicians