# Is blood thicker than water? Information flow among competing cardiologists

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Variations in physician practice are pervasive and costly, and may be harmful. The objective of much policy is to increase the interconnectedness of physicians, furthering the transfer of information and thus reducing variation. This study tests whether physicians are influenced by the practice of peers, or if propensity, mere context or sorting of like-minded physicians better explain similarities and differences in practice. We study cardiologists who place coronary stents into patients with blocked arteries around the heart. Organized in locally competing physician groups or as solo practitioners, they see patients in different offices, but insert stents at a shared production facility – the cath lab.

We examine their use of the popular drug-eluting coronary stents between their launch and rapid adoption in early 2003, and through the period of late 2006 in which private and public reports of serious late side-effects eventually led to reductions in use. Our analyses use administrative claims data on nearly 1,000 cardiologists and their patients in Florida, merged with Florida physician licensure data. Collectively these physicians used these stents nearly a quarter of a million times in the 4 year period reviewed. Pooled and panel linear regressions for device utilization by a physicians are estimated using measures of peer utilization, physician characteristics and controls for unobservable physician characteristics, common shocks and selection effects.

We find strong evidence for intra-group but against inter-group practice spillovers. Even when sharing the same lab, competing cardiologists did not appear to correlate practices. Our results are consistent with a view that policies aimed at increasing the interconnectedness of physicians must first consider the organizational barriers and competitive forces that can stymie knowledge transfer even among physicians working closely together.

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*"Some interventional cardiologists are beginning to talk among themselves about a problem some of them think they have seen with drug coated stents" (Fogoros, 2005:1).*

Variations in physician practice are well-known (Wennberg & Cooper, 1999), and policies that aim to enhance connections between and improve information flow among healthcare providers may be effective (O'Connor et al., 1996; Valente & Davis, 1999; Majumdar et al., 2002; Nicholson, 2003; Majumdar et al., 2004; Jippes et al., 2010). The premise of such policies is illustrated in the classic Coleman et al. (1966) study which showed physician peer effects played an important part in the adoption of tetracyclines. Much research finds the potential influence of other physicians and key opinion leaders remains strong (Grilli & Lomas, 1994; Escarce, 1997; Borbas et al., 2000; Bikhchandani et al., 2002; Berwick, 2003; Greenhalgh, 2004; Burke, Fournier and Prasad, 2007; Chandra & Staiger, 2007).

Yet the transfer of best practices within healthcare settings has not been simple (de Jong et al., 2010), and practice patterns appear relatively immutable to the influence of peers (Nicholson & Epstein, 2003; Tucker et al., 2006). Observed variations in the utilization of medical service remain widespread (Fisher et al., 2003), while unobserved differences in which patients are treated likely mask further variation in community health (Huesch, 2010a).

In this study we contribute to this literature by exploring possible peer effects and variation in the utilization of a new medical device by nearly 1,000 specialist physicians in Florida over the period 2003 to 2006. Collectively these physicians used drug-coated coronary stent device [DES] to relieve blockages in the arteries around the heart nearly a quarter of a million times. This period was characterized by rapid adoption and subsequent decreases in use as reports of late side-effects of the device emerged. We relate the use of DES by one physician to the use by his or her partners and competitors, and to observed and unobserved characteristics of the physicians.

We account for differing opportunities for physicians to interact with each other and also attempt to control for alternative explanations of correlations in physician behavior that have nothing to do with observation, imitation or information transfer. These include random individual propensities which may explain some practice variations (Omoigui et al., 1998; Skinner & Staiger, 2003; Nicholson & Epstein, 2003; McGuire et al., 2003; Armstrong, 2003). Similarly, the non-random sorting of like-minded individuals into groups (Manski, 1993) may simulate peer effects. Finally, aggregate contextual effects which impact all physicians can produce the illusion of knowledge transfer. For example, when the Coleman et al. (1966) study was re-analyzed incorporating aggregate pharmaceutical advertising spend and pages, peer effects became insignificant (Van den Bulte & Lilien, 2001).

*Background*

Information gained by one physician and shared with others may reduce other physicians' cost of, or uncertainty about practicing in a particular manner (Escarce, 1997). Many of the features of the healthcare sector ought to predispose to similar success. Social norms support and encourage altruistic information transmission and best practice transfer, and few legal anti-competitive obstacles block individual physicians sharing commercially sensitive information across organizational boundaries. Medico-legal pressure to conform to a community standard may drive harmonization in individual practices (Burke et al., 2004). Many medical services are also performed in a shared social and physical setting with opportunities for close direct interactions or via intermediaries (e.g. sales representatives).

However, the lack of widespread success suggests that other features of the healthcare sector may stymie successful knowledge transfer, and allow practice variations to persist. For examples, incentives to provide such information may be missing (Phelps, 1992), barriers may hinder its flow, and issues of trust might inhibit acceptance. Such attributes of the *conduits* between physicians, the *contents* of the information to be shared, and the *conditions* that might motivate or inhibit such sharing are all important.

*Contents*

In our setting, the contents of the information to be transferred include awareness of the new DES stent product. Stents are used by physicians to treat blockages of the coronary arteries before, during or immediately after a heart attack. To prevent the artery closing again, a small bare metal scaffold or stent [BMS] was inserted. Drug-eluting stents [DES] were hailed by many physicians as a 'new era' in cardiovascular disease management and were approved by the US Food and Drug Administration [FDA] in April 2003, by which time the major government payor had already announced higher hospital reimbursements for DES, and created new billing codes to simplify adoption.

This public information was widely available to physicians through media, marketing, journal and peer specialty society guidelines (see Table 1). Other information on DES' immediate effectiveness (e.g. at relieving the arterial block, or eliminating symptoms of angina), possible information regarding problems associated with its use (e.g. the stent was too large for a particular vessel, or the introducer was too stiff) and occasionally information about late side-effects was also available privately.

<<Figure 1 about here>>

Based on the widespread availability and positive view of DES' effectiveness compared to BMS, the US reached an 80% DES implantation rate by the first quarter of 2004. Stricter 'on label' use ought to have led to far fewer patients receiving DES. Instead 'off label' use was prevalent: legal use by cardiologists of DES in ways neither formally approved by the FDA nor proven in the original clinical trials. These adoption dynamics are shown for Florida in Figure 1.

In 2004, the medical journal *The Lancet*, noted isolated cases of late adverse effects of DES in Europe. Late stent thrombosis [LST] was a sudden and unexpected blockage of the stented vessel a year after implantation often leading to death, often after 'off-label' patient use. Over the next 9 months several journal articles and one conference presentation mentioned this rare but lethal late DES side effect. By August 2005 the FDA had warned that DES patients needed longer anti-clotting therapy and cardiologists had started to privately comment on the DES problem (Fogoros, 2005).

The use of DES fell steadily from the beginning of 2006 as existing practice guidelines set by U.S. specialty peer groups were amended. In March 2006 at the American College of Cardiology conference in Atlanta, results from a large Swiss study showed unequivocal LST evidence. By the end of 2006, the FDA regulator had strenuously warned about 'off-label' use, and the need for DAT to prevent LST. In hindsight, as Steven Nissen of the Cleveland Clinic commented: "[cardiologists had] traded a short-term benefit on a relatively benign disorder, namely restenosis, for a long term mortality disadvantage." (Nissen, in Schuchman, 2006, 1951.)

<<Table 1 about here>>

In our setting, evidence also exists that some of the information on adverse side effects was private (Fogoros, 2005), and not always verifiable through personal experience. As one interventional cardiologist noted "there is a little background noise of thrombosis. If you treat [only] 200-300 patients a year, you don't notice it." (Anonymous, cited in Trends – in – Medicine, 2005, p1). Our objective is to focus on the physician-to-physician transfer of this information, and to focus on this conduit we control for the aggregate contextual effects of publicly available information. We detail this approach in later sections.

*Conduits*

Previous research into the flow of information between individuals or firms first treated learning as a passive contact process where proximity, interaction and opportunity drive diffusion through contagion (Griliches, 1957; Rogers, 1962; Bass, 1969; Strang & Soule, 1998). In other views, social relations may develop alongside the business transactions that characterize economic exchange (Granovetter, 1985; Burt, 1987).

These include weak (Granovetter, 1973) or bridging ties (Burt, 1992) which connect individuals with diverse backgrounds (Uzzi & Lancaster, 2003). Much closer social relationships or strong ties and facilitate mutually beneficial economizing on search costs and enforcement costs (Uzzi, 1997). The properties of such social connections between individuals across firms then impact the flow of information between firms (Van de Ven, 1986; Reagans, Argote, & Brooks, 2005).

In our setting, physician partners of a medical group have strong economic, administrative and social ties. They are in constant interaction with their partners in their shared offices in which they receive new patients and follow-up established patients. However, advanced diagnostic services (e.g. angiograms) and treatment interventions (e.g. angioplasties) cannot readily be performed in these offices. Instead, these are delivered at a local hospital's catheterization laboratory [cath lab]. There, shared infrastructure, nursing and technical assistant staff and supplies are available to physicians appointed by the hospital who may belong to competing local practice groups.

*Conditions*

Separate lines of research in organizational economics and organizational sociology have focused on the conditions under which knowledge transfer occurs or fails. Organizational science has also investigated how motivation drives the acquisition of knowledge. Correlated adoption of medical innovations by physicians (Coleman et al., 1966) was reinterpreted by Burt (1987) as responses by rivals to possible changes in social status in the space of physicians.

More prosaic motivation may be found in economic theory which predicts that the ability to appropriate the benefits of information sharing may determine the degree to which physician practice decisions are shared (Phelps, 1992). A group of physicians may thus deliberately share practice decisions to maximize group profit. Conversely, strategic effects may reduce or eliminate the spread of practice decisions between competing practice groups. To what extent organizational boundaries tend to inhibit transfer separately from competitive effects is not well understood, although it has been found in some service industries that individuals in competing firms nonetheless maintain close social ties (Ingram and Roberts, 2000).

*Hypotheses*

Our study makes three related hypotheses. First, when conduit, content and conditions 'fit', we predict that knowledge will be transferred, accepted and acted on readily. Second, when the conditions support knowledge transfer, even in the absence of close interactions, we still expect information to flow as before. Finally, when the conditions do not support knowledge transfer, even in the presence of close interactions, we do not expect knowledge to flow well:

***$H_1$:*** Use of DES will be highly positively correlated between physician group members.

***H₂:*** Use of DES will be positively correlated between physician group members, even if these physicians produce at different sites.

***H₃:*** Use of DES will be not be correlated between members of competing physician groups delivering services at the same hospital and the same cath lab.

## Data and method

*Sample*

All physicians performing adult PTCA in Florida during the 16 quarters between 2003 Q1 and 2006 Q4 are included in the sample, after validation described in Online Appendix 1. This resulted in a total of 989 physicians who performed 238,965 adult PTCA cases. Our patient data was obtained from the Florida Department of Health's Agency for Healthcare Administration under a data use agreement, while publicly available physician profile data was obtained from the Florida Department of Health. Office addresses and web searches were used to code firm membership. Literature searches on Pub Med, newswires and other journal search engines was used to gather evidence for external influences such as adverse marketing news, adverse clinical use news and adverse trial news. Our university health system's Institutional Review Board approved this study.

*Measures*

Use of DES by a physician was the dependent variable, coded as the number of admissions in a quarter in which the physician was recorded as the treating physician, and use of a DES stent was recorded as a procedure. We similarly aggregated other individual physicians' DES use to construct analogous independent variables, lagged these by one quarter. To control for the intensity of competition, we computed county-level numbers of physicians performing these coronary artery interventions each quarter, the county share of DES cases each quarter for each physician and group, and the corresponding concentration and Herfindahl indices.

We controlled for physician covariates related to idiosyncratic propensity to use DES stents, and for heterogeneity in susceptibility to the influence of peers (Escarce, 1997; Artis et al., 2006). Whether the physician trained in, and was credentialed in internal medicine alone, in cardiology or cardiovascular diseases subs-specialty or finally in interventional cardiology was coded as specialist interventionalists are likely to know more than generalist cardiologists and general internal medicine specialists. Overseas training is a dummy, as are training in a hospital currently ranked anywhere in the *U.S. News & World Report*'s list of heart specialist hospitals, top 25 hospitals and honor roll hospitals was also coded. Experience and seniority were proxied by the last year of training.

Past research suggests that positional attributes may be associated with conservatism in making decisions on treatment choices (Escarce, 1997). The physician's social position and professional status is proxied by the number of staff privileges (admitting physician or attending physician privileges) at hospitals in the state, the average number of other sites worked across, the number of other states in which he or she is licensed to practice medicine, the size of the practice, and whether faculty (academic medicine) positions are held. Whether the physician was a quick adopter of DES may indicate similarly fast changes in DES use subsequently, or better access to clinical trials or suppliers. Accordingly use of DES before formal marketing approval was coded.

Landon et al. (2001) find in primary care physicians that solo practitioners tended to have more 'aggressive' treatment plans than those from larger organizational settings. In a similar vein, Ketcham et al. (2007) found that the patients of group practice physicians did better than those of solo practitioners. Accordingly we coded for whether the physician was a solo physician, or practices in a group, and the number of partners in the practice.

*Statistical methods*

We use ordinary linear least squares regressions and physician fixed effects panel regressions to evaluate the impact of our key predictor variables on our measure of physician behavior: his or her utilization of DES in the current quarter. We introduce results by starting with the basic linear regression model and sequentially adding independent variables and controls. Finally we add physician fixed effects to obtain the panel regression, designed to mitigate some of the alternative explanations for possible correlations in physician behavior (Manski, 1993; Sacerdote, 2001; Lyle, 2007). In all models, standard errors are robust and clustered by physician.

We specified a linear relationship between the use of DES by physician *i* in practice group *p* at time *t* and respective use by the physician's peer group or reference set.

$$OwnBehavior_{i,p,t} = \alpha + \beta \cdot PeerGroupBehavior_{i,p,t\text{-}1} + \gamma \cdot OwnCharacteristics_{i} +$$
$$+ \delta \cdot PeerGroupCharacteristics_{i,p,t} + Time_{t} + MainHospital_{i,t} + \varepsilon_{i,p,t}$$

This reduced form relationship is assumed to capture the unobserved exchange of information, if any, between the focal individual and other individuals and the resulting influence of other individuals on the focal individual's action. We are interested in $\beta$, the extent to which a physician changes practices when other physicians in a reference set have done so in the quarter before. There are several challenges in obtaining unbiased estimates of $\beta$ (Manski, 1993; Sacerdote, 2001). Our discussion follows the schema of Lyle (2007) closely.

First, the **'reflection problem'** prevents a true causal interpretation of the endogenous effect, $\beta$. Physician *i* will simultaneously be influenced by and influence a different member of the peer group, *j*, leading to a multiplier effect. We lag the measured behavior of the peer group to provide some mitigation of this problem, but finding a significant positive estimate of $\beta$ can still only be interpreted only as evidence of information dissemination in our setting. If we had had large numbers of physicians regularly joining our panel, we could have obtained a less biased estimate. That is, the influence of new members on the other members of the peer group could be assumed to be small compared to the influence in the reverse direction. Unfortunately the data did not allow this strategy.

Second, true exogenous effects captured by $\delta$ may be confounded with the endogenous effects measured by $\beta$. Such **'pre-treatment' effects** measure the extent to which a physician changes his or her behavior because of the influence of pre-existing behavior and attitudes of the other physicians in his or her social group. In our setting, characteristics of the peer group are not observed to change over time, and are thus collinear with the physician-level fixed effect for any particular specification of peer group. The panel regression approach described below mitigates the confounding to the extent that such characteristics truly do not change over time.

Third, **unobserved physician-level heterogeneity** may confound peer influences and information dissemination as is made clearer by disaggregating the error term $\varepsilon_{i,p,t}$ above. The final component ν represents a classically distributed disturbance:

$$\varepsilon_{i,p,t} = Selection_{i,p,t} + CommonShock_{p,t} + PhysicianUnobservable_{i} + \nu_{i,p,t}$$

The *PhysicianUnobservable* variable is the time-invariant component of the compound error. This captures an individual's propensity to act on information acquired from others and his or her susceptibility to peer influences. We mitigate these, to the extent that they are time-invariant, by a panel regression approach.

The possible presence of correlated effects comprise the fourth and fifth challenges: selection biases and common shocks may further bias our estimates of interest. **Selection**

**biases** represents the unobserved sorting of physicians into or out of a physician group on the basis of characteristics that are correlated with the use or disuse of DES stents.

Ours is observational data where non-random sorting of physicians into practice groups is very likely. There is also sorting occurring at the shared hospital appointment and geography level, since competing physicians appointed to the same hospital are responsible for vetting and approving applications by other competing physicians to practice at that hospital. This homophily among physicians at the same hospital or in the same geography may counterbalance the homophily of physicians in the same practice group and at the same hospital. Unobserved correlation may thus exist between *PeerGroupBehavior* and either the *Selection* effect component of the disturbances or the physician *Unobservable* effect. We cannot sign this potential bias with any confidence, although the *Selection* effect correlation should increase $\beta$.

Our analytical strategy to overcome the problem of selection effects is as follows. Physician membership in practice groups is time-invariant over the three years of our data. That is, while physicians enter and exit the sample, there is no information on physicians changing groups while in the sample. The physician licensure data reports prior office and mailing addresses where applicable. None of these addresses matched the office or mailing addresses of other groups. While this implies no movement across groups, it does not rule out other organizational changes such as moving from solo practitioner to group practice or vice versa.

Thus the *Selection* effect is collinear with the physician-level time invariant effect and both are amenable to de-meaning through physician fixed effects. We use the unpooled data and estimate a cross-sectional time series linear regression specifying physician fixed effects, accepting the cost of being unable to estimate the impact of time-invariant physician characteristics. Of course, fixed effects techniques are not foolproof since they cannot control for potentially confounding time-varying changes.

The other type of correlated effects stems from **common shocks** acting similarly on each physician (in a group or small area) and includes detailing, marketing, medical literature or peer group society recommendations. These also include supply or demand shocks and information in academic conferences and journals, peer societies and regulatory decisions (Table A1). It is likely that there is auto-correlation in *PeerGroupBehavior*, so that there may also be correlation between current period *CommonShocks* and lagged *PeerGroupBehavior*. Both types of correlated effects may thus bias the parameter of interest. We cannot sign this potential bias on $\beta$ with any confidence either.

Finally, we use quarterly fixed effects $Time_t$ to capture common secular trends or shocks that are similar over all geographical areas and organizations (Bothner, 2003), and $MainHospital_{i,t}$ effects to capture time- and geographically-varying effects associated with the hospital where a physician performed his or her majority or plurality of cases each quarter.

**Results**

Summary statistics for the physicians analyzed is presented in Online Appendix 2 in which one notes immediately the heterogeneity in training and certification for physicians, who all perform essentially the same medical services. The typical physician is a male, trained locally, and practices in a four cardiologist group firm. He is less likely to possess advanced qualifications or training as sub-specialist interventional cardiologists than basic internal medicine training.

Our sample contains a total of 11,104 physician*quarter observations for 989 physicians over a maximum of 16 quarters. We have 414 solo practitioners (of whom 384 are truly alone, and 30 are part of a diversified multi-specialty group practice, but the only cardiologist there) and 575 multi-physician cardiology group in 179 groups. Online Appendix 3 contains the sample summary statistics and correlation matrices. Geographically, 286 zipcodes were represented, clustered within 130 cities or towns and then within 36 counties in Florida.

*Individual attributes*

To understand the influence of individual physician attributes we performed ordinary least squares, pooling the physician*quarter observations. We report the influence of measures that proxy for individual propensity and susceptibility on the number of quarterly DES cases in Online Appendix 4.

Being a solo practitioner predicts a significantly lower than average number of DES cases each quarter, compared to being a member of a practice group (the omitted category). An imprecisely estimated increase accrues to group members for each additional partner, while working across more cath labs each quarter is associated with substantially more DES cases carried out. Additional training and/or credentialing as an interventional cardiologist (a sub-specialty of cardiology) predicts significantly more DES cases each quarter.

<<Table 2 about here>>

In each of the 565 county*quarter observations there was an average of 20 physicians, of which a little more than 8 were solo physicians and there were 5 groups. The county share of DES cases performed by the busiest 4 physicians averaged 0.64 over the quarters, with a mean Herfindahl index of 0.26 averaged over counties and quarters. There was significant variation in these county sample statistics over time (Online Appendix 6), allowing them to be used in the fixed effects models.

*Hypothesis 1: Intra-group correlation*

We report our main regression results in Table 2 where the first three rows are our focus of interest. All standard errors are robust and clustered by treating physician, a member of a group practice. Model 0 is the baseline pooled least squares model in which physician characteristics are entered but not reported. This baseline model had an $R^2$ of 0.17 and acceptable model fit.

In Model 1 we added the first of the predictor variables, the total number of DES cases performed by the focal physician's group partners last quarter. The estimated coefficient has the expected sign and was precisely estimated (+0.083, $p<.001$). Model 2 reports the sign and magnitude of the estimated impact of decisions by group competitors (-0.007, $p<.01$) and solo competitors (-0.004, $p>.10$), counting as competitors all cardiologists observed to perform interventional cardiology within the local county. These two latter coefficients are not just an order of magnitude smaller in size, but have negative point estimates. This suggests that the focal physicians' actions are modestly at odds with those of their peer competitors.

However, estimates in a model such as Model 1 or 2 may be confounded by time-varying contextual effects (Bothner, 2003). In our setting, we have a time-changing adoption and partial abandonment dynamic (Figure 1, Table 1), making confounding more likely. To mitigate this risk, we include quarterly time fixed effects in Model 3, with modestly improved model fit. All quarterly effects (unreported) were strongly significant, and their magnitudes reflected the adoption and partial abandonment dynamics seen in Figure 1. The focal estimates of interest change only slightly: partners' actions are still positively correlated with own actions, while competitors' actions are still either negatively and weakly correlated in the case of competitors, or uncorrelated (the solo practitioners).

We next attempt to make sure that our estimates are not merely spurious side-effects in a highly competitive market. The negative coefficients on competitor volume could merely reflect a constant supply of patients being fought over by a constant supply of physicians. If more are performed by a competitor, then less may be done by the focal physician. Alternatively, supplier-induced demand can originate when partners and competitors essentially create their own demand by enlarging the pool of patients whom they believe would benefit from such interventions. Here, if more are being performed by anyone, then more may be done by the focal physician.

We control for these possibilities by adding measures related to these potential mechanisms in Model 4: the number of physicians observed to perform DES. We observe a weak negative partial correlation between the total number of physicians performing coronary artery interventions and own DES caseload. After controlling for this, the point estimates of partners' DES cases remain almost unchanged, while the estimates on group competitor actions lose significance. Model fit improves marginally, with the $R^2$ reaching 0.28. In unreported results we used related measures such as the number of physicians performing DES in practice groups or alone, and the number of groups. All yielded qualitatively similar results.

Up to this point we have pooled physician*quarter observations and ignored the natural panel structure of the data. More importantly, these specifications cannot address the selection effects and any unobserved physician-level heterogeneity beyond that controlled for with the physician covariates (see attached Appendix). A Hausman test strongly rejected the consistency of a random effects specification ($p$<.001). Accordingly, in Model 5 we specified a physician fixed effects panel model, dropping all the (time-invariant) physician covariates.

We again find evidence in support of our baseline hypothesis. The estimated coefficient on lagged DES use by physicians in the same practice group remains significant and retains the expected sign (+0.017, p<.05). Smaller negative partial correlations in practices was found between physicians in one group and competing physicians in other groups (-0.007, p<.01) or solo providers (-0.011, p<.01) competing at the county level. In unreported analysis at finer geographical units of analysis (town/city or zipcode), these results were qualitatively unchanged. Note that the $R^2$ is not directly comparable across models 5 and 4: the former is within $R^2$, while the latter is adjusted and pooled $R^2$.

Lower-level marketing activity usually takes place at the hospital level: detailing is done by device representatives and supply deals agreed with hospital purchasing managers. To control for such time- and geography-varying common shocks, we include indicators for the focal physician's main hospital each quarter in Model 6 (Huesch, 2009). This effect is not fixed: most physicians worked over multiple hospitals and the relative caseload changed over time. This hospital represents the hospital in which the physician performed a majority or plurality of interventions that quarter.

The estimates in Model 6 are qualitatively similar to those in Model 5, suggesting that time-varying site-specific common shocks did not substantially impact own actions, although model fit improves to reach a within $R^2$ of 0.31.

The results from Models 1-6 support Hypothesis 1: the close ties found in partnership ties are sufficient for correlation in practices. In Online Appendix 5 we report the results of analogous regressions for solo practitioners, estimating the impacts of competitors' actions on focal physicians *not* belonging to practice groups. Given the lack of close relations such as partnership ties between these and other physicians, we expected and found *no* statistically significant relationship between their use of DES and that of their competitors.

*Hypotheses 2: Correlation of practice by partners at different physical facilities*

Turning to our second hypothesis, we expected that shared physical settings would not be necessary for knowledge transfer, if the physicians shared the close social and economic ties of partnership. Table 3 reports on the influence of group partners on own use. Model 7 builds on Model 6 by distinguishing the cases that a partner performs at one's own major hospital and those that the partner performed elsewhere. We expected that DES use by partners ought to be significantly associated with own use regardless of where such use occurs, but Model 7 provides no evidence for this.

<<Table 3 about here>>

*Hypotheses 3: Correlation by competitors at the same physical facility*

Our third hypothesis is weakly supported in Table 3 in the final Model 8. Here, we isolate the utilization of competitors that occurs at the focal physician's main hospital. We had expected that even a shared physical setting would not be sufficient to drive the correlation of practices if there were no strong partnership ties. However, we failed to estimate a significant positive effect of competitor DES volume at one's own major hospital on own DES utilization. We interpret these estimates as showing that vicarious learning from other individuals at such shared social and physical sites is negligible.

*Robustness checks*

We investigated the robustness of our results to several changes in specification or estimation. Since we examined the movement of aggregates – quarterly flows of procedures – it is likely that errors are correlated across quarters, within physicians. In unreported analysis, a first order autoregressive error structure found significant positive serial correlation across quarters, but our estimates of interest were very similar to those reported here with robust standard errors and clustering by physicians.

We were also concerned with the risk that variations across physicians in the type of their patients (e.g. clinical differences in patient risk) could drive rates of DES use independently (Huesch, 2010b). In unreported analysis we computed a measure of individual patient expected in-hospital mortality and aggregated this across a physician's patients each quarter. Adding this variable showed its impact was significant and negatively signed (seeing riskier patients decreased DES use in line with on-label guidelines), but did not lead to meaningful differences in our coefficients of interest.

Our reported results modeled the dependent variable as the number of DES cases performed in a quarter. This approach may confound changes in practice scale with changes in practice focus (DES versus BMS). However our results were robust to replacing the dependent variable with the physician's quarterly ratio of DES cases per total angioplasty cases (DES + BMS + balloon only, no stent).

*Limitations*

Our findings are circumscribed by several caveats. Foremost among these is that our setting examines healthcare in one cardiac specialty in one Southeastern state in the US: results therefore lack external validity. Administrative billing data use is another limitation, since data of this provenance is well-known to have accuracy and integrity issues. However hospitals have a financial interest in coding DES stent procedures since the reimbursement amounts were higher than for the older BMS stents.

We have assumed that physicians were able to adopt or exnovate without substantial adjustment costs, and thus that such costs would not be spuriously correlated within a group or across a hospital. We justify this by pointing out that physicians who had previously made financial and human capital investments in learning how to use BMS found that these investments were fungible to DES and vice versa. This is due to the fact that the actual stent was very similar, and was inserted in an almost identical way. Manufacturers provided assistance and advice to deal with remaining small technical differences. In the empirical data, usage of

DES by individual physicians went from no cases to forty or more cases in successive quarters, illustrating the fungibility of techniques, clinical acumen and prior stent experience.

Another serious limitation is our use of self-reported publicly available licensure data and online searches of physician group members. These were collected in 2007, after the end of the 2003-2006 panel and did not allow us to understand all the network relationships in the more comprehensive manner that field work would have permitted.

In particular, the approach used in this study infers network relations through joint membership of a medical firm, mutual appointment to a hospital, or through geographical collocation. These inferences are flawed since they represent the superset of possible professional and geographical relations that could exist. The actual reference set for firms and members in those firms is likely smaller, more nuanced and varying over time in strength and type of tie (Lawrence, 2006).

As such, it is possible that network effects are systematically overestimated if partners communicate less frequently than assumed or with different referent groups than assumed or have changed groups repeatedly. However this bias would be towards the null of no association between peer behavior and own actions, hence is conservative. While our data use agreement forbade us from contacting physicians directly in this study, future field research in the manner of Edmondson et al. (2003) would better reflect dynamic and self-reported relationships between actors.

**Discussion and conclusions**

This study was undertaken to explore whether organizational barriers and competitive forces may affect knowledge transfer and harmonization of practices. The impetus for the study is the apparent conflict between those who see peer effects as possibly an important and positive force for reducing variation, and between those who point out the apparent persistence of practice variation. We used the dynamic adoption, utilization and partial abandonment of drug eluting stents in Florida between 2003 and 2006 to investigate possible peer effects among nearly 1,000 specialist cardiologists organized in locally competing practice groups or as solo practitioners.

Our empirical setting contrasts individuals in a physician group partnership with obvious close economic and social identity ties, and ones who 'merely' share a physical production site, and thus share a more diffuse social identity as physicians with the right to admit patients to a hospital and perform medical services in a cath lab. We inferred the transfer of knowledge by investigating the correlation in practices across all these different physicians.

The results suggest a nuanced picture. We find relatively high positive correlation in the practice behavior of specialist physicians who are partners in a group practice but relatively low or absent correlation in the practices of physicians who are competitors. The latter finding held whether considering solo cardiologists (for whom essentially every other cardiologist locally is a competitor) and also members of competing groups who are delivering care at the same main hospital. Sharing a production facility at a local hospital did not appear to overcome the apparent organizational barriers and competitive forces between cardiologists outside the same practice group.

We used a variety of regression specifications to attempt to control for alternative explanations for the correlation in DES use seen among members of the same group. Idiosyncratic propensity to curtail technology use was controlled for by a large number of individual and firm covariates or unobserved physician fixed effects. The lack of independence in repeated observations was addressed with robust standard errors clustered by physician. Aggregate contextual effects were controlled for using calendar fixed effects and time-varying geographical effects. Non-random sorting of physicians into firms was highly likely, but we presented plausible reasons that our physician fixed effect approach should have mitigated the homophily bias.

We cannot be certain that sorting of like-minded physicians into the same group has been adequately controlled for, nor that common shocks at the level of the practice might be causing spurious correlation. However the similarity of key estimates before and after appropriate controls for such spurious effects mitigates such concerns somewhat.

Past work often sees and models information spillovers in the medical sphere as acting at a distance without moderation by organizational structure or competition (Chandra and Staiger, 2007), strongly informed by social networks (Fowler and Christakis, 2008) and key opinion leaders (Valente and Davis, 1999). Our results imply a nuanced view should take into account the impact of the content of the information and the moderating influence of competitive forces on such knowledge transfer.

We see three tentative conclusions based on our results. First, a positive implication is that the risk of excessive imitation or widespread local herding by physicians on inefficient choices might be lower than once thought. Such mechanisms have been linked to iatroepidemics (Bikhchandani et al., 2002). Second, another positive implication is that when the conditions for successful knowledge transfer are auspicious then peer effects may be more likely to be important mechanisms for harmonizing physician behavior. In particular, when incentives, organizational setting, culture and interactions are all aligned as in practice groups, correlation in practice seems likely.

Finally, a third and more negative conclusion is relevant to the key conflict in the literature between evidence of successful efforts to use peer effects to improve care and reduced variation, and evidence of failure or incomplete success. Organizational barriers, different group cultures, and the negative incentives of competition for patients and reputation in a local market maybe key factor predicting the failure of peer effects as an instrument of policy. We believe these are important lessons for policy makers and regulators to bear in mind, and for other researchers to explore, as the search for effective actions to reduce costly and harmful variation continues.

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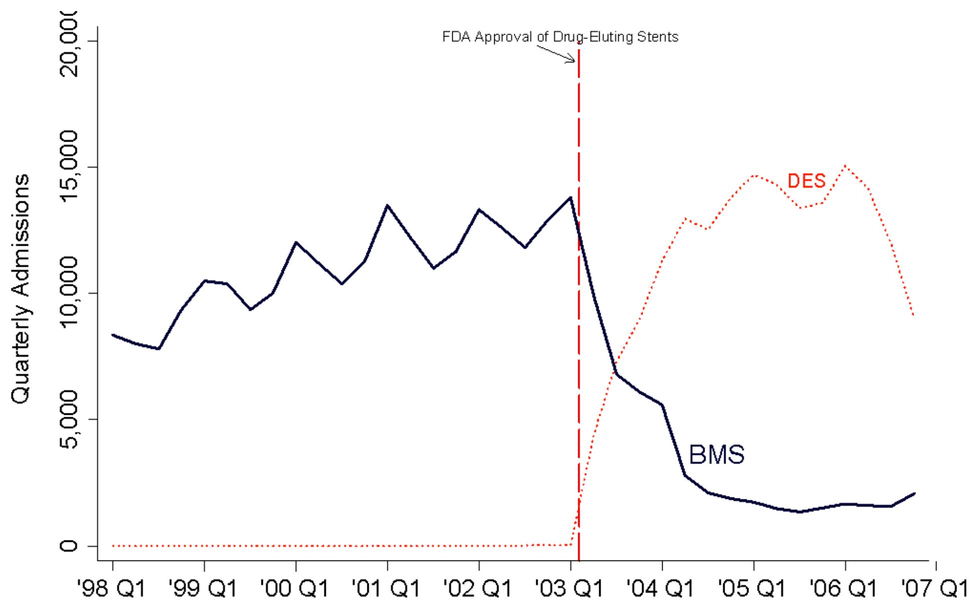
**Figure 1.** Aggregate DES stent diffusion dynamics in Florida.




Note: The uptick of DES use before the FDA approval in April 2003 is due to participation of Floridian interventional cardiologists in clinical trials.

**Table 1.** Key public events in the adoption and partial abandonment of DES stents, 2002-2007

| Date | | Public Information Sources | | | | |
|---|---|---|---|---|---|---|
| | | Market | Clinical Conferences | Clinical Journals | Peer Society Guidelines | FDA Regulator |
| 2002 | Q4 | CMS: new billing codes, ups payment | | | | |
| 2003 | Q1 | Physicians in trials: bullish | | | | Unanimously recommends DES |
| | Q2 | J&J: launches 'Cypher' | | | | Approves Cypher DES |
| | Q3 | Dramatic adoption, strong 'off-label' use | | | | |
| | Q4 | J&J: 'too much 'off-label' | | | | Warns 'off-label use' |
| 2004 | Q1 | Boston Scientific: launches 'Taxus' | | *JACC*: 'DES safe' | *ACC*: 'DES safe and effective' | Approves Taxus |
| | Q2 | J&J: 2 year DES follow-up positive | | | | Recalls some Taxus due to |
| | Q4 | DES rate 80% US, 20% Canada, 10% Europe | | *Lancet*: 'First LST cases' | | |
| 2005 | Q1 | | *ACC*: 'LST serious but infrequent' | *JACC*: 'LST cases found' | | |
| | Q2 | | | *JACC*: 'DES OK, need DAT'. JAMA: 'LST' | | |
| | Q3 | Dr Fogoros blogs: 'LST' | | | | Warns on need for DAT |
| 2006 | Q1 | *CRT*: 'LST not on the radar' | *ACC*: 'Basel definitive LST' | *JACC*: 'still optimistic on LST. Need DAT' | *ACC*/*AHA*/*SCAI*: 'stress DAT need' | |
| | Q2 | *WSJ*: 'Find LST' | | *JACC*: 'Warns on LST, need for DAT' | | |
| | Q3 | | *WCC*: 'LST'. ESC notes LST mortality | | | 'LST data insufficient' |
| | Q4 | *TCT*: 'LST'. WSJ: 'industry heartburn' | | *NEJM* and JACC: 'LST, DES risks'. | | 'On label' use only. Warns DAT |
| 2007 | Q1 | | | | *SCAI*: 'Clinical alert' | |

DES = Drug-eluting stents; LST = late stent thrombosis; DAT = dual antiplatelets therapy. CMS = Centers for Medicare and Medicaid Services; FDA = Food and Drug Authority. AHA = American Hospitals Association; ACC = American College of Cardiology; WCC = World Congress of Cardiology; ESC = European Society of Cardiologists; TCT = Transcatheter Cardiovascular Therapeutics; CRT = Cardiovascular Revascularization Therapies SCAI = Society for Coronary Angiographics and Interventions. JACC = Journal of the American College of Cardiology; JAMA = Journal of the American Medical Association; NEJM = New England Journal of Medicine, WSJ = Wall Street Journal.

**Table 2.** Estimating the impact of partner and competitor decisions on use of DES stents by physicians in group practices

| | How many DES stent cases did a group physician perform in the quarter? | | | | | | |
|---|---|---|---|---|---|---|---|
| Lagged independent variables | Model 0 | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 |
| DES by partners (cases) | | 0.083 *** | 0.086 *** | 0.065 *** | 0.066 *** | 0.017 * | 0.015 * |
| | | (0.012) | (0.012) | (0.014) | (0.014) | (0.007) | (0.007) |
| By group competitors (cases) | | | -0.007 ** | -0.011 *** | -0.004 | -0.007 ** | -0.007 ** |
| | | | (0.002) | (0.003) | (0.004) | (0.003) | (0.003) |
| By solo competitors (cases) | | | -0.004 | -0.003 | 0.006 | -0.011 ** | -0.010 ** |
| | | | (0.004) | (0.005) | (0.007) | (0.003) | (0.003) |
| Calendar fixed effects (quarters) | | | | Yes | Yes | Yes | Yes |
| County physicians (number) | | | | | -0.137 * | -0.163 ** | -0.189 ** |
| | | | | | (0.057) | (0.061) | (0.061) |
| Physician covariates | Yes | Yes | Yes | Yes | Yes | No | No |
| Physician fixed effects | | | | | | Yes | Yes |
| Main hospital effects | | | | | | | Yes |
| $R^2$ | 0.17 | 0.24 | 0.24 | 0.27 | 0.28 | 0.23 | 0.31 |
| *F* test statistic | 14.91 *** | 16.39 *** | 15.48 *** | 18.96 *** | 18.36 *** | 25.35 *** | 26.94 *** |
| Obs (physician*quarters) | 6,815 | 5,760 | 5,760 | 5,760 | 5,755 | 5,785 | 5,785 |
| Obs (physicians) | 568 | 549 | 549 | 549 | 547 | 553 | 553 |

Pooled least squares (models 0-4) and physician fixed effects panel regressions (models 5-6) on quarterly DES cases of physicians in group practices. Robust standard errors clustered by physician in brackets. Estimates (***), (**), (*) are significant at p-values <.001, .01, and .05.

**Table 3.** Estimating the impact of shared physical and social setting on use of DES stents

| How many DES stent cases did a group physician perform in quarter? | | |
|---|---|---|
| Lagged independent variables | Model 7 | Model 8 |
| DES by partners at main hospital (cases) | 0.017 * | 0.020 ** |
| | (0.007) | (0.007) |
| By partners elsewhere (cases) | 0.011 | 0.018 ¶ |
| | (0.010) | (0.009) |
| By group competitors (cases) | -0.008 ** | |
| | (0.003) | |
| By solo competitors (cases) | -0.010 ** | |
| | (0.003) | |
| By group competitors at main hospital (cases) | | -0.009 * |
| | | (0.004) |
| By solo competitors at main hospital (cases) | | 0.002 |
| | | (0.004) |
| Calendar fixed effects (quarters) | Yes | Yes |
| County physicians | -0.187 ** | -0.279 *** |
| | (0.061) | (0.061) |
| Physician fixed effects | Yes | Yes |
| Main hospital effects | Yes | Yes |
| $R^2$ | 31% | 30% |
| Obs (physician*quarters) | 5,785 | 5,785 |
| Obs (physicians) | 553 | 553 |

Note: Physician fixed effects panel regressions on physician quarterly DES cases of physicians in group practices. Robust standard errors clustered by physician in brackets. Estimates (***), (**), (*) and (¶) significant at p-values <.001, .01, .05 and .10.

**Online Appendices:**

## A1. Dataset construction and validation

Of 244,649 records of admission 2003 Q1 and 2006 Q4, records containing solitary treating physician tags (likely miscodes) and physicians identified as performing less than 1 case per quarter on average (likely assistants or miscodes) were removed.

This left 242,721 records with 1,216 treating physicians. Using publicly available data from the Florida Department of Health, we identified operating surgeons (since around 1% of PTCA admissions have a same-stay open heart surgery) coded in the treating cardiologist field. Patient records associated with these surgeons were discarded, as were records for physicians who were not present in the data for at least two quarters. After these procedures the panel data set comprised 238,965 patient records and 989 distinct treating non-surgeon physicians.

**A2**. Physician attributes by organizational form

| | Group physicians | | Solo physicians | |
|---|---|---|---|---|
| | Mean | SD | Mean | SD |
| Female gender | 3.1 | 0.2 | 5.8 | 0.2 |
| Practice size (members) | 5.5 | 4.7 | 1.0 | - |
| Quarterly patients (average cases) | 23.3 | 22.1 | 18.5 | 19.3 |
| Participation (quarters) | 12.0 | 4.6 | 10.2 | 5.0 |
| Total patients (cases 2003-2006) | 279 | 349.1 | 189 | 284.4 |
| Total patients (cases 1998-2002) | 348 | 413.4 | 238 | 347.4 |
| Privileges and licenses | | | | |
| Staff privileges (number of hospitals) | 2.8 | 1.9 | 2.4 | 1.7 |
| Licensed outside FL | 78.6 | 1.1 | 81.9 | 1.4 |
| Licensed outside USA | 1.1 | 0.1 | 2.0 | 0.1 |
| Holds faculty post | 0.2 | 0.4 | 0.2 | 0.4 |
| Training | | | | |
| Overseas MD or training | 6.1 | 0.2 | 5.1 | 0.2 |
| Last year | 1991 | 8.0 | 1991 | 8.6 |
| As internist | 84.7 | 0.4 | 75.7 | 0.4 |
| As cardiologist | 78.0 | 0.4 | 69.6 | 0.5 |
| As interventional cardiologist | 17.2 | 0.4 | 16.7 | 0.4 |
| In 'Honor Roll' institution | 20.3 | 0.4 | 17.1 | 0.4 |
| In 'Heart Hospital' | 45.6 | 0.5 | 37.7 | 0.5 |
| In 'Top 25 Hospital' | 28.3 | 0.5 | 22.5 | 0.4 |
| In 'Top 10 Hospital' | 17.1 | 0.4 | 13.1 | 0.3 |
| Credentials (number of certificates) | | | | |
| Internal medicine | 1.6 | 1.0 | 1.3 | 1.0 |
| Cardiology | 1.0 | 0.7 | 0.8 | 0.7 |
| Interventional cardiology | 0.2 | 0.4 | 0.1 | 0.3 |
| Early DES adoption | | | | |
| Used in 2002 Q4 | 1.5 | 0.1 | 2.3 | 0.2 |
| Used in 2003 Q1 | 1.7 | 0.1 | 1.3 | 0.1 |
| Used in 2003 Q2 | 65.8 | 0.5 | 65.5 | 0.5 |

Note: Unweighted summary statistics, percentages (unless otherwise noted). N = 575 for physicians in group practices, 414 for solo practitioners. 'Honor Roll', 'Heart Hospital', 'Top 25 Hospital' and 'Top 10 Hospital' refers to 2007 US News & World Report rankings for cardiovascular medical care.

**A3**. Estimating the impact of individual physician propensity and susceptibility attributes on use of DES stents

| How many DES stent cases did a physician perform in the quarter? | | | | | |
|---|---|---|---|---|---|
| Female gender | -2.23 | * | Staff privileges (#) | -0.25 | * |
| | (0.97) | | | (0.10) | |
| Calendar year of last training | -0.01 | | Licensed to practise outside FL | 0.87 | *** |
| | (0.02) | | | (0.15) | |
| Overseas MD or training | 1.96 | ** | outside US | 2.75 | * |
| | (0.72) | | | (1.39) | |
| Trained as internist | 2.74 | *** | Solo in a multi-specialty center | -1.98 | * |
| | (0.59) | | | (0.99) | |
| cardiologist | 2.47 | *** | Solo in a standalone office | -2.34 | *** |
| | (0.51) | | | (0.44) | |
| interventional cardiologist | 4.17 | *** | Group partners (#) | 0.14 | * |
| | (0.48) | | | (0.06) | |
| Trained at honor roll hospital | -2.18 | *** | Used DES before FDA marketing approval | 9.87 | *** |
| | (0.54) | | | (0.40) | |
| heart specialist hospital | 1.30 | ** | Quarterly average cath labs (#) | 7.87 | *** |
| | (0.45) | | | (0.37) | |
| top 25 heart hospital | 1.97 | ** | Quarterly fixed effects | Yes | |
| | (0.57) | | Main hospital fixed effects | Yes | |
| Credentials in internal medicine (#) | 0.58 | ¶ | | | |
| | (0.33) | | F test of physician covariates | 122.2 | *** |
| cardiology | -2.91 | *** | hospital effects | 26.0 | *** |
| | (0.51) | | quarterly effects | 86.6 | *** |
| interventional cardiology | 6.09 | *** | | | |
| | (0.61) | | $R^2$ | 0.354 | |
| Faculty posts held (#) | 0.44 | | Observations (physician*quarters) | 10,895 | |
| | (0.45) | | Observations (physicians) | 989 | |

Note: Pooled least squares regression on physician quarterly DES cases for all physicians. Robust standard errors clustered by physician. (***), (**), (*), (¶) indicate coefficient estimates significant at p-values <.001, .01, .05 and .10.

**A4**. Correlation matrix and descriptive statistics

| Sample restricted to focal physicians in groups, quarterly DES count by | | Obs | Mean | Std. Dev. | v1 | v2 | v3 | v4 | v5 | v6 | v7 | v8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| v1 | Focal physician | 6873 | 16.96 | 21.04 | 1.00 | | | | | | | |
| v2 | All physicians, in county, t-1 | 5802 | 592.26 | 399.94 | 0.08 | 1.00 | | | | | | |
| v3 | Group competitors, in county, t-1 | 5802 | 406.02 | 308.84 | 0.06 | 0.87 | 1.00 | | | | | |
| v4 | Solo competitors, in county, t-1 | 5802 | 167.36 | 202.47 | -0.02 | 0.64 | 0.17 | 1.00 | | | | |
| v5 | Partners, at main hospital, t-1 | 5802 | 66.83 | 97.83 | 0.25 | 0.28 | 0.42 | -0.12 | 1.00 | | | |
| v6 | Partners, not at main hospital, t-1 | 5802 | 16.75 | 48.16 | 0.03 | 0.02 | 0.11 | -0.13 | 0.00 | 1.00 | | |
| v7 | Group competitors, at main hospital, t-1 | 5802 | 91.25 | 119.86 | -0.05 | 0.26 | 0.35 | -0.01 | -0.03 | 0.01 | 1.00 | |
| v8 | Solo competitors, at main hospital, t-1 | 5802 | 67.95 | 86.88 | 0.04 | 0.37 | 0.25 | 0.35 | 0.09 | -0.10 | 0.62 | 1.00 |

| Sample restricted to focal physicians not in groups, quarterly DES count by | | Obs | Mean | Std. Dev. | v9 | v10 | v11 | v12 | v13 | v14 |
|---|---|---|---|---|---|---|---|---|---|---|
| v9 | Focal physician | 4231 | 13.43 | 18.56 | 1.00 | | | | | |
| v10 | All physicians, in county, t-1 | 3429 | 601.69 | 427.68 | 0.11 | 1.00 | | | | |
| v11 | Group competitors, in county, t-1 | 3429 | 327.39 | 257.35 | 0.03 | 0.87 | 1.00 | | | |
| v12 | Solo competitors, in county, t-1 | 3429 | 258.96 | 237.61 | 0.09 | 0.85 | 0.47 | 1.00 | | |
| v13 | Group competitors, at main hospital, t-1 | 3429 | 125.59 | 140.26 | 0.12 | 0.15 | 0.34 | -0.10 | 1.00 | |
| v14 | Solo competitors, at main hospital, t-1 | 3429 | 84.07 | 83.96 | 0.11 | 0.30 | 0.21 | 0.31 | 0.51 | 1.00 |

Patient-weighted sample statistics restricted as indicated. All correlations with absolute value greater than 0.03 are significant at p-value < .01.

**A5.** Estimating the impact of partner and competitor decisions on use of DES stents by solo physicians

| | How many DES stent cases did a solo physician perform in the quarter? | | | | | | |
|---|---|---|---|---|---|---|---|
| Lagged independent variables | Model 0b | Model 1b | Model 2b | Model 3b | Model 4b | Model 5b | Model 6b |
| DES in county (cases) | | 0.003 | | | | | |
| | | (0.002) | | | | | |
| By group competitors (cases) | | | -0.002 | -0.008 * | -0.007 ¶ | -0.002 | -0.002 |
| | | | (0.003) | (0.004) | (0.004) | (0.003) | (0.003) |
| By solo competitors (cases) | | | 0.009 * | 0.004 | 0.005 | 0.002 | 0.001 |
| | | | (0.004) | (0.004) | (0.005) | (0.004) | (0.004) |
| Calendar fixed effects (quarters) | | | | Yes | Yes | Yes | Yes |
| County physicians (number) | | | | | -0.020 | -0.037 | -0.029 |
| | | | | | (0.055) | (0.082) | (0.082) |
| Physician covariates | Yes | Yes | Yes | Yes | Yes | No | No |
| Physician fixed effects | | | | | | Yes | Yes |
| Main hospital effects | | | | | | | Yes |
| $R^2$ | 0.13 | 0.12 | 0.12 | 0.16 | 0.17 | 0.17 | 0.24 |
| *F* test statistic | 5.42 *** | 3.25 *** | 3.13 *** | 7.35 *** | 7.06 *** | 10.20 *** | 12.06 *** |
| Obs (physician*quarters) | 4,080 | 3,330 | 3,330 | 3,330 | 3,264 | 3,264 | 3,264 |
| Obs (physicians) | 391 | 376 | 376 | 376 | 366 | 366 | 366 |

Pooled least squares (models 0-4) and physician fixed effects panel regressions (models 5-6) on quarterly DES cases of solo physicians *not* in group practices. Robust standard errors clustered by physician in brackets. Estimates (***), (**), (*) and (¶) are significant at p-values <.001, .01, .05 and .10.

**A6.** Attributes of physician industrial organization (*N*= 565 county*quarter obs)