Experience and Performance: Evidence from Acute Myocardial Infarctions*

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Abstract

Estimating the effect of experience on performance is complicated due to the non-random sorting of workers to tasks. We propose a new empirical approach that addresses such sorting by exploiting as-if random assignment of physicians to patients during call-hours. For this purpose, we use linked patient-physician data on acute heart attack treatment in Sweden and show that the systematic sorting of doctors to patients disappears during call-hours. Using data collected during call-hours, we show that experience has long-lasting effects on physician proficiency and decision-making, but that effects on patient outcomes are rapid and short-lasting. Our paper shows that using on-call time data could be a promising way to estimate causal learning curves.

Keywords: operation volume, learning-by-doing, survival, causal effect.
JEL-codes: I11, I12, I18, L11.

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1 Introduction

Does experience increase worker productivity? Becker (1964) formalized the idea that human capital increases through the very act of working, reflected in increasing seniority-wage profiles. Others have questioned whether such profiles reflect learning and instead proposed delayed compensation mechanisms as responsible where workers are paid below their marginal productivity early on in their careers but above later (see, for example, Lazear and Moore 1984).[1] The correct interpretation is of fundamental importance for the understanding of labor markets, but also for evaluating the importance of worker experience in markets such as health care, where concerns often arise about the performance of unexperienced physicians.

Examining whether experience improves workers productivity has proven challenging. First, the researcher needs to observe individual work performance which is typically lacking in most administrative registers and surveys. Second, workers are often allocated to tasks partly based on their experience. In the health care sector, for instance, more experienced physicians typically treat more frail patients. Third, dynamic selection effects mean that more productive workers are more likely to stay on the job, producing a spurious relationship between experience and performance. For these reasons, there is relatively little causal evidence to date on the effect of experience on productivity.

Our paper addresses the challenges above and provides new evidence on how experience affects performance. We use detailed data on Swedish myocardial infarction treatments where we can link physicians to patients and follow individual physicians over time. These data give us several advantages. First, we can measure performance through individuals patient outcomes and through the physicians use of medical inputs. Second, we can exploit a situation where we break any systematic allocation of workers to tasks. We do so by focusing on acute myocardial infarction treatments during on-call shifts at Swedish hospitals where only one physician is in charge and where there thus can be no systematic allocation of physicians to patients.[2] Moreover, we can study the importance of dynamic selection effects by following the same physician over time as (s)he accumulates more experience.

Myocardial infarction treatment constitutes an interesting case study on the role of experience since they are complicated tasks that involve a range of decisions to be taken under time pressure. If learning-by-doing is an important phenomenon we would

[1] Upward-sloping earnings-tenure profiles have also been interpreted in a matching-model framework (Jovanovic, 1979)

[2] We define on-call shifts as nights, holidays and weekend shifts.

expect to see it play out in this context. In that sense our study contrasts to some earlier work that have focused on standardized and trivial tasks in order to avoid any systematic allocation of workers to tasks but where the scope for learning is limited.

In our analysis, we focus on myocardial infarctions treated by percutaneous coronary interventions (PCI). We start our analysis by studying how patients are allocated to physicians during office hours and during on-call shifts. As expected, we observe a strong positive correlation between physician experience and predicted risk of the patient during office hours, reflecting that more difficult cases are often allocated to more experienced physicians. When we redo this analysis during on-call shifts the correlation vanishes and both predicted health risk and individual patient characteristics are unrelated to physician experience.

Having established that the allocation of patients to physicians during on-call shifts is as good as random we then estimate the effect of experience on the use of medical inputs and on patient health outcomes. Our results suggest that experience improves the skills of physicians treating myocardial infarctions. More experienced physicians are faster in identifying blockages in the arteries and expose their patients to less radiation when doing x-rays. In addition, they use more invasive procedures as measured through the number of arteries treated and the number of stents inserted. We find less effect of experience on health outcomes. However, since learning may occur faster in the beginning of ones career, and may be more rapid for difficult tasks, we also perform regressions on the lower part of the experience distribution and focus on myocardial infarctions among high risk patients. Here, we find large health effects over the first 100 PCI treatments that quickly disappears as the number of PCI's increase. This shows that learning is rapid when dealing with difficult tasks but also confirm the suspicion that there are health risks involved when having unexperienced physicians treating frail patients on their own.

We deal with a number of potential threats to our empirical design. We show that experience is unrelated to the number of patients treated during night shifts, assuring that our results on experience are not driven by fatigue or stress. We also show that early patient outcomes of PCI treatments are unrelated to whether a physician stays on the job in the future, suggesting that dynamic selection effects are not important in our context.

Taken together, our results have implications for the literature on experience and learning. Our results show that experience matters for performance in an advanced job task where the scope for learning is large. These job characteristics are shared by many jobs in the Western world suggesting that our results have wider generalizability. Our results also lend some support to a human capital-based explanation for upward-sloping experience-wages profiles where workers accumulate human capital by learning-by-doing and where wages increase with tenure because experienced workers have accumulated more human capital.

Our paper also adds to the labor economics literature that has estimated the causal effect of experience on worker productivity. In two influential studies, Medoff and Abraham (1980, 1981) showed that differences in performance ratings between employees in a U.S. firm could not explain cross-sectional earnings-experience. Arguing that using subjective performance evaluation is potentially problematic Flabbi and Ichini (2001) replicated the findings of Medoff and Abraham using more objective performance measures such as misconduct and absence and found largely similar results using data on Italian bank employees. Shaw and Lazaer (2008) use data on Windshield installation at a U.S. factory and estimate steep and short learning curves. The benefit of that setting is that performance is easy to measure and that the task is standardized which avoids any systematic allocation of workers to task.[3]

2 Context and background

We next first describe PCI treatments in more detail to provide the context in which we estimate the causal effect of experience on performance. We then discuss why experience could matter in this context and how learning may take place.

2.1 Context: Percutaneous coronary intervention (PCI)

In our empirical analyses, we focus on the treatment of coronary artery diseases, including myocardial infarctions and anginas, which occurs when the artery becomes hardened and narrowed, obstructing the blood flow to the heart. This occurs due to the buildup of cholesterol and other material, called plague, inside the artery. If the reduced blood persists for some time it can result in a acute myocardial infarction but even if the blood flow is restored quickly it may still lead to chest pain (angina). Coronary artery diseases are important as they are the leading causes of death worldwide among both men and women.[4]

[3]A related literature estimates the effect of teacher experience on student test scores using value-added models (e.g. Rockoff 2004; Rivkin et al. 2005; Ost 2014). Particular challenges for this literature is potential student sorting and sorting of teachers to classes based on experience (Rothstein 2010).

[4]Each year, more than 30,000 Swedish residents and about 1 million Americans suffer from an acute myocardial infarction (AMI). Source: CDC http://www.cdc.gov/NCHS/data/nvsr/nvsr58/nvsr58_19.pdf.

Coronary artery diseases are treated using reperfusion therapy, i.e. by restoring the blood flow through the blocked arteries. Various techniques exist how to accomplish this and in this paper we focus on coronary catheterization procedures, often referred to as PCI (Percutaneous Coronary Interventions), which involves a catheter-based treatment of heart diseases. During the PCI a sheath is inserted into a major artery, either in the groin (femoral artery) or in the arm (radial artery). The sheath is used to perform various procedures. Initially, the physician aims to identify the blocked arteries using contrast medium and X-ray, which shows how the blood flows through the arteries (so-called fluoroscopy). The blocked arteries that are identified are usually pushed open using the inflation of a balloon within the artery that crushes the blockage into the walls of the vessel. To ensure that the vessel remains open after the balloon dilation, the cardiologist may also insert a stent, a tube-shaped metal device, holding the vessel open with the aim to prevent future blockage.

The major advantages of using catheters compared to open surgery in treatment of coronary heart disease lies in their less invasive nature and, as such, avoids scars, pain and long recovery periods. Catheterization techniques have therefore become the gold standard for treating, e.g., acute myocardial infarctions.[5]

2.2 PCIs and learning

PCI treatments constitute an interesting context to study the effect of experience on performance since it is widely believed in the medical profession that learning is important. The PCI physician, or cardiologist, face a number of important decisions that may be affected by learning and experience. First, the physician has to choose between inserting the catheter through the groin (femoral artery) or in the arm (radial artery). In a meta-anlysis of randomized trials, Ferrante et al. (2016) concluded that radial access reduces major bleeding and patient complications, but inadequate training and experience might prevent the use of the radial technique (Gilchrist 2015). Second, the physician needs to act fast in identifying the blocked arteries using contrast medium and X-ray expose. Here, the skill of the physician is often measured through the length of radiation exposure (so-called fluoroscopy time), and several recent medical studies

[5]Besides PCI the main alternative treatments are Pharmacological thrombolysis and Coronary Artery Bypass Grafting (CABG) surgery. In Sweden, pharmacological thrombolysis, which consists of giving the patient drugs which actively breaks down the blood clots that block the artery, typically is considered a secondary treatment that is performed if a PCI could not be performed within 120 minutes from the onset of the acute myocardial infarction. This mainly occurs as a result of long travel distances in sparsely populated areas (Socialstyrelsen 2015). Particularly severe cases of heart attacks, e.g. in which multiple coronary arteries are blocked, may undergo CABG surgery, in which arteries from other parts of the body are surgically grafted onto the arteries.

find a positive relationship between experience and fluoroscopy time (Hess et al. 2014; Ferrante et al. 2013; Jensen et al. (2012). Third, the physician also has to decide on how many vessels and segments to treat, and for each vessel the physician has to decide on the exact type of treatment, relating to the invasiveness of the procedure. All these decisions can have important consequences for the patient's health.

Besides these treatment decisions, the experience of the PCI physician might affect the quality of a given procedure. For instance, if the balloons and stents are not optimally placed in the blood vessel this could influence the likelihood of another coronary artery diseases, and thus affect the likelihood of a new PCI and ultimately mortality. The experience of the physician is, thus, potentially important both for decisions about technology and practice-style but also for the quality of the performance of a given medical procedures.

Treatment decisions may also be affected by financial incentives faced by physicians but the Swedish context of our study allows us to rule out the role of any such incentives.[6] The reason is that the health care sector in Sweden is highly regulated with hospitals almost entirely owned and run by the public sector. One consequence of this is that most physicians at the hospitals in Sweden are salaried and receive no monetary rewards for treating more patients or for providing higher quality care.

3 Data description

Our data originates from the Swedish Coronary Angiography and Angioplasty Registry (SCAAR), which is a Swedish national database that registers all coronary procedures.[7] From 2002 and onwards it is a complete register on all patients from all 29 centers that perform coronary interventions in Sweden.. We use data for the period 2004-2013, since information on on-call time is available from 2004. We restrict the sample to physicians who performed their first PCI in 2002 or later, since we observe all PCIs that each physician has ever performed for this group. The register links physicians to patients and includes detailed information on all medical procedures performed during the PCI. We are able to follow physicians over time, so that we can construct a detailed history of all patients that they ever treated.

By linking the SCAAR register to the SWEDEHEART register, which provides information on all heart patients in Sweden, we are also able to observe patient health

[6]Evidence that physicians financial incentives affect their treatment choices in myocardial infarction management have been obtained in the US. (Coey 2015).

[7]The registry is developed and administered by the Uppsala Clinical Research Center (UCR) and sponsored by the Swedish Health Authorities and is thus independent of commercial funding.

outcomes. Using this information we construct health histories for each patient in our sample, following the approach in earlier medical studies of PCIs (see e.g., Hambraeus et al. 2016). In our regressions we can control for health characteristics measured before the PCI, such as the patients age, BMI, gender, previous infarctions and PCIs, and information on diabetes and smoking. We also use these variables to show that the experience of physicians is unrelated to the characteristics of the patients treated during on-call shifts, i.e. that our quasi-experimental approach work.

A key variable in our empirical analysis is physician experience. We define experience as the cumulated number of PCIs, i.e. the number of previously performed procedures. In additional analyses, we also explore other measures of experience, such as experience from treating acute cases and if physicians learn more from PCIs where treatment mistakes took place. An alternative would be to measure experience in terms of years and months since the first PCI, but as seen in Figure 1 the relationship between experience in terms of the number of PCIs and experience in years since the first PCI is almost linear. From this figure we see that physician on average perform about 80 PCIs during their first year followed by about 100 PCIs per year in subsequent years.

We study effects on several outcomes related to physician proficiency, physician decision making and patient health. To measure physician proficiency we use outcome measures routinely used in the medical literature on PCI treatments (see e.g., Hess et al. 2013; Jensen et al. 2012). We use detailed information on all medical procedures that are performed during the PCI to examine the relationship between physician experience and physician decision making in the form of the level of invasiveness of the procedures performed during the PCI. Our main health outcomes are the probability of dying or having a new infarction within one year after the PCI and and indicator for any complications during the PCI. All these outcomes are described and discussed in more detail in Section 5.

Table 1 provides sample statistics for our analysis sample. We have information on 27,727 PCIs. The sample includes 76 different physicians across 28 PCI centers in Sweden. The table also provides descriptive statistics for all background characteristics and all outcomes used in the analysis. From this we see that the patients are old (41% are older than 70) and that quite a few have had a previous infarctions (51%).

4 Empirical strategy

In order to study the causal effect of experience on performance the most important goal of our empirical design is to break any systematic allocation of patients to physicians.

We therefore next study how cardiologists are allocated to patients in the Swedish context in more detail. First, we relate the experience of the surgeon to the pre-determined health of the patient during day-time shifts. Here, we expect to see substantial sorting since there is typically several physicians around and since high-risk patients may be allocated to more experienced physicians. We will then redo this exercise on data from on-call shifts, where we expect no systematic sorting of physicians to patients since there is only one single physician around treating patients. Below we provide the details of these analyses.

To study the sorting of physicians to patients we first construct a measure of patient risk. We do this by using the pre-determined health characteristics to predict the 1-year mortality/infarction rate for each patient.[8] We then correlate this measure of patient risk with the experience of the physician allocated to the patient. Panel A of Figure 2a shows this correlation between predicted patient risk and physician experience for all PCIs conducted during office hours, when usually more than one physician is available at each PCI center. The dots show the average experience when the patients are divided into different risk bins, and the solid line is the estimated quadratic relationship between the two variables.[9] As expected we find a strong relationship between physician experience and predicted mortality/infarction risk. This pattern is in line with the results from previous studies on the allocation of surgeons and suggests that experienced physicians often take on high-risk patients (see e.g., Glance et al. 2008).

At a given point in time, any systematic sorting of physicians to patients can only take place if there is several PCI physician around. During on-call time, defined as weekends, holidays, early morning, and late nights, there is normally only one single physician around, meaning that there could be no systematic sorting of patients to physicians. Selection during call-time may still occur, however, if certain types of physicians are scheduled to work during certain weekends and holidays. Conditional on hospital, year, month and weekday effects, however, we expect no relationship between patient health and physician experience during on-call time. This is confirmed by Figure 2b, which shows that the correlation between predicted patient risk and physician disappears during on-call time.[10] Using data from on-call shift we are thus able to

[8]Specifically, we estimate a logit regression using the observed characteristics described in Table 1, and use the estimates from this model to predict the individual risk.

[9]We show residual plots after taking out hospital and time fixed effects, since we are interested in the selection of physicians within hospitals. For ease of comparison we have added the variable means to the residuals.

[10]In the data, the physician records if the PCI was performed during on-call time. We use this information together with the exact date and time to construct our on-call time indicator, taking the value on if the physician records it as on-call time and if the PCI was performed during a holiday, weekend, or Monday to Friday before 7am and after 18pm. The latter removes some PCIs that was

generate the as-if random allocation of physicians to patients needed to study the effect of experience on performance.

The selection patterns for office hours and on-call time described above are confirmed by the results in Table 2, which reports estimates of the relationship between physician experience, measured as number of previous PCIs, and predicted patient mortality risk, while controlling for hospital and time fixed effects. The estimate in Column 1 for office hours shows an increase in the predicted risk is associated with a sizeable and significant increase the experience (average number of PCIs) of the PCI physician. But, note that, PCIs performed during office hours include both acute and non-acute cases, while during on-call time almost all of the treated patients suffer from an acute disease. In Column 2, we therefore, restrict the office hours sample to only acute cases, but for this subpopulation we also obtain a strong correlation between predicted patient risk and physician experience. As expected, this correlation vanishes during on-call time (Column 3). Moreover, Table 5 in the Appendix reports the correlation between physician experience and each patient characteristic used to construct the predicted risk. For variables like age and previous health we find significant correlations during office hours, but for the on-call time sample only one out of 12 estimates is significant at the 10-percent level.

The evidence presented so far suggests that patients are as-if randomly allocation to physicians during on-call shifts, when only a single physician treats all patients. To shed further light on the allocation of different types of work shifts Figure 3a shows the total number of work shifts by experience in years since the first PCI.[11] In their first year of work, physicians do about 60 work shifts on average. We then see a gradual increase but from the third year on the yearly number of shifts stays rather constant. Next, Figure 3b shows that the fraction of on-call time work shifts also changes with experience. Two things stand out from the figure. In the beginning of the career (first three years), the physicians on average are allocated to fewer on-call time shifts but after these first years the fraction of on-call time shifts stays rather constant at around 20 percent. This illustrates that both experienced and very experienced physicians are scheduled to work on on-call time. It reflects that physicians who can perform a PCI are in high demand and that each hospital only has a handful of PCI physicians in place, so that all of them have to do on-call shifts.

Another potential concern is that physicians who perform poorly in the beginning

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incorrectly recorded as on-call time and the former removes PCIs performed by the office hour group after office hours.

[11]This counts work shifts with at least on PCI. During some on-call time shifts there are no patients, in which case we have no information on the physician that was on-call but who was not called to the PCI center.

of their career stop performing PCIs, either because they choose another speciality or because they are fired by the hospitals. This would create a selection problem where the least skilled physicians would never reach a large number of PCIs, giving rise to a spurious correlation between experience and performance. We can explore this possibility by quantifying early performance in the first two years using our outcome measures and examining if early performance predicts the number of PCIs the physicians perform later in their careers (during years 3 and 4). The latter is set to zero if the physician quits. We use two measure of early performance; average 1-year infarction/mortality (Figure 4a) and average fluoroscopy time (Figure 4b). In none of the cases do we find a significant correlation between early performance and the future number of PCIs. This probably again illustrates that PCI physicians are in high demand and that hospitals use them even if their initial performance is below average. We have also used other performance measures and studied early performance in the first year, leading to the same conclusion.

A final concern is that the physicians at the emergency room may not send a (high-risk) patient with a myocardial infarction to the PCI clinic if an unexperienced physician is on call.[12] In such case we would see a correlation between the *number* of PCIs performed during an on-call shifts and physician experience but as shown in Figure 5) both unexperienced and experienced physicians perform on average around 1.4 PCIs per on-call shift.

4.1 Econometric model

Our baseline model for outcome, y, of individual i at hospital h on weekday w in month m and year y is:

$$y_{ihymw} = \lambda_h + \nu_y + \delta_m + \mu_w + \gamma log(experience) + X_i\beta + \varepsilon_{ihymw}. \qquad (1)$$

Here, we capture the effects of experience using the log of the cumulated number of PCIs performed, but we also use the same model to examine effects of experience in different bins. In the model we control for hospital fixed effects, i.e. PCI clinic fixed effects since each hospital have one PCI clinic at most. This allows us to focus on the allocation of patients and physicians within hospitals, thus controlling for any sorting of patients and physicians across hospitals. Model 1 also includes year- and month

[12]The number of PCIs during a shift may also change if experience affects how quickly the PCI is performed as this may result in congestion at the PCI center. But, note that each physician perform on average 1.4 PCIs during each shift and the average time of an PCI is around 30 minutes, so that congestion is not a problem.

fixed effects (ν_y and δ_m) to control for seasonal variations in patient health. Weekday fixed effects (μ_w) are also included to control for within week variation, since certain physicians might be more likely to be scheduled on certain days of the week. We also include a set of individual characteristics (X_i), that is chosen on the basis of previous studies of PCI treatments (see e.g., Hambraeus et al. 2016).[13]

5 Main results

5.1 Physician proficiency and decision making

We start our empirical analysis by studying how experience affects physician proficiency, using proficiency measures that are routinely used in the medical literature. Our first measure is fluoroscopy time, which describes how efficiently (in time) the PCI is performed (see e.g., Hess et al. 2013; Jensen et al. 2012). This is an important measure, since X-rays are used throughout the PCI procedure, both during the initial examination of the blood flow and when performing all sub-treatments.[14] If any difficulties arise, for instance because of a mistake made by the physician, this will results in a longer fluoroscopy time, meaning that shorter fluoroscopy time indicates a more successful PCI and a higher level of physician proficiency. Our second measure physician proficiency is an indicator of the radial technique, which has been found to reduce complications but is considered more complex, so that experience may be important (Ferrante et al. 2016). Thus, the radial technique offers another way to study physician proficiency since physicians with better technical skills will choose the radial technique, which is associated with fewer complications but more complex.

Figure 6a describes the relationship between fluoroscopy time and physician experience. The figure reveals a very distinct learning pattern where average fluoroscopy time is substantially lower for more experienced physicians. The learning process appears to start early on, continues during at least the first 1000 cases, but slows down beyond that.[15] Next, Figure 6b shows a similar learning pattern for the radial punc-

[13] The risk factors include indicators for diabetes, insulin treated diabetes, hypertension, lipid lowering medicine, previous infarction, previous Coronary artery bypass surgery, previous PCI, Male patient, Age 60-69, Age 70-79, Age 80+, Smoker, BMI over 25, normal atheromatous, 1-vessel disease, 2-vessel disease, 3-vessel disease, and main stem vessel disease.

[14] One example is when the balloons and the stents are placed at the right place. This requires a high level of technical skills as the physician needs to guide the catheter through the artery into the heart and place the catheter exactly at the right place in the blood vessel.

[15] After roughly 1000 cases fluoroscopy time starts to increase, but this is because physicians start to provide more invasive treatments at this point, and this by construction lead to longer fluoroscopy time as the X-ray is used when ballons/stents are placed.

ture technique. This technique, which is preferred to the alternative femoral technique, gradually increase with experience, but after around 1000 cases we see no additional effect of experience. In sum, experience over the first 600 case matters the most for physician proficiency. Having performed 600 PCI treatments corresponds to around 5 years of experience (see Figure 1).

The patterns in the figures are confirmed by the estimates in Column 1 of Table 3 where we estimate effects of experience between 251–500 cases, 501–1000 cases and above 1000 cases. The omitted reference category is experience below 250 cases. The estimates for fluoroscopy time is significant while the estimates for the radial puncture does not reach statistical significance.

Besides proficiency, experience could also affect decision making and we next study if the level of invasiveness is affected by experience. This is an important dimension, because in many cases the diagnostics during the PCI show that more than one segment of the heart is affected by some form of blockage. The physician then has to decide if (s)he should treat all or several affected vessels, instead of treating only the vessel with the most reduced blood flow. Thus, the number of treated segments is one measure of the level of invasiveness. Another related measure is how stents are used during the PCI. Stents are metal nets that are placed and left within the artery as a way to prevent future infarctions. Here, we use the total stent length, which varies both due to the length of each stent and due to the number of stents, as another measure of the level of invasiveness. It should be noted that these measures do not necessarily inform us whether or not optimal decisions were taken since an increase in the number of treated segments or stents is not necessarily better. With these measures we can thus only study if experienced physicians choose more invasive treatments.

In Figure 6c we see that stent length is unaffected by experience during the first 600 PCIs performed but starts to increase after that. The corresponding regression estimates in Column 3 of Table 3 confirm that stent length is unaffected for experience between 0 and 500 cases. Beyond that, stent length increases with experience but the difference is only significant for experience above 1000 PCIs. For the number of treated segments we see more of a positive and linear relationship with experience, as illustrated in Figure 6. Column 4 shows that the effects are significant for those having performed more than 500 PCIs.

We conclude that the learning patterns for physician decision making are very different compared to the patterns for physician proficiency, where the sharpest learning effects took place over the first 600 PCIs with very little learning beyond that. These patterns are consistent with physicians initially focusing on improving their technical skills, leading to more efficient PCIs and using more modern techniques. Once physicians reach a high level of proficiency after around 600 cases or roughly five years of experience, they seem to start focusing on the invasiveness of the treatments but only after the learning effect for proficiency has flattened out.

5.2 Patient health

We next examine if the effects on physician proficiency and decision making translate into effects on patient health. As health outcomes, we use the 1-year mortality/infarction rate and an indicator for any complication during the PCI. As above, we first illustrate the effects of physician experience graphically. Interestingly, Figure 6e and Figure 6f reveal no effects of operator experience on mortality/infarctions or complications. These patterns are confirmed by the regression estimates in Columns 5-6 of Table 3, which reveals no significant effects, except for one estimate that is significant at the 10-percent level.

Figures 6e-f and Table 3 focus on experience up to 1500 PCIs, but a number of medical studies on learning curves for PCIs suggest that learning effects for health outcomes mainly occurs during the first 50 cases. For instance, Ball et al. (2011) finds that experience from 50 PCIs is enough to achieve outcomes comparable to those for experienced physicians. In nationwide US study, Hess et al. (2014) also documents learning effects below 50 cases, but very little learning beyond that. Although both these studies use observed characteristics to adjust for selection, and therefore cannot establish causality, they provide suggestive evidence that learning effects on patient health only occur at very low levels of experience.

For these reasons, we zoom in on learning over the first 250 PCIs performed and divide our sample by patient risk since experience may be more important for the treatment of high-risk groups. As indicators of patient risk we use the predicted risk and information on the type of myocardial infarction. Specifically, we study all myocardial infarctions and the sub-sample of patients with a STEMI infarction, which means that one artery is completely blocked. STEMI patients also has the highest mortality rate.

Figure 7 illustrates the experience patterns when we divide the patients into low- and high risk groups and by type of infarction. The figure shows that experience leads to lower mortality/infarction rates but only among high-risk patients and only when we focus on low levels of experience. In particular, Figure 7d reveals learning effects for high-risk STEMI infarctions over the initial 100 cases treated, but no learning after that. We quantify these patterns in Table 4 where we use log experience as explanatory variable. These regression estimates confirm the patterns illustrated in Figure 7 and for high-risk STEMI patients we find significant learning effects over the initial 100 PCIs (Column 4). For all PCIs we also find a tendency towards a learning effect over the first 100 cases, but the estimate is insignificant (Column 2). If we focus on the first 250 cases we find no significant effects of physician experience (Columns 1 and 3).

Summing up, we find some evidence that experience in terms of effects on patient health matters for the most difficult cases (STEMI infarction patients and high-risk patients), which suggests that it takes longer time for physicians to learn how to treat more severe and complicated cases. This learning process is very rapid and disappears after the first 100 PCIs performed, confirming the patterns obtained in some previous observational studies in the medical literature.

6 Conclusions

This paper documents causal effects of physician experience on physician proficiency, physician decision making, and patient outcomes. Using data on the universe of PCI treatments in Sweden we document evidence of learning in several dimensions. One conclusion is that operator experience results in greater physician proficiency and altered decision making. Using proficiency measures commonly used in the medical literature we demonstrate a strong causal relationship between experience, measured as the cumulated number of PCIs, and proficiency. This learning effect is persistent with improved physician proficiency during the first 1000 PCIs performed, but with slower learning after the first 600 cases.

Greater experience also affects physician decision making in several dimensions. We find that experienced physicians are more likely to choose a more invasive treatment strategy compared to less experienced physicians. The learning patterns for decision making are rather different compared to those for physician proficiency, however. For decision making, experience only starts to matter after the initial 600 cases, while for proficiency learning mainly takes place during the first 600 cases. These patterns are consistent with physicians initially focusing on improving their technical skills and after that turning their attention to decision making.

Our paper also documents some evidence of a causal relationship between physician experience and patient outcomes. One conclusion is that physician experience is more pronounced for the treatment of the high-risk patient groups and for severe myocardial infarctions, which is in line with the idea that it takes longer time for physicians to learn how to treat the more complex cases. The learning effects are concentrated to the first 100 PCIs, however, with very little learning beyond that.

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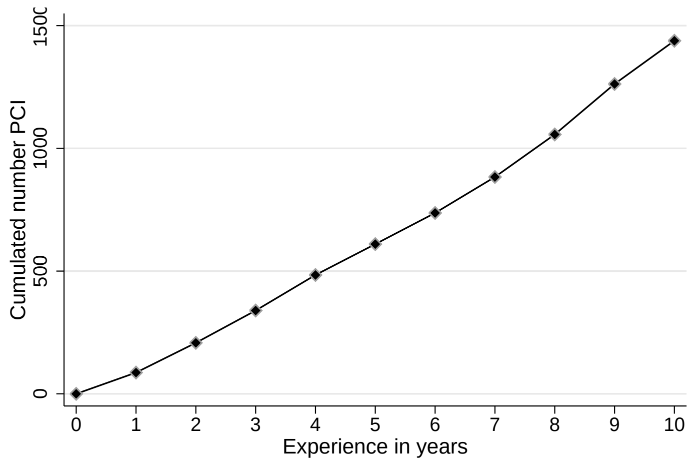
Table and Figures

Table 1: Descriptive statistics for the analyses samples

	All PCIs		STEMI infarctions	
	All	On-call time	All	On-call time
	(1)	(2)	(3)	(4)
# Patients	27,727	3499	5051	2243
# Physicians	76	71	75	65
# Clinics	28	25	27	23
		Pre-PCI patient characteristics		
Male patient	72.9	71.2	71.9	72.2
Age -59	25.0	30.0	27.5	30.1
Age 60-69	33.9	30.0	30.3	29.9
Age 70-79	29.2	26.1	25.7	25.1
Age 80+	11.9	13.9	16.5	14.9
Smoker	54.3	55.2	52.1	54.7
BMI over 25	76.9	75.1	75.3	76.0
Diabetes	19.7	15.8	13.1	14.0
Insulin treated diabetes	8.5	7.4	5.8	6.2
Hypertension	73.0	79.1	83.4	79.7
Lipid lowering medicine	74.8	72.4	70.5	67.2
Previous infarction	51.2	45.8	49.1	42.0
Previous CABG	9.7	6.8	4.2	4.9
Previous PCI	28.5	16.6	12.0	11.8
		Angiographic findings		
Normal atheromatous	5.4	3.1	1.6	1.9
1-vessel disease	45.5	45.5	47.6	46.4
2-vessel disease	28.1	27.7	29.0	28.4
3-vessel disease	16.3	18.5	17.4	18.4
		Heart disease		
Main stem vessel disease	4.4	5.2	4.3	4.8
STEMI infarction	18.2	64.1	100.0	100.0
NSTEMI infarction	35.2	23.8	0.0	0.0
Stabile angina	27.1	0.5	0.0	0.0
Unstable angina	14.6	8.6	0.0	0.0
Other	4.9	3.0	0.0	0.0

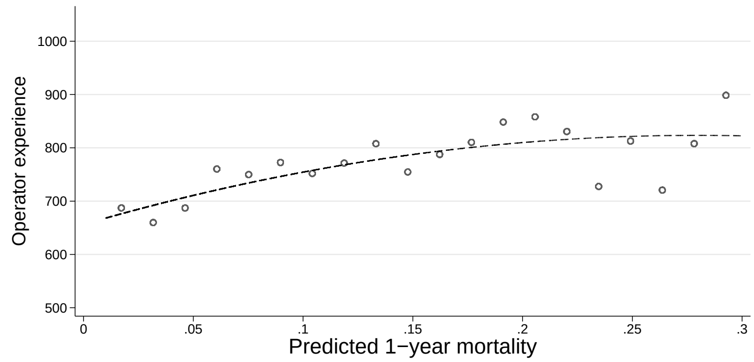
Notes: PCIs in Sweden during 2004-2013. Operators with experience < 500.

Figure 1: Operator experience vs. tenure in years.

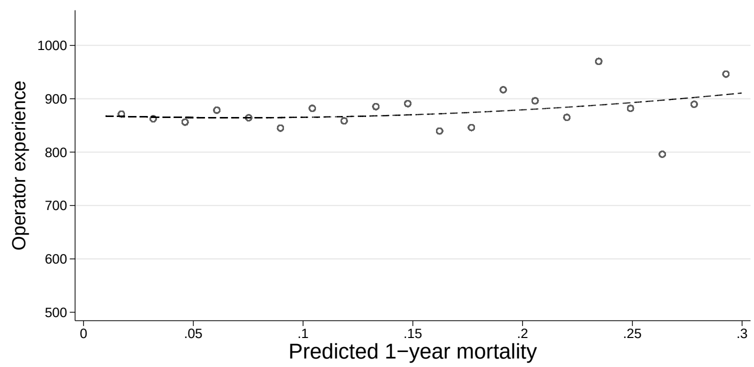


Note: Tenure is in years since the first PCI. For new operators since 2002.

Figure 2: Allocation of physicians during office hours and on-call time. Operator experience vs. predicted 1-year mortality



(a) Office hours



(b) On-call time

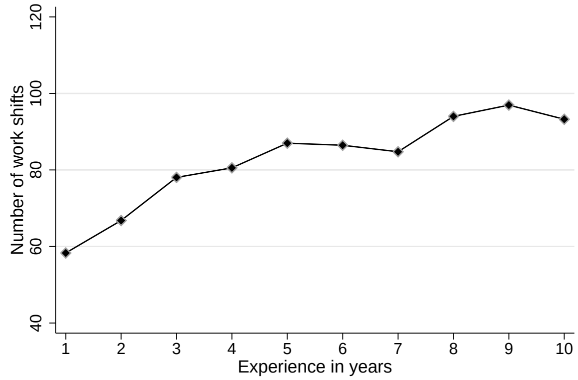
Note: PCIs in Sweden during 2002-2013. Dots are averages in bins and the line a fitted quadratic regression line. Predicted mortality after adjusting for hospital fixed effects and time fixed effects (year, month, weekday). Mortality is predicted using indicators for diabetes, insulin treated diabetes, hypertension, lipid lowering medicine, previous infarction, previous Coronary artery bypass surgery, previous PCI, Male patient, Age 60-69, Age 70-79, Age 80+, Smoker, BMI over 25, normal atheromatous, 1-vessel disease, 2-vessel disease, 3-vessel disease, main stem vessel disease, STEMI, NSTEMI, Angina and other heart disease.

Table 2: Allocation of physicians during office hours and on-call time. Operator experience and predicted 1-year mortality/infarction rate

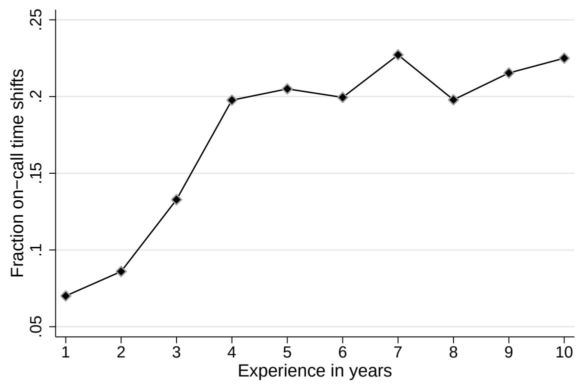
	Office hours		
	All	Acute	On-call time
	(1)	(2)	(3)
Predicted mortality rate	188**	230**	-19.1
	(72.5)	(95.3)	(55.2)
# obs.	79,065	13,361	15,314

Notes: OLS estimates using PCIs in Sweden during 2004-2013. All models include hospital, year, month, weekday fixed effects, holiday dummy, and physician gender and immigrant dummy. Mortality/Infarction rates are predicted using indicators for diabetes, insulin treated diabetes, hypertension, lipid lowering medicine, previous infarction, previous Coronary artery bypass surgery, previous PCI, Male patient, Age 60-69, Age 70-79, Age 80+, Smoker, BMI over 25, normal atheromatous, 1-vessel disease, 2-vessel disease, 3-vessel disease, main stem vessel disease, STEMI, NSTEMI, Angina and other heart disease. Standard errors are clustered at the hospital level. *, ** and *** denote significance at the 10, 5 and 1 percent levels.

Figure 3: Physician tenure and the number of on-call time shifts



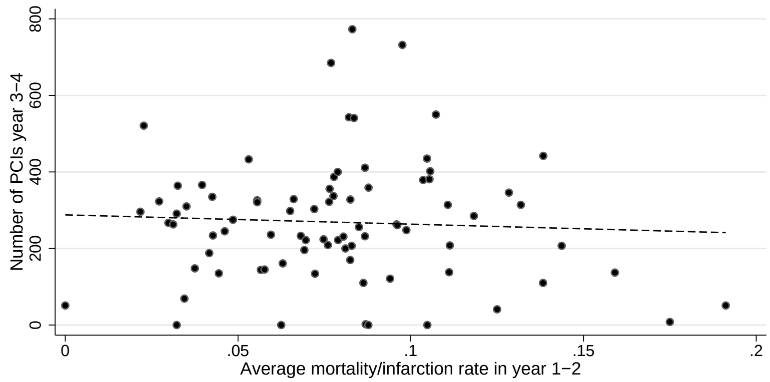
(a) Total number of work shifts



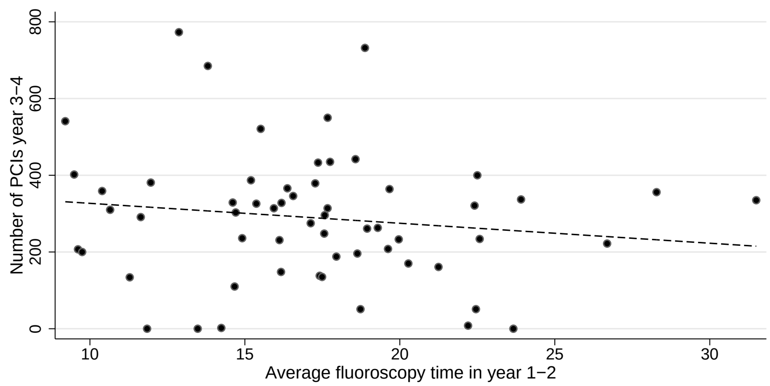
(b) Fraction weekend work shifts

Note: PCIs in Sweden during 2004-2013.

Figure 4: Early performance and later career.



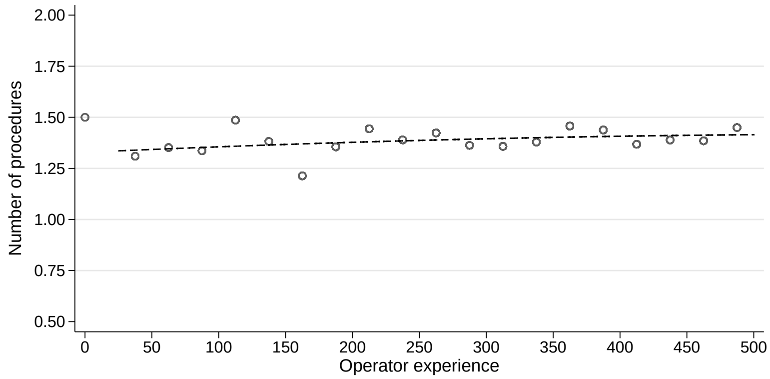
(a) Number of PCIs and early mortality/infarction rate



(b) Number of PCIs and early fluoroscopy time

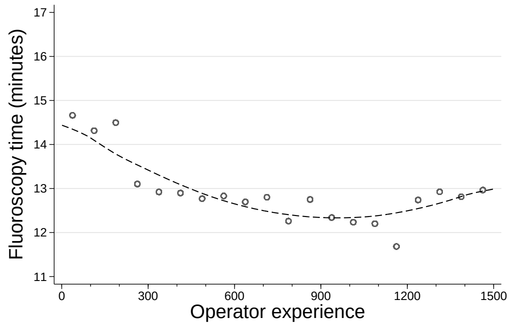
Note: PCIs in Sweden during 2004-2013.

Figure 5: Operator experience vs. number of procedures per on-call shift.

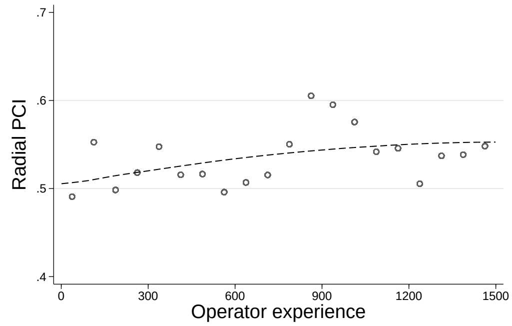


Note: Average number of PCIs per on-call shift.

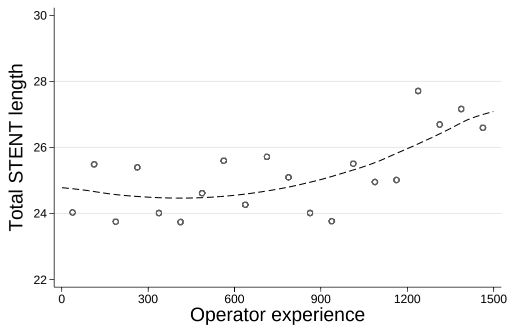
Figure 6: Physician experience, proficiency, decision making and patient health.



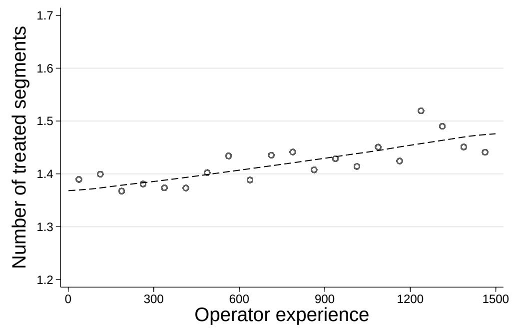
(a) Proficiency: Fluoroscopy time



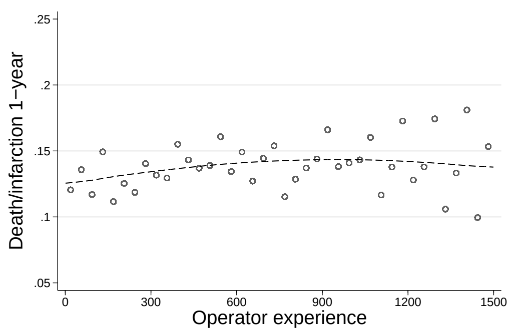
(b) Proficiency: Radial technique



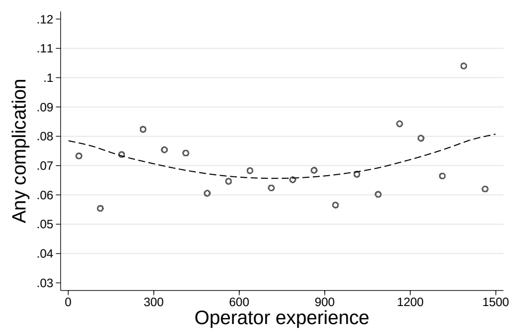
(c) Invasiveness: Totalt stent length



(d) Invasiveness: Treated segments



(e) Patient health: Mortality/Infarction



(f) Patient health: Complications

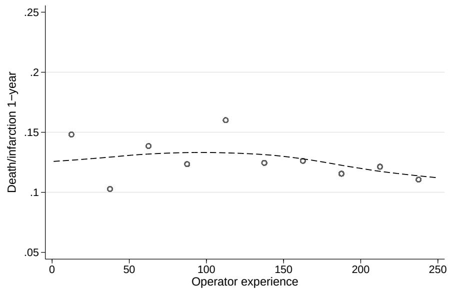
Note: PCIs in Sweden during 2004-2013. Adjusted for hospital and time (year, month, weekday) fixed effect, and adjusted for risk factors including indicators for diabetes, insulin treated diabetes, hypertension, lipid lowering medicine, previous infarction, previous Coronary artery bypass surgery, previous PCI, Male patient, Age 60-69, Age 70-79, Age 80+, Smoker, BMI over 25, normal atheromatous, 1-vessel disease, 2-vessel disease, 3-vessel disease, and main stem vessel disease.

Table 3: Estimates for proficiency, decision making and patient health.

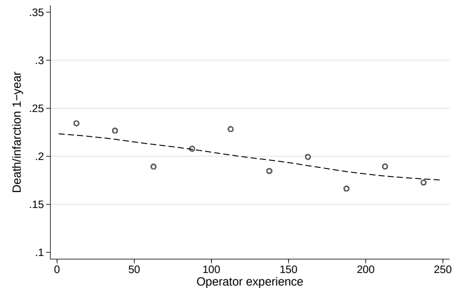
	Proficiency		Invasiveness		Patient health	
	Fluoroscopy time	Radial technique	Total stent length	Treated segments	Mortality or Infarction	Any complication
	(1)	(2)	(3)	(4)	(5)	(6)
Experience 251–500	-1.521**	0.0107	-0.305	-0.00284	0.0156*	-0.00141
	(0.604)	(0.0220)	(0.585)	(0.0167)	(0.00901)	(0.00462)
Experience 5001–1000	-2.244***	0.0216	0.713	0.0628**	0.0161	-0.00973
	(0.496)	(0.0296)	(0.555)	(0.0253)	(0.0136)	(0.00848)
Experience 1000+	-2.725***	0.0144	2.700**	0.125***	0.0185	-0.000165
	(0.506)	(0.0320)	(1.245)	(0.0446)	(0.0113)	(0.00813)

Notes: PCIs in Sweden during 2004-2013. Adjusted for hospital and time (year, month, weekday) fixed effect, and adjusted for risk factors including indicators for diabetes, insulin treated diabetes, hypertension, lipid lowering medicine, previous infarction, previous Coronary artery bypass surgery, previous PCI, Male patient, Age 60-69, Age 70-79, Age 80+, Smoker, BMI over 25, normal atheromatous, 1-vessel disease, 2-vessel disease, 3-vessel disease, and main stem vessel disease. Standard errors are clustered at the hospital level. *, ** and *** denote significance at the 10, 5 and 1 percent levels.

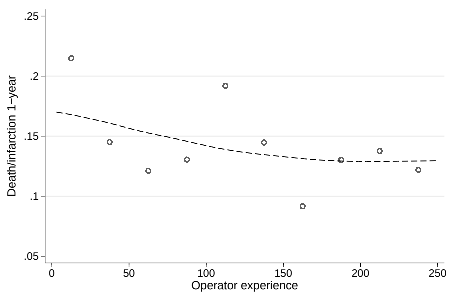
Figure 7: Low level of experience, patient health and patient risk.



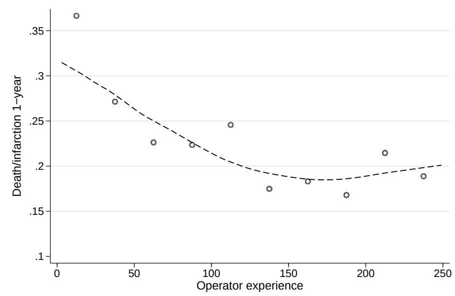
(a) Low risk



(b) High risk



(c) Low risk



(d) High risk

Note: ALL PCIs and STEMI-Infarction PCIs in Sweden during 2004-2013. Adjusted for hospital and time (year, month, weekday) fixed effect, and adjusted for risk factors including indicators for diabetes, insulin treated diabetes, hypertension, lipid lowering medicine, previous infarction, previous Coronary artery bypass surgery, previous PCI, Male patient, Age 60-69, Age 70-79, Age 80+, Smoker, BMI over 25, normal atheromatous, 1-vessel disease, 2-vessel disease, 3-vessel disease, and main stem vessel disease.

Table 4: Estimates of log physician experience on patient health.

	All PCIs		STEMI	
	Exp. < 250 (1)	Exp. < 100 (2)	Exp. < 250 (3)	Exp. < 100 (4)
Log(experience)	-0.0021 (0.0087)	-0.027 (0.024)	-0.019 (0.012)	-0.072** (0.029)
Observations	1,802	475	1,178	284

Notes: Operators with experience < 100. LS estimates using PCIs during on-call time in Sweden during 2004-2013. All models include risk factors, hospital, year, month and weekday fixed effects. Risk is the predicted 1-year mortality/infarction rate using pre-determined risk factors. Risk factors include indicators for diabetes, insulin treated diabetes, hypertension, lipid lowering medicine, previous infarction, previous Coronary artery bypass surgery, previous PCI, Male patient, Age 60-69, Age 70-79, Age 80+, Smoker, BMI over 25, normal atheromatous, 1-vessel disease, 2-vessel disease, 3-vessel disease, main stem vessel disease and time indicators. Standard errors are clustered at the hospital level. *, ** and *** denote significance at the 10, 5 and 1 percent levels.

Appendix: Additional figures and tables

Table 5: Operator experience and patient characteristics

	Office hours (1)	On-call time (2)
Age 60-69	-6.66*	0.87
	(3.44)	(9.45)
Age 70-79	-1.12	-5.46
	(4.77)	(6.12)
Age 80+	20.5***	24.6*
	(5.13)	(13.8)
Smoker	-10.7	-14.9
	(7.44)	(24.4)
BMI > 25	-10.4	-13.6
	(6.44)	(13.5)
Diabetes	7.87**	3.35
	(3.94)	(14.3)
Diabetes x Insulin	19.1***	-11.4
	(6.70)	(15.9)
Hypertension	3.93	0.17
	(3.50)	(4.59)
Lipid low. medicine	7.00	-1.77
	(4.46)	(4.13)
Previous infarction	5.95**	0.60
	(2.58)	(3.45)
Previous CABG	36.0***	-14.4
	(9.26)	(15.1)
Previous PCI	19.4***	4.91
	(6.13)	(14.5)

Notes: OLS estimates using PCIs in Sweden during 2004-2013. All models include hospital, year, month, weekday fixed effects, holiday dummy, and physician gender and immigrant dummy. Mortality/Infarction rates are predicted using indicators for diabetes, insulin treated diabetes, hypertension, lipid lowering medicine, previous infarction, previous Coronary artery bypass surgery, previous PCI, Male patient, Age 60-69, Age 70-79, Age 80+, Smoker, BMI over 25, normal atheromatous, 1-vessel disease, 2-vessel disease, 3-vessel disease, main stem vessel disease, STEMI, NSTEMI, Angina and other heart disease. Standard errors are clustered at the hospital level. *, ** and *** denote significance at the 10, 5 and 1 percent levels.