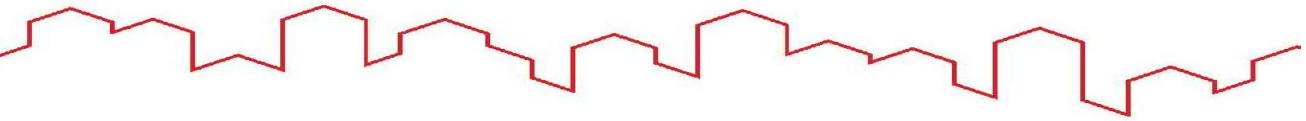

## Department of Economics

# Exploring the Impact of New Medical Technology on Workforce Planning


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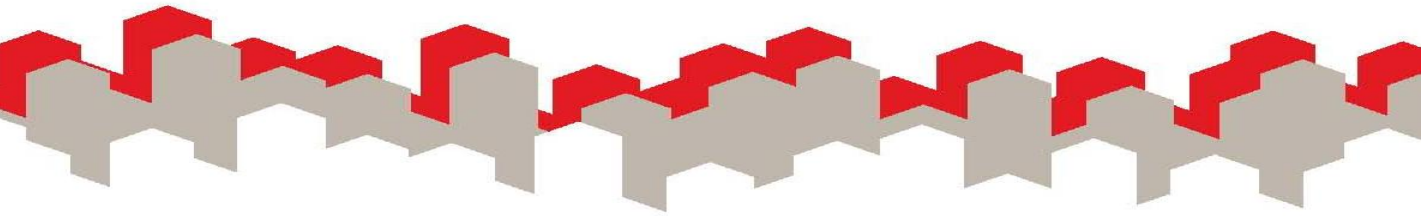


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# Exploring the impact of new medical technology on workforce planning *†

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**Abstract**

This paper considers the manner in which technology is diffused, with a particular emphasis on the impact on workforce composition as it matures. The lack of quantitative evidence of technology on the medical labour-force limits our knowledge of the full impact of technological change in the healthcare sector. We examine the diffusion of PTCA as it replaces CABG in the treatment of cardiovascular disease in England, estimating the degree to which the workforce reacts to the introduction of the newer technology, through calculating elasticity of supply measures. Using administrative data we trace the complementarity between CABG and PTCA during the mature phase of technology adoption, mapped against an increasing employment of cardiologists over cardiothoracic surgeons. Our findings show evidence of indication creep as PTCA is increasingly expanded to older and sicker patients, and that cardiothoracic surgery, other than CABG, increases in a manner consistent with replacement activity and cardiothoracic employment.

*Keywords*: Technological change, workforce, complementarity, dynamic model.

*JEL Classification*: O33, I11, C33, J2

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# 1 Introduction

Technology uptake in health care, although associated with improvements in health outcomes (Skinner & Staiger 2015) has also been established as a major driver of health care expenditure for most developed countries (Newhouse 1992, Okunade & Murthy 2002, Smith et al. 2009, Lamiraud & Lhuillery 2016). The contribution of medical innovation to health care productivity has been related to the cost-effectiveness of the technology itself (Chandra & Skinner 2012). Those technologies that have a higher initial unit cost than existing technologies may be adopted as the higher marginal cost may be offset by high marginal benefits to patients over the long-run (Skinner & Staiger 2015). Yet even those medical innovations introduced into the health care sector with a lower initial per unit cost, may increase overall expenditure through increasing demand.

While this additional impact of demand expansion has been recognised (see, Cutler & Huckman 2003), there has been little analysis of the manner through which the demand expansion occurs or the impact that new technology has on labour, and no analysis that we can point to on the general impact of new technological diffusion as it affects the general composition of the workforce. This study is, to the best of our knowledge, the first to provide empirical evidence on the aggregate impacts on labour of the diffusion of a specific new health care technology as it matures and replaces an older technology. The specific technology we analyse is Percutaneous Transluminal Coronary Angioplasty (PTCA)[1], as it displaces Coronary Artery Bypass Graft (CABG). PTCA was introduced as a less invasive and cheaper procedure than the existing technology, CABG to treat cardiovascular disease.

As first noted by Cutler & Huckman (2003), two effects might arise on the introduction of a new innovation: an expansion and/or substitution effect. An expansion effect occurs when the technology opens up new treatment possibilities that were previously unavailable. In addition, there may also be a substitution effect that leads to replacement (partial or total) of an existing technology. Cutler & Huckman (2003) estimated that the substitution effect of PTCA over CABG accounted for 25-35% of new PTCAs that followed an initial expansion effect in the US. McGuire et al. (2010) found similar results for the UK, however, the substitution effect was lower and the expansion effect was higher in the UK compared to the estimates suggested by Cutler & Huckman (2003) for the US.

Generally the analysis of health care technology has considered adoption and diffusion aspects of new technologies in the health care sector largely through issues of quality improvement (McClellan et al. 1994, Cutler & McClellan 2001, Chandra & Skinner 2012). Different lines of research have focussed on different technology types. Evidence on drug diffusion (Coscelli & Shum 2004, Crawford & Shum 2005, Serra-Sastre & McGuire 2013), physical capital (Baker & Phibbs 2000, Baker 2001, Clemens & Gottlieb 2014), health technology

[1]We use PTCA throughout to include angioplasty as first introduced without stents, as well as the up-graded technology that includes stents and drug-eluting stents sometimes referred to as PCI

information (Lammers 2013, Dranove et al. 2015) or surgical procedures (Cutler & Huckman 2003, McGuire et al. 2010) have shed light on different aspects of diffusion such as informational spillovers, organisational structure and the role of insurance. Some studies have considered the impact of differential technology adoption on outcomes, mapping adoption rates and the form of technology adoption to productivity (Skinner & Staiger 2015). While yet others have considered the rate of substitution between surgical and medical intervention on resource use and outcomes (Chandra & Staiger 2007).

There has been less analysis of the impact of technology adoption on labour substitutability or labour-force composition more generally as the newly adopted technology matures. While some studies do document specific productivity gains as correlated with differential technology adoption such as Chandra & Staiger (2007) and Skinner & Staiger (2015), there has been little examination of workforce composition effects arising as a consequence of technology adoption and diffusion. Given that the workforce accounts for approximately 60% of expenditure in most health care systems (Imison & Bohmer 2013), the lack of analysis of the impact that medical innovations have on staffing is surprising.

The general economics literature has examined the impact of technological change on the composition of labour inputs, suggesting that new technology adoption is largely skill-biased (Bekman et al. 1998, Morrison Paul & Siegel 2001, Acemoglu 2002), acting as a substitute for non-skilled labour and a complement for skilled labour (Autor et al. 2003). Despite the general conclusion of technological progress inducing a bias towards a complementary, highly skilled labour force, there are of course sectoral differences in the degree of skill upgrading across industries (Autor et al. 1998, Ho 2008). In the health care sector, there is sparse empirical evidence of the potential substitution or complementarity between technology and labour as new technologies are introduced.

David et al. (2009) examine the impact on hospital specialists of technology uptake in three diagnostic and treatment technologies and find some evidence of new technology reducing the use of highly specialised labour, with the precise impact differing across different employment arrangements. They consider the type of capital-embodied technologies used in Acemoglu & Finkelstein (2008). Acemoglu & Finkelstein (2008) find that moving to a fixed-price system such as the Medicare Prospective Payment System (PPS) induces an increase in the capital-labour ratio through a decline in labour and a push for the adoption of new technologies.[2] Of course any predicted impacts of technology on workforce will depend on both the specific technology under consideration and the institutional context. The TECH Investigators (Bech et al. 2009) show that new technology is associated with a slower rate of up-take and diffusion in centrally funded jurisdictions than in those that have less central control. Most empirical evidence focuses on technological change in the form of capital-embodied

[2]There has been little analysis of capital-labour substitution within the UK NHS, although research undertaken at the aggregate level finds a strong substitutability between various categories of labour and capital generally (Gray & McGuire 1989).

technology, but it is unclear whether technological change that is labour-embedded, as in the case of some surgical innovations, would lead to a similar labour reallocation. The economics literature has focused on the changes in skilled versus non-skilled labour; however, we examine the impact of technology in labour composition across workforce of the same skill-type.

The objective of this paper is to examine the introduction of PTCA as a technology, which has rapidly replaced CABG and assess what happens to both demand for the intervention and the impact on the workforce. All analysis is undertaken within the context of the English NHS, with data drawn from two large administrative databases. Following Cutler & Huckman (2003) we initially examine the degree of substitution or complementarity effects of this less invasive and cheaper technology on CABG. We explicitly concentrate on PTCA as it approaches maturity in it's diffusion as a technology, as we wish to consider the permanent impacts of technology adoption on demand and the workforce. We then document the treatment (demand) expansion effect, which we refer to as the indication creep, as the new technology is rolled out to riskier patient groups. No study considers the actual demand expansion as we do below, by examining how PTCA is increasingly used for a larger pool of patients who are older and sicker.[3] We then expand the analysis to estimate the degree to which the workforce reacts to the introduction of the new technology, through calculating elasticity of supply measures. This is possible as distinct types of medical labour, cardiologists and cardiothoracic surgeons respectively, perform the two types of intervention. Finally, we document the displacement of cardiothoracic surgeons workload to other procedures as PTCA replaces CABG.

Ultimately, we find complementarity among the two technologies in this mature phase of PTCA adoption, with a 1% increase in CABG volumes associated with a 34% increase in PTCA volumes across hospitals providing both procedures. We then find that PTCA is associated with indication creep as output expands through differing patient treatment populations. In analysing the impact on the workforce, we find that a 1% increase in the PTCA/CABG relationship increases the workforce ratio (cardiologist over cardiothoracic surgeons ratio) by 0.6% for the sample of hospitals providing both procedures. A final effect is that cardiothoracic surgeons are seen to increase the volume of other cardiovascular procedures, namely valve replacement, that fall within their specialty workload. Overall we conclude that the diffusion of the new technology has a direct impact through treatment expansion, and an indirect effect as the composition of the workload for cardiothoracic surgeons changes.

The paper is structured as follows. We begin by describing our data and presenting some background on the evolution of PTCA and CABG use within the UK. We follow this by

[3]Tu et al. (1997) do partially assess the impact of PTCA use as demand expands to more elderly patients.

outlining the empirical strategies used to investigate the various impacts of adopting PTCA over CABG, (the substitution effect, the output expansion associated with the indication creep of PTCA, the workforce impact and the cardiothoracic surgeon displacement effect), within the UK NHS. The empirical results of our investigation follow and we finish with concluding comments.

# 2 Data and Descriptive Statistics

In order to test empirically the impact of new technology on workforce, we use the Hospital Episode Statistics (HES), a rich administrative dataset that contains all episodes for patients admitted into hospitals in England. Our sample includes all HES records from financial year 2000/2001 to financial year 2012/13[4] for each patient admitted into hospital who had as main surgery CABG or PTCA based on the procedure codes (OPCS-4). We consider both elective and emergency admissions[5]. Each patient record contains clinical information on the admission date, main operation, date of operation, discharge date and all other operations the patient might have had as well as the main diagnosis. The dataset also includes organisational and geographical information, and we are able to link each episode to the anonymised identifier of the physician performing the intervention.

HES data is aggregated at the provider level to construct a longitudinal dataset that includes total volumes for PTCA and CABG by provider and year. The final dataset is an unbalanced panel of 199 providers from 2000 to 2012. PTCA and CABG volumes are adjusted by population at risk, therefore volumes are over population of individuals aged 45 and above in the Primary Care Trust (PCT)[6] where the provider is located. Figure 1 shows the population-adjusted volumes for PTCA and CABG[7]. While the average annual rate of growth for PTCA was 7.95% during the period 2000-2012, it was -2.43% for CABG, suggesting that as PTCA matures the demand for CABG is significantly reduced. Providers with volumes of either PTCA or CABG below 50 procedures per year (less than one intervention per week) are removed[8]. After accounting for hospital mergers, the final dataset identifies 79 hospitals across the period 2000-2012 undertaking sufficient volume of PTCA and/or CABG. Of these 79 providers, 29 hospitals perform both surgeries (PTCA and CABG), while the remainder

[4]Hereafter, we refer to each financial year by the year in which it starts, e.g. 2000 refers to financial year 2000/2001.

[5]Transfers from one provider to another one were considered an elective admission.

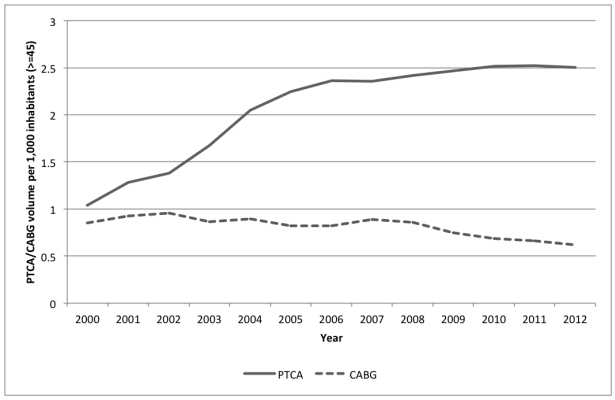
[6]PCTs were administrative organisations in place during our study period responsible for the commissioning of primary and secondary heaalth care services. After the Health and Social care Act of 2012, these were replaced by Clinical Commissioning Groups (CCGs)

[7]Figure 1, volumes for PTCA and CABG, presents all interventions retrieved from HES data from 2000/01 to 2012/13.

[8]Providers that have a high volume of PTCA but few for CABG (or vice versa) are kept. Providers that have low volume levels at the beginning of the study period, but after show volumes above 50, are kept for the whole period.

50 providers only perform PTCA. In the empirical results presented below the analysis of the sample of 79 hospitals can be interpreted as providing evidence on the aggregate NHS impact that PTCA has on the workforce and the complementary technology (CABG), while the analysis based on the 29 providers who undertake both procedures provides specific evidence on hospital specific impacts.

Figure 1: Volume PTCA and CABG




Source: HES data.

Our dataset also contains HES provider-averaged information on case-mix such as the percentage of male patients, percentage of emergency procedures, Charlson morbidity index, Index of Multiple Deprivation of the area where the patient resides, age and patient comorbidities.[9] We also include a number of provider characteristics such as whether they have foundation trust status, bed occupancy rates, the total number of sites which the trust occupies for health care service delivery, total annual cost for estate services and total annual admission per provider[10]. In some specifications we also include the volume of statins (used for primary and secondary prevention for cardiovascular disease) in each PCT to control for the use of alternative non-surgical technologies that may reduce the need for PTCA/CABG. Table A1 in the Appendix lists the variables used and provides some descriptive statistics.

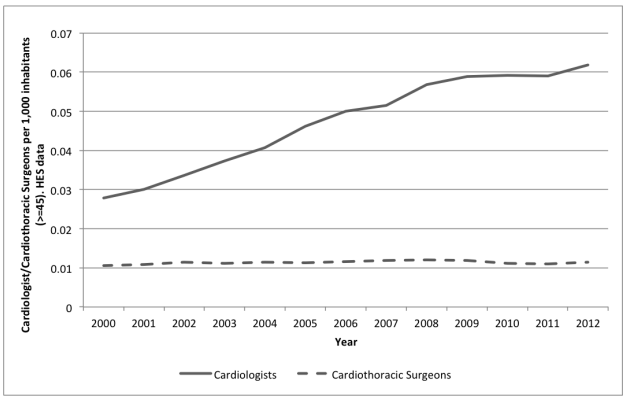
HES data also includes an anonymised consultant code for the consultant in charge performing the intervention. Based on this information, we compute the count of Full Time Equivalent (FTE) consultants per provider and year associated with each intervention. We distinguish between cardiologists, who perform PTCA in a catheterisation laboratory, and cardiothoracic surgeons who perform CABG in an operating theater (Gray et al. 2000, Molina

[9]Comorbities have been computed as the sum of a number of main diseases defined per patient in the HES data (diabetes, cancer, acute myocardial infarction, cerebral vascular accident, congestive heart failure, connective tissue disorder, dementia, liver disease, peptic ulcer, peripheral vascular disease, pulmonary disease, paraplegia, renal disease and HIV)

[10]Teaching trust is not included in the econometric specifications for consistency in the specifications due to multicollinearity and in any case it reflects a fixed effect over time which is accounted for in the empirical analysis.

& Heng 2009). Figure 2 shows the count of FTE cardiologists and cardiothoracic surgeons in our dataset performing PTCA and CABG, respectively. The figure shows that cardiologists performing PTCA increased over the time period, with an average annual rate of growth of 6.96%, while the number of cardiothoracic surgeons performing CABG remained relatively stable.

Figure 2: Cardiologist and Cardiothoracic surgeons

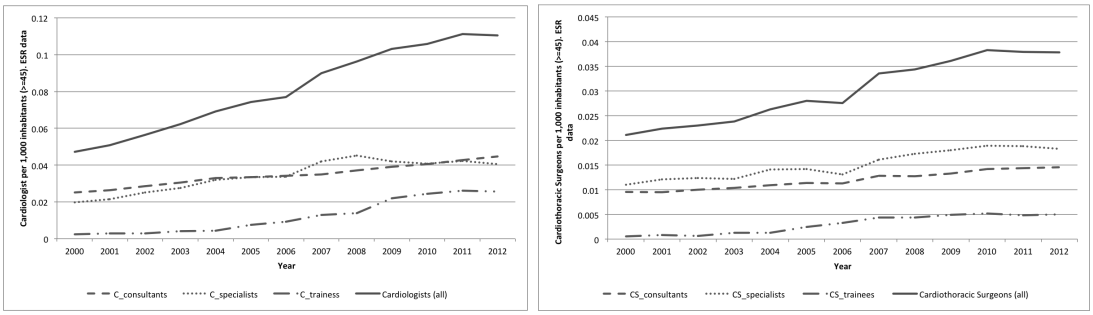



Source: HES data.

We also have data on the total count of cardiologists and cardiothoracic surgeons from the NHS Electronic Staff Records (ESR). ESR provides information on FTE of medical professionals detailed by seniority level; however, staff numbers from ESR on these two medical specialty groups will be larger than the counts retrieved from HES data given that not all cardiologists undertake PTCA and not all cardiothoracic surgeons perform CABG. When looking at FTE counts in HES compared to FTEs in the ESR, HES data accounts for 68% of ESR cardiologist counts and 43% of cardiothoracic surgeons. This reflects the fact that through the HES database we only identify the actual consultants who undertake PTCA or CABG, whil the ESR database covers all cardiologists and caridothoracic surgeons. Figure 3 shows the increase in cardiologists and cardiothoracic surgeons by seniority level based on ESR counts: consultants, specialists (Associate Specialist, Specialty Doctor, Staff Grade and Specialty Registrar), and trainees (Core Medical Training, Foundation Doctor Year 1 and Year 2). For the whole period of analysis (2000-2012), the average annual growth rate was 7.43% for all cardiologists; only slightly greater than the growth in cardiologists known to perform PTCA (shown in Figure 2). In contrast with Figure 2, which showed a stable count of cardiothoracic surgeons performing CABG, Figure 3 shows an average annual growth rate of 5.16% in this specialty. The increasing numbers for all cardiothoracic surgeons is especially striking from 2006 onwards given the markedly decreasing trend in CABG volumes in the second half of our study period. This suggests the increase in cardiothoracic surgeons may be driven by an increased volume of other surgical procedures performed by this specialty

group.

Figure 3: Cardiologists (I) and Cardiothoracic Surgeons (II) by seniority level




(I) (II)

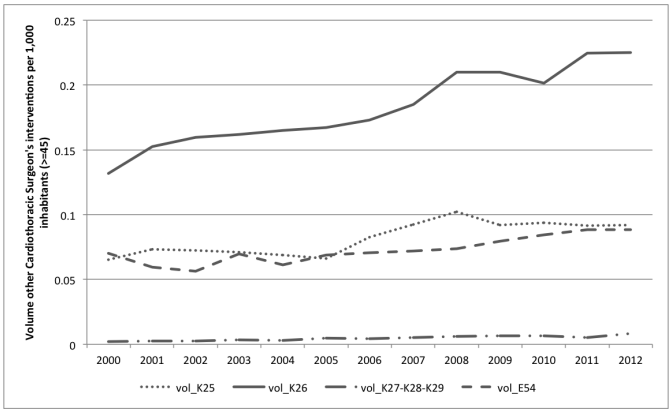
Source: ESR data.

The consolidation of PTCA over CABG seems to re-direct service provision by cardiothoracic surgeons to other surgical procedures. Using the anonymised consultant code for cardiothoracic surgeons available in HES, we track all their surgical volume for all operations other than CABG activity. We focus on the list of the main operations that fall into the remit of cardiothoracic surgeons as specified by the Royal College of Surgeons.[11] The list of included cardiothoracic surgeries are valve replacement, pneumonectomy, wedge resection and lobectomy. CABG and valve replacement are cardiac procedures, which is where our explicit interest lies. While pneumonectomy, wedge resection and lobectomy are all thoracic procedures, and although not of direct interest, we still consider them below. All surgical volumes related to these alternative specialties were identified by the OPCS-4 code.[12] Figure 4 shows the volume of these other cardiothoracic surgeons interventions. Tricuspid, pulmonary and heart (K27-K29) are joined due to the low number of observations per provider and year. While all are increasing over time, aortic valve replacement (K26) shows higher volume increase, followed by mitral valve replacement (K25) and lung interventions(E54). Such increases are compatible with the hypothesis of a shift in the composition of surgical interventions performed by cardiothoracic surgeons.

[11]https://www.rcseng.ac.uk/news-and-events/media-centre/media-background-briefings-and-statistics/cardiothoracic-surgery/

[12]OPCS-4 codes for: (1) Valve replacement are mitral-K25, aortic-K26, tricuspid-K27, pulmonary-K28 and heart-K29; (2) pneumonectomy, wedge resection and lobectomy is E54

Figure 4: Volume non-CABG interventions by Cardiothoracic Surgeons




Source: HES data.

# 3 Empirical Strategy

## 3.1 PTCA diffusion

We first examine the diffusion of PTCA at the provider level through a number of empirical specifications. The diffusion model is based on specifications in Cutler & Huckman (2003) and McGuire et al. (2010), accounting for the time-varying nature of the diffusion of PTCA relative to CABG. As we are primarily interested in the impact of PTCA on the demand for cardiologists who undertake angioplasty as opposed to CABG, we specify the dependent variable as the PTCA volume in the following empirical specification:

$$\frac{PTCA}{pop45}_{it} = \alpha + \beta_1 \frac{CABG}{pop45}_{it} + (\beta_s - \beta_1)[\frac{CABG}{pop45}_{it} * (t\epsilon s)] + \gamma' X_{it} + T_t + c_i + u_{it} \quad (1)$$

where the dependent variable is the population-adjusted PTCA volume by provider $i$ at year $t$ and the main explanatory variable is population-adjusted CABG volume. We interact the population-adjusted CABG volume with a vector of time indicators (2000-2002, 2003-2007, 2008-2012)[13]. By using time-varying coefficients we allow the interaction between PTCA and CABG to vary over time, as we are specifically interested in these effects as PTCA matures. Through Equation (1) we are able to quanitfy the elasticity of substitution or complementarity between CABG and PTCA. We also include a set of control variables $X_{it}$ as defined in Section 2, year fixed-effects $T_t$, provider fixed-effect $c_i$ and the disturbance term $u_{it}$.

Other non-surgical technologies may influence the PTCA/CABG ratio trajectory. For

[13]These periods were decided based on the evolution of PTCA/CABG to differentiate between periods of clear divergence between these technologies, as seen in Figure 1.

instance, statins are a class of cholesterol-lowering drugs prescribed for primary and secondary prevention of cardiovascular disease. If primary prevention via medical treatment influences the volume of surgical procedures the estimates in the results section may be upward biased and the specification may suffer from potential omitted variable bias. We explicitly examine the role that this non-surgical technology may has on the diffusion of PTCA. Data availability is, however, restricted to the period 2008-2012 for which we have the total number of statins prescribed at the Primary Care Trust (PCT) level.

### 3.1.1 PTCA indication creep

Having documented the degree of substitution as PTCA matures, we then examine the notion of output expansion. We follow a similar specification to that in Equation 1 but now PTCA becomes the main explanatory variable of interest, as we aim to analyse the spread of PTCA to a wider patient pool for which CABG would have been deemed more appropriate. We specifically consider the potential indication creep of PTCA, whereby PTCA is performed in older and sicker patients as surgeons become more familiar with the technology. The explicit indication creep specification is as follows:

$$\frac{CABG}{pop}_{it} = \alpha + \beta_1 \frac{PTCA}{pop}_{it} + (\beta_s - \beta_1)[\frac{PTCA}{pop}_{it} * (t\epsilon s)] + \beta_2 Morb_{it} + (\beta_s - \beta_1)[Morb_{it} * (t\epsilon s)] + \gamma^{'} X_{it} + T_t + c_i + u_{it} \quad (2)$$

where CABG and PTCA are population-adjusted to different age groups (55-64, 65-74, 75+) in order to test whether PTCA was progressively performed in older patients. PTCA and CABG volumes are also interacted with the time dummies defined in Section 3.1 to examine whether there exist differences for the indication creep over time. In addition to differentiating the expansion of PTCA across older patient groups, PTCA may also be performed in sicker patients. To proxy for patient severity we have created a comorbidity variable ($Morb$). The raw HES data records up to 14 comorbodities for each patient. From this raw data, we calculate the average number of comorbities seen in patients by provider and year. This ranges from an average number of 0 to 3 comorbidities across individual hospitals per year. We then generate a dummy where a hospital has an average of no comorbidities, one comorbidity, and an average of more than one comorbidity in the patient population. The reference category is zero commorbities and we also interact these dummies with time periods.

## 3.2 Elasticity of substitution

Next we turn to our central empirical analysis that quantifies the elasticity between workforce and the PTCA/CABG ratio, which we initially assess using a static panel model:

$$WF_{it} = \alpha + \beta_1 \frac{PTCA}{CABG}_{it} + \gamma^{'} X_{it} + T_t + c_i + u_{it} \tag{3}$$

where the dependent variable $WF_{it}$ is the ratio between two counts of different FTE in the workforce. The underlying assumption is that if PTCA volume has been increasing over time this will theoretically be associated with a change in the workforce skill mix; that is, an increase in cardiologists relative to cardiothoracic surgeons. We therefore examine the ratio of labour types relating to the provision of PTCA/CABG in Equation 3, where $WF_{it}$ is the log of the ratio of cardiologists (C) over cardiothoracic surgeons (CS) per provider $i$ and year $t$.

The point estimate $\beta_1$ is likely to be biased due to the potential endogeneity arising from the simultaneity of the workforce composition and the PTCA/CABG relationship. As result, we pursue different estimation strategies to overcome this endogeneity. First, we implement a Two-State Least Square (2SLS) - Instrumental Variable (IV) approach in a static equation. In the first stage (Equation 4), we model the PTCA/CABG ratio on patient and providers' characteristics and the instrument $Z_{it}$ reflects access to health care services, as based on referrals from the General Practitioner (GP) practices where the treatment patients are registered.This IV, we believe is individually correlated with the volume of PTCA to CABG procedures undertaken by the specified provider, operating through a mechanism that associates increases in procedure rates with increases in access to treatment procedure, but is not directly related to the provider employment ratio of cardiologists to cardiothoracic surgeons.

$$\frac{PTCA}{CABG}_{it} = \alpha + \beta^{'} Z_{it} + \gamma^{'} X_{it} + + T_t + c_i + u_{it} \tag{4}$$

We consider two definitions for the instruments used in the first stage: 1) the distance of the referring GP to the provider; and 2) the number of GPs referring to each provider. For both IVs, we first calculate geographical areas from which each hospital could draw potential patients. These areas are based on referral patterns and distances travelled by patients, using their GP practice as their proxy for residence. In computing the distance of individual GP practices to the hospital, we first calculate the radial distance of 50km around each provider to define referring GP practices. This radial measure is commonly used in the provider competition literature. Within this 50km radius, we identify GP practices who contributed at least 30% of a hospital's referred patients, where this cutoff was chosen to avoid exceptional patient referral patterns. This defines the geographical area from which each hospital draws its patient population.

For the IV based on distance, we use this geographical area which defines the total population served by each hospital and we calculate four distinct IVs based on the mean, median, $75^{th}$ percentile and $90^{th}$ percentile of the distance from the referring GP practice to the hospital. Our preferred measure relates to a geographical area based on a radial distance of 50km and 30% of referred patients, and the $75^{th}$ percentile IV estimate. For the IV based on GP numbers we use the total number of practices within the defined geographical area (i.e. radial distance of 50km and 30% of referred patients).

Using the predicted PTCA/CABG values from Equation 4, in the second stage of the 2SLS we estimate the following:

$$WF_{it} = \alpha + \beta_1 \widehat{\frac{PTCA}{CABG}}_{it} + \gamma^{'} X_{it} + c_i + T_t + v_{it} \tag{5}$$

This 2SLS estimation procedure is one means of solving for the endogeneity between workforce composition and the PTCA/CABG ratio. However, it reflects a static approach while more plausibly the relationship between treatment procedure adjustments and workforce composition is a dynamic one, reflecting lags due to training and/or staff redeployment. As a result, we also consider a dynamic panel data approach and estimate the following specification:

$$WF_{it} = \alpha + \beta_1 WF_{it-1} + \beta_2 \frac{PTCA}{CABG}_{it} + \gamma^{'} X_{it} + T_t + c_i + u_{it} \tag{6}$$

The system GMM estimator proposed by Blundell & Bond (1998) and Bond (2002) obtains consistent estimators, with first-differences taken to eliminate $c_i$ and remove any bias caused by the correlation of $c_i$ and the lagged dependent variable. As the first difference of the lagged dependent variable is now correlated with the first-differenced error component, an IV structure must be used in order to obtain consistent estimates. To control for the correlation between the lagged dependent variable $WF_{it-1}$ and the error term we use as IVs the following lags: 1) $WF_{it-2}$, $WF_{it-3}$, $WF_{it-4}$ and $WF_{it-5}$ for equations in first-differences; and 2) $\Delta WF_{it-1}$, $\Delta WF_{it-2}$, $\Delta WF_{it-3}$ and $\Delta WF_{it-4}$ for the equations in levels, where $\Delta WF_{it-1} = WF_{it-1} - WF_{it-2}$.

We further address the problem of endogeneity by using the same instruments outlined for estimating Equation (4) within a final specification of the dynamic structure. We also exploit the flexibility of the system GMM estimator and use lagged values of the PTCA/CABG ratio with the same structure to the instrument set used for $WF_{it-1}$.

### 3.2.1 Cardiothoracic surgery displacement

Our descriptive analysis in Section 2 suggests that while there is a decrease in CABG volume over time, the count of cardiothoracic surgeons increases (see Figure 3) along with the volumes of other surgical subspecialties that this workforce group undertakes (see Figure 4). We

empirically analyse the potential displacement activity of cardiothoracic surgeons to other interventions, as CABG volumes decline. For each consultant performing CABG identified in our sample over the study period, we track volumes of all other activity undertaken in a give year. Specifically, we consider a specification similar to that given as Equation (1), with the main difference being that the analysis is now at the consultant level:

$$\frac{CABG}{pop45}_{ijt} = \alpha + \beta_1 \frac{otherCS}{pop45}_{ijt} + (\beta_s - \beta_1)[\frac{otherCS}{pop45}_{ijt} * (t\epsilon s)] + \gamma^{'} X_{ijt} + T_t + c_i + u_{ijt} \quad (7)$$

where the population-adjusted CABG volume performed by consultant $j$ in $i$ at time $t$ is regressed on the volume of other cardiothoracic surgical interventions, ($otherCS$), controlling for the population at risk and interacted with time-periods. As described above, the other cardiothoracic volumes considered are valve replacement (mitral-K25, aortic-K26, tricuspid-K27, pulmonary-K28 and heart-K29) and lung interventions (pneumonectomy, wedge resection and lobectomy - E54).

# 4 Results

## 4.1 Technology diffusion

### 4.1.1 Basecase results

Table 1 presents the results of estimating the degree of substitution/complementarity between our two technologies as in Equation 1. The dependent variable is the volume of PTCA over the population aged 45 and above (in 1000s) and the main explanatory variable is the corresponding measure for CABG. Table 1 shows the estimates of a fixed-effects panel data model. In this Table, the columns report the estimates for the whole sample, 79 providers, and for the subsample of 29 providers performing both procedures, for the period 2000-2012. Each interaction term represents a change in the CABG rate coefficient relative to 2000-2002.

The results in Table 1 confirm that complementarity exists between these two technologies (all estimates are positive and statistically significant) for the period of our study, reflecting the maturing phase of the new technology. Based on these estimates, our measure of overall elasticity indicate that 1% increase in CABG volumes, increases PTCA volumes by 26% in the sample of 79 and 34% in the 29 subsample. The interaction terms (marginal complementarity) are positive and significant for column 1 and 2. However, there is a significant decrease in the estimates from 2003-2007 to 2008-2012 compared to the baseline period 2000-2002. This decrease in marginal complementarity may be due to PTCA being increasingly expanded over time to older patients and/or patients with more comorbidities, in what we term as the "indication creep" effect.

Volumes for both PTCA and CABG may respond to the competition introduced by non-surgical, medical technologies to treat cardiovascular disease. Statins are cholesterol lowering drugs that are prescribed for primary prevention for cardiovascular disease, and wider use of this drug type may translate into reduced need for the use of PTCA or CABG. In columns 3 and 4 we also include the log of statins to control for other non-surgical competing technologies that may affect the volume of PTCA. The sample now only covers the period 2008-2012, as prescription information was only available for this period. The results reported in Table 1 indicate that statins are substitutes (negative in sign) although the estimates are not precisely estimated, possibly reflecting the reduction in sample size due to data availability for statins.

Table 1: Technology Diffusion: Basecase Results

| Dep.Var: PTCA/45+ | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| CABG/45+ | 0.534** | 0.523* | 0.567 | 0.408 |
| | (0.216) | (0.261) | (0.352) | (0.426) |
| CABG/45+*(2003-2007) | 0.706*** | 0.849*** | | |
| | (0.134) | (0.279) | | |
| CABG/45+*(2008-2012) | 0.338*** | 0.467*** | | |
| | (0.108) | (0.118) | | |
| Log Statins | | | -3.450 | -4.005 |
| | | | (5.009) | (9.669) |
| No. Hospitals | 79 | 29 | 75 | 29 |
| N | 856 | 363 | 362 | 144 |
| Time fixed-effects | Yes | Yes | Yes | Yes |
| Provider fixed-effects | Yes | Yes | Yes | Yes |
| Controls Patients | Yes | Yes | Yes | Yes |
| Controls Provider | Yes | Yes | Yes | Yes |
| $R^2$ | 0.464 | 0.559 | 0.171 | 0.339 |
| Years | 2000-2012 | 2000-2012 | 2008-2012 | 2008-2012 |

*Notes:* Robust standard errors in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1. Control variables: percentage of male patients, percentage of emergency procedures, charlson morbidity index, Index of Multiple Deprivation of the area where the patient resides, mean age, percentage of population over 45 by PCT, bed occupancy rate, total number of admissions, total number of sites, estate service cost and foundation trust dummy.

### 4.1.2 Indication creep

Having documented the degree of complementarity as PTCA matures, we now examine explicitly the notion of output expansion associated with the PTCA "indication creep" effect. We do so following the specification in Equation 2 to quantify the potential expansion effect of PTCA to patients that are sicker and older. Table 2 presents the results of interacting PTCA volumes (and their corresponding time interactions) with age groups and with the average number of comorbidities in patients treated by specific providers in any given year to capture any indication creep, for both samples, the sample that includes all 79 providers and the sample that includes the 29 providers that do both PTCA and CABG. Each column

represents a patient group of different age (55-64, 65-74 and 75+) and the PTCA volume is again interacted with time dummies. In each column we also include dummies accounting for moderate (*Morb1*) to high (*Morb2*) patient risk as proxied by the average level of comorbidities, with the reference category being no commorbidities.These dummies are also interacted with time periods. For the subsample with 29 providers, the high commobidities dummy has zero observations for the first period. As a result, the baseline is period 2.

These results support the general notion of indication creep in PTCA treatment over time. For the sample of 79 hospitals, there is a significant substitution effect specially in the third period (2008-2012) for age groups 55-64 and 65-74, while there is a significant complementary effect in the same period for 75+. The estimates for the comorbidity dummies suggest that overall CABG volumes were higher for patients with comorbidities with respect to those with no comorbidities for the 55-64 age group. However, this effect is reversed towards later stages of diffusion as indicated by the interaction terms. For patients in the 65-74 and 75+ age groups, there is only some evidence for sicker patients to be less likely to have CABG but only towards the end of the study period. Results for the subsample of 29 hospitals indicates a stronger overall effect of morbidity for moderate risk levels on CABG volume consistent across age groups with evidence again that during the 2003-2007 diffusion period CABG volumes were reduced for patients with moderate risk. There is weaker evidence that sicker patients will receive CABG in the 2008-2012 period compared to 2003-2007.

## 4.2 Technology diffusion and workforce effects

Turning to our central question on the workforce effects, we present two sets of results. First, Table 3 presents the static results for both samples, with all 79 hospitals and only the subsample of 29 hospitals performing both PTCA and CABG. Columns 1 and 2 show the results for the OLS estimator. The workforce elasticity is 0.34 for the full sample and 0.24 for the sample with 29 hospitals. The results in Columns 3 and 4 show the estimates obtained using a fixed-effects panel data model, elasticities between 0.25 and 0.42. To address the potential endogeneity arising from the reverse causality of workforce and PTCA/CABG ratio, we show in columns 5-8 the 2SLS estimates using both IVs based on the geographical area defined by a radial distance of 50km and 30% referral rate. Columns 5 and 6 show the IV defined as the distance from the GPs to each provider based on the $75^th$ percentile and Columns 7 and 8 show the results when using the number of GPs in this geographical area.

These results show a positive and significant effect of the ratio of PTCA over CABG on the ratio of cardiologist over cardiothoracic surgeons. This is consistent with an increase (decrease) in PTCA (CABG) treatments resulting in increases (decreases) in cardiologists (cardiothoracic surgeon) staffing levels. The elasticities are estimated precisely only in the sample with all 79 hospitals, as seen in Columns 5 and 7. When endogeneity is purged with the 2SLS in the whole sample the resulting coefficient decreases from 0.4 to 0.3, and this is

Table 2: PTCA Indication Creep

| Dep. Var: | (1) CABG/55-64 | (2) CABG/65-74 | (3) CABG/75+ | (4) CABG/55-64 | (5) CABG/65-74 | (6) CABG/75+ |
|---|---|---|---|---|---|---|
| PTCA/55-64 | 0.217*** | | | 0.209*** | | |
| | (0.0647) | | | (0.0653) | | |
| PTCA/55-64*(2003-2007) | -0.0845* | | | -0.0502 | | |
| | (0.0469) | | | (0.0376) | | |
| PTCA/55-64*(2008-2012) | -0.141** | | | -0.0939* | | |
| | (0.0563) | | | (0.0482) | | |
| PTCA/65-74 | | 0.278*** | | | 0.291*** | |
| | | (0.0806) | | | (0.0899) | |
| PTCA/65-74*(2003-2007) | | -0.0584 | | | -0.0457 | |
| | | (0.0587) | | | (0.0577) | |
| PTCA/65-74*(2008-2012) | | -0.141* | | | -0.129 | |
| | | (0.0835) | | | (0.0869) | |
| PTCA/75+ | | | 0.0662 | | | 0.193*** |
| | | | (0.0726) | | | (0.0695) |
| PTCA/75+*(2003-2007) | | | 0.157*** | | | 0.0674 |
| | | | (0.0558) | | | (0.0582) |
| PTCA/75+*(2008-2012) | | | 0.165*** | | | 0.0406 |
| | | | (0.0580) | | | (0.0588) |
| Morb.1 | 0.852** | 0.796 | -0.0401 | 4.354*** | 6.418*** | 2.094*** |
| | (0.366) | (0.609) | (0.331) | (0.898) | (1.458) | (0.654) |
| Morb.1*(2003-2007) | -0.790** | -0.799 | -0.0727 | -6.437** | -8.129* | -4.479 |
| | (0.372) | (0.582) | (0.392) | (2.330) | (4.402) | (2.688) |
| Morb.1*(2008-2012) | -0.409 | -0.560 | -0.325 | -1.034 | -1.188 | 0.189 |
| | (0.324) | (0.592) | (0.297) | (0.642) | (1.381) | (0.759) |
| Morb.2 | 0.404* | 0.541 | 0.293 | -3.391* | -2.971 | -1.632 |
| | (0.238) | (0.416) | (0.268) | (1.931) | (3.931) | (2.572) |
| Morb.2*(2003-2007) | -0.412 | -0.474 | -0.201 | | | |
| | (0.251) | (0.408) | (0.292) | | | |
| Morb.2*(2008-2012) | -0.340 | -0.871** | -1.337*** | 6.072** | 7.232 | 3.104 |
| | (0.219) | (0.428) | (0.339) | (2.433) | (4.839) | (3.072) |
| No. Hospitals | 79 | 79 | 79 | 29 | 29 | 29 |
| N | 856 | 856 | 856 | 363 | 363 | 363 |
| Year FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Provider FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Controls Patients | Yes | Yes | Yes | Yes | Yes | Yes |
| Controls Providers | Yes | Yes | Yes | Yes | Yes | Yes |
| $R^2$ | 0.437 | 0.365 | 0.522 | 0.564 | 0.448 | 0.615 |
| Year | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 |

*Notes:* See *Notes* in Table 1. Robust standard errors in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

consistent regardless of the IV used. The estimates in the specifications using the subsample of 29 hospitals (columns 6 and 8), the elasticities are insignificant and even wrong signed (column 6). All IV models fulfill the F statistic exclusion restriction (F>=10), except for the model in column 6.

Estimates in columns (5) and (6) in Table 3 were obtained using the distance IV based on the $75^th$ percentile of distance within the geographical area (50km radial distance and the 30% of referred patients). We also estimated coefficients using the mean, median and $90^{th}$ percentile within these areas and results are available in Table A2 in the Appendix. Similar to results in Table 3, once instrumenting the PTCA/CABG ratio we lose significance of the elasticity measure for the subsample of 29 hospitals, with exception of the specification that includes the $90^{th}$ percentile. The fact the estimates are more precisely estimated when using higher percentile values might suggest that these measures are a better reflection of patient

access than those based on the mean and median distance, allowing better capture of the treatment population. We also estimated our coefficients of interest using the distance IV with a definition of geographical area based on a cut-off point of 37km instead of 50km (37km being the average distance for the whole sample). Results are reported in Table A3 in the Appendix and are comparable to those in Table 3.

The second set of workforce composition results report our preferred dynamic specification, as outlined in Equation 6, that accounts for any workforce adjustment costs. Table 4 presents the different dynamic estimations for both the 79 and the 29 hospitals. As a baseline, the first 4 columns show the results of a dynamic OLS and fixed-effects panel estimation, which we presume are biased due to endogeneity through both the lagged value of the dependent variable and the PTCA/CABG ratio. Columns 5 through 12 present the system GMM estimations. Results in columns 5 and 6 only instrument the lagged dependent variable using up to four lag periods but do not instrument the PTCA/CABG variable. The estimated workforce elasticity is 0.28 for the whole sample and 0.24 for the subsample of 29 hospitals.

In columns (7) through (12) we report the results instrumenting for the PTCA/CABG ratio endogeneity. We first use in columns (7) to (10) using the same IVs as in Table 3 based on the distance from GP to provider to define patient access and count of GPs referring to each hospital. As explained above, both IVs are based on the geographical areas defined by the 50km radial distance and the 30% of referred patients. Results show that the coefficient relating to the effect of workforce redeployment (as represented by the lag of the dependent variable) is positive and highly significant across all these corrected estimations, except in column (10).

Our preferred specification is reported in columns (11) and (12) using a dynamic structure with instruments based on lags and differences as proposed by Blundell & Bond (1998). By using lags of the endogenous variable in the differenced and levels equations in system GMM, the number of instruments may be too large compared to the sample size leading to potentially unreliable p-values for the Hansen test of instrument validity. We take two approaches in order to address this problem. We restrict the number of instruments to up to four lags and we also collapse the instrument matrix as suggested by Roodman (2009). The results show that a 1% increase in the PTCA/CABG relationship, increase the C/CS ratio by 0.27% for the sample of 79 and by 0.6% for the subsample of 29 hospitals. Descriptive evidence presented in Section 2 (see Figure 2) show that the number of cardiothoracic surgeons remained stable over time, implying that the cardiologist count is increasing, although at a somewhat lower rate than the PTCA treatment volume.

These preferred dynamic IV models are supported by several specification tests. We fail to reject the null hypotheses of valid overidentifying restrictions in the Hansen test for all specifications. The p-value for the test of no first-order autocorrelation fails to reject the null

hypothesis, while the null of no second-order autocorrelation is not rejected. As showed by Arellano & Bond (1991) the presence of first-order autocorrelation does not affect the consistency of the specification of the model as long as there is no second-order autocorrelation, therefore our estimates remain consistent under the presence of first-order autocorrelation. We also tested for unit root using the Fisher-type unit-root test, based on the augmented Dickey-Fuller and the Phillips-Perron tests, and our variables of interest (i.e. Log C/CS and Log PTCA/CABG) rejected the null hypothesis of all panels contain unit-roots.

Table 3: Workforce Elasticity - Static Specifications

| Dep. Var: Log C/CS | (1) OLS | (2) OLS | (3) FE | (4) FE | (5) 2SLS Distance P75 | (6) 2SLS Distance P75 | (7) 2SLS No. GPs | (8) 2SLS No. GPs |
|---|---|---|---|---|---|---|---|---|
| Log PTCA/CABG | 0.343*** | 0.238*** | 0.420*** | 0.247*** | 0.302*** | -0.125 | 0.300*** | 0.0492 |
| | (0.00854) | (0.0470) | (0.0193) | (0.0484) | (0.0664) | (0.325) | (0.0535) | (0.143) |
| First stage - Instrument | | | | | 0.066*** | 0.024** | 0.009*** | 0.004** |
| | | | | | (0.011) | (0.010) | (0.002) | (0.002) |
| F Statistic | | | | | 77.439 | 8.476 | 114.855 | 63.776 |
| No. Hospitals | 79 | 29 | 79 | 29 | 79 | 29 | 79 | 29 |
| N | 856 | 363 | 856 | 363 | 755 | 360 | 755 | 360 |
| Time FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Provider FE | No | No | Yes | Yes | Yes | Yes | Yes | Yes |
| Controls Patients | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Controls Providers | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| $R^2$ | 0.774 | 0.355 | 0.791 | 0.322 | 0.587 | 0.112 | 0.587 | 0.262 |
| Years | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 |

*Notes:* See *Notes* in Table 1. Robust standard errors in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1. F Statistic on exclusion restrictions.

As a further robustness check, and to give some precision to workforce composition effects, Table 5 follows the dynamic specification of Table 4 using workforce counts from the ESR data. ESR records all cardiologists and cardiothoracic surgeons working in the NHS, but, as discussed in Section 2, the ESR data gives larger counts of workforce because not all cardiologists and cardiothoracic surgeons perform PTCA or CABG. While we cannot link individual workforce from ESR to the treatment procedures we analyse, as we do for HES data, the ESR data have detailed data on workforce seniority levels that allows us to break down the impact of the maturing use of PTCA by staff grade, as there are data on counts of consultants (attending or chief resident physician), specialists (residents) and trainees (fellows) at individual provider and year level.

Instead of reporting alternatively for the 79 hospitals and then for the 29 provider subsample, Table 4 reports on staffing levels first for the 79 providers and then for the 29 providers. Generally the PTCA/CABG ratio is positive and supportive of earlier results, except for trainees where the coefficients are negative, significantly so for the 29 hospital providers. Columns (1) and (5) show the results when including the overall count of workforce (sum of the three staff groups). This result is consistent with the results using HES data (columns (11) and (12) in Table 4), but not surprisingly the coefficients are significantly lower. This can be explained by the differences between HES workforce count, which reflects the accurate count of physicians performing PTCA or CABG, compared to ESR, which has the total count of physicians in these two surgical specialties, and therefore the results may be downward biased. The workforce elasticity is very similar for consultants and specialists, becoming negative for trainees. This negative elasticity may indicate that less cardiologists are trained (relative to cardiothoracic surgeons) to deal with PTCA volumes, reflecting either a shortage of cardiologists being trained or increases in cardiologists' labour productivity such that lower counts are required to meet PTCA volumes.

Table 4: Workforce Elasticity - Dynamic Specifications

| Dep. Var: Log C/CS | (1) OLS | (2) OLS | (3) FE | (4) FE | (5) System GMM | (6) System GMM | (7) System GMM | (8) System GMM | (9) System GMM | (10) System GMM | (11) System GMM | (12) System GMM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| L.Log C/CS | 0.375*** | 0.637*** | 0.107** | 0.185*** | 0.172* | 0.229*** | 0.183** | 0.157* | 0.191*** | 0.248*** | 0.225*** | 0.225** |
| | (0.0354) | (0.0447) | (0.0467) | (0.0571) | (0.0970) | (0.0885) | (0.0722) | (0.0936) | (0.0700) | (0.0650) | (0.0794) | (0.0990) |
| Log PTCA/CABG | 0.229*** | 0.168*** | 0.416*** | 0.297*** | 0.286*** | 0.239*** | 0.317*** | 0.568** | 0.309*** | 0.155 | 0.268*** | 0.594*** |
| | (0.0137) | (0.0535) | (0.0264) | (0.0620) | (0.0339) | (0.0757) | (0.0501) | (0.232) | (0.0461) | (0.147) | (0.0350) | (0.230) |
| No. Hospitals | 79 | 29 | 79 | 29 | 79 | 29 | 79 | 29 | 79 | 29 | 79 | 29 |
| N | 747 | 334 | 747 | 334 | 747 | 334 | 689 | 334 | 689 | 334 | 747 | 334 |
| Year FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Controls Patients | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Controls Provider | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| PTCA/CABG IV | No | No | No | No | No | No | Dist. P75 | Dist. P75 | No. GPs | No. GPs | Dyn. struc. | Dyn. struc. |
| $R^2$ | 0.826 | 0.651 | 0.758 | 0.350 | | | | | | | | |
| AR1 | | | | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| AR2 | | | | | 0.122 | 0.939 | 0.298 | 0.766 | 0.288 | 0.898 | 0.120 | 0.915 |
| Hansen | | | | | 0.393 | 0.071 | 0.123 | 0.205 | 0.128 | 0.872 | 0.107 | 0.786 |
| Fisher test (ADF) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Years | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 |

*Notes:* See *Notes* in Table 1. Estimates are obtained using the one-step GMM procedure. Robust standard errors in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1. Provider fixed-effects included in Columns (3) and (4). P-values shown for the AR1, AR2, Hansen and the Fisher test for unit root (Phillips-Perron test had the same result). Fisher test tests for the sationarity of the dependent variable Log C/CS and Log PTCA/CABG. In columns (11) and (12) our instruments for L.Log C/CS are $LogC/CS_{it-2}$, $LogC/CS_{it-3}$, $LogC/CS_{it-4}$ and $LogC/CS_{it-5}$ for equations in first-differences; and 2) $\Delta LogC/CS_{it-1}$, $\Delta LogC/CS_{it-2}$, $\Delta LogC/CS_{it-3}$ and $\Delta LogC/CS_{it-4}$ for the equations in levels, where $\Delta LogC/CS_{it-1} = LogC/CS_{it-1} - LogC/CS_{it-2}$. In columns (11) and (12) our instruments for Log PTCA/CABG are $LogPTCA/CABG_{it-2}$, $LogPTCA/CABG_{it-3}$, $LogPTCA/CABG_{it-4}$ and $LogPTCA/CABG_{it-5}$ for equations in first-differences; and 2) $\Delta LogPTCA/CABG_{it-1}$, $\Delta LogPTCA/CABG_{it-2}$, $\Delta LogPTCA/CABG_{it-3}$ and $\Delta LogPTCA/CABG_{it-4}$ for the equations in levels, where $\Delta LogPTCA/CABG_{it-1} = LogPTCA/CABG_{it-1} - LogPTCA/CABG_{it-2}$. 1.

Table 5: Workforce Elasticity - Dynamic Specifications by Seniority Level using ESR Data

| Dep. Var: | (1) Log C/CS | (2) LogC/CS Consultants | (3) Log C/CS Specialists | (4) Log C/CS Trainees | (5) Log C/CS | (6) LogC/CS Consultants | (7) Log C/CS Specialists | (8) Log C/CS Trainees |
|---|---|---|---|---|---|---|---|---|
| L.Log C/CS | 0.583*** | 0.581*** | 0.387*** | 0.578*** | 0.395*** | 0.487*** | 0.279*** | 0.358*** |
| | (0.0719) | (0.0897) | (0.0600) | (0.0722) | (0.108) | (0.0585) | (0.105) | (0.112) |
| Log PTCA/CABG | 0.0995*** | 0.0740** | 0.0792** | -0.00184 | 0.200* | 0.167* | 0.280 | -0.439** |
| | (0.0368) | (0.0371) | (0.0369) | (0.0312) | (0.109) | (0.0920) | (0.178) | (0.190) |
| No. Hospitals | 79 | 79 | 79 | 79 | 29 | 29 | 29 | 29 |
| N | 747 | 747 | 747 | 747 | 334 | 334 | 334 | 334 |
| Year FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Controls Patients | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Controls Providers | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| AR1 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| AR2 | 0.665 | 0.333 | 0.961 | 0.572 | 0.328 | 0.572 | 0.210 | 0.993 |
| Hansen test | 0.494 | 0.284 | 0.168 | 0.094 | 0.995 | 0.936 | 0.819 | 0.763 |
| Fisher unit-root (ADF) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Years | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 |

*Notes:* See *Notes* in Tables 1 and 4. Robust standard errors in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1. P-values provided for all specifications tests. All models fulfill the autocorrelation, Hansen and the unit root tests (the Phillips-Perron had the same result).

### 4.2.1 CABG vs other cardiothoracic surgeons' interventions

If CABG volumes have been decreasing over time, we would expect individual consultant productivity for cardiothoracic surgeons to decrease. Instead, we observe an increase in volumes of the other cardiac procedures that cardiothoracic surgeons perform. In order to investigate this displacement activity, we examine the level of substitution across alternative interventions undertaken by this workforce group. Table 6 presents the estimates of a pooled OLS with year and provider fixed-effects at the consultant level, where CABG is regressed on the volume of other cardiothoracic surgeons' interventions (interacted with time periods). The same consultant may practice in different providers therefore we could not use a fixed-effects panel model. As explained in the data section, the other main interventions are valve replacement (mitral-K25, aortic-K26, tricuspid-K27, pulmonary-K28 and heart-K29) and lung interventions (pneumonectomy, wedge resection and lobectomy - E54). Table 6 shows the estimates only for the consultants identified in HES as performing CABG, who are only observed in the subsample of the 29 hospitals. The difference between the first two models and the last two is that models in columns 3 and 4 also include controls for patients and providers.

The results are very similar whether controls are or are not included. Columns (1) and (3) present results aggregating all valve replacement interventions (K25-K29). Columns (2) and (4) show the estimates when all valve replacement procedures are disaggregated by individual valve replacement interventions (K25,K26,K27-K29). Results show a significant substitution effect between volumes of valve replacement and CABG for the third period (2008-2012) compared to the baseline period. In the specifications that dissagregate valve replacement types results show a significant substitution effect for periods 2 (2003-2007) and 3 (2008-2012) for K25 and K26, but not for K27-K29 where there seems to be a significant complementarity among these procedures. For thoracic interventions (E54), the effect is not significant simply reflecting that the direct competition is between CABG and the other type of cardiac procedures, not between cardiac and thoracic types. This reinforces the idea that as CABG decreases, and with a relatively stable number of cardiothoracic surgeons over time, the reduction in CABG volume is substituted by an increasing volume of valve replacements.

Table 6: CABG Displacement

| Dep. Var: CABG/45+ | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| K25-K29 | 1.820*** | | 1.725*** | |
| | (0.233) | | (0.216) | |
| K25-K29*(2003-2007) | -0.252 | | -0.244 | |
| | (0.195) | | (0.182) | |
| K25-K29*(2008-2012) | -0.977*** | | -0.953*** | |
| | (0.257) | | (0.238) | |
| K25 | | 13.442*** | | 12.770*** |
| | | (4.629) | | (4.590) |
| K25*(2003-2007) | | -9.634*** | | -8.892*** |
| | | (2.737) | | (2.442) |
| K25*(2008-2012) | | -11.710** | | -11.147** |
| | | (4.369) | | (4.456) |
| K26 | | 15.408*** | | 14.713*** |
| | | (4.586) | | (4.554) |
| K26*(2003-2007) | | -9.020*** | | -8.297*** |
| | | (2.303) | | (1.987) |
| K26*(2008-2012) | | -11.887*** | | -11.389*** |
| | | (4.118) | | (4.193) |
| K27-K29 | | -12.696*** | | -12.100** |
| | | (4.621) | | (4.598) |
| K27-K29*(2003-2007) | | 8.972*** | | 8.259*** |
| | | (2.425) | | (2.154) |
| K27-K29*(2008-2012) | | 10.903** | | 10.405** |
| | | (4.109) | | (4.216) |
| E54 | 0.535* | 0.383 | 0.472 | 0.324 |
| | (0.297) | (0.298) | (0.281) | (0.279) |
| E54*(2003-2007) | -0.235 | -0.224 | -0.237 | -0.213 |
| | (0.293) | (0.297) | (0.280) | (0.284) |
| E54*(2008-2012) | -0.484 | -0.411 | -0.449 | -0.359 |
| | (0.288) | (0.294) | (0.268) | (0.270) |
| No. Hospitals | 29 | 29 | 29 | 29 |
| N | 2883 | 2883 | 2839 | 2839 |
| Year FE | Yes | Yes | Yes | Yes |
| Provider FE | Yes | Yes | Yes | Yes |
| Controls Patients | No | No | Yes | Yes |
| Controls Providers | No | No | Yes | Yes |
| $R^2$ | 0.5443 | 0.6088 | 0.5624 | 0.6220 |
| Years | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 |

*Notes:* See *Notes* in Table 1 for controls included.Standard errors (in parentheses) clustered at the provider level. Significance levels: *** p<0.01, ** p<0.05, * p<0.1. The same consultant may practice in different providers therefore we could not use a fixed-effects panel model. Estimates obtained using a pooled OLS with year and provider fixed-effects.

# 5 Discussion

The objective of this paper was to consider the full impact of a maturing new technology on workforce composition in the English NHS. We examine two competing technologies for treating cardiovascular disease: CABG, an open procedure first introduced, and PTCA, a less invasive and cheaper procedure. Each of these surgical technologies are performed by a different set of physicians in the NHS. CABG is performed by cardiothoracic surgeons and PTCA by cardiologists. This allows us examining changes in workforce of the same skill type arising from technology change. We use two major UK administrative databases to undertake our analysis: the Hospital Episodes Statistics (HES) and the NHS Electronic Staff Records (ESR). HES allows specific identification of the consultants (cardiologists and cardiothoracic surgeons) undertaking PTCA or CABG. ESR identifies all NHS cardiologists and cardiothoracic surgeons, providing greater detail on staffing levels by seniority levels.

Through analysing the maturing of PTCA as a partial replacement for CABG, we first documented complementarity effects across the two technologies. The estimated elasticity indicated complementarity, reflecting the maturity in the uptake of PTCA, with a 1% increase in CABG volumes associated with an increase in PTCA volumes of 26% in the sample of all 79 providers and 34% in the subsample of 29 hospitals undertaking both procedures. This builds on previous research on the topic that found a substitution effect across these technologies in earlier time periods (Cutler & Huckman 2003, McGuire et al. 2010). However, these studies did no look at the mechanisms through which the increasing use of PTCA leads to output expansion. Our results suggest that this PTCA output expansion is associated with indication creep. This resulted in PTCA treatment being offered to increasing numbers of elderly and comorbid patients.

Secondly, we computed estimates of the degree to which the workforce reacts to the introduction of new technology, based on elasticity of supply measures by adopting two different approaches, a static and a dynamic approach. Both empirical approaches addressed the potential endogeneity caused by the reverse causality of the PTCA/CABG treatment ratio on the workforce ratio, as measured by the distinct staff categories of cardiologists and cardiothoracic surgeons employed to undertake these treatment technologies. The maturing phase of PTCA was found to be associated with a positive and significant effect of the PTCA/CABG ratio on the workforce ratio (cardiologist over cardiothoracic surgeons). The trends exposed by our graphical analysis and the established relative complementarity between PTCA and CABG supports a growth in the number of cardiologists as compared to a flattening of the employment of cardiothoracic surgeons. The witnessed growth in cardiologists holds for the investigations based on both the HES data and ESR data. Our preferred dynamic specification reveals that a 1% increase in the PTCA/CABG relationship, increases the WF ratio by 0.27% for the sample of 79 and by 0.6% for the subsample of 29 hospitals. As cardiothoracic surgeon employment for CABG was stable over time, the 0.27% or 0.6%

increase reflects purely a relative growth in cardiologists. As a result, cardiologist count is increasing, although at a somewhat lower rate than the PTCA treatment volume.

The workforce elasticity estimate is greater for the subsample of 29 providers that perform the two interventions. Throughout our analysis we have presented results using the sample of 79 providers (that includes the 29 hospitals that undertake both PTCA and CABG but also 50 providers who only undertake PTCA) and for the subsample of 29 providers. The full sample of 79 hospitals represents the aggregate impact across the NHS of the workforce reaction, while the impact for the subsample of 29 providers details an accurate account of workforce adjustments for those providers performing both interventions.

Finally, our last analysis covered the displacement of CABG volume to other interventions, finding that as CABG volume decreases the volume of valve replacement interventions increased and accounts for the levelling off, rather than any decrease, in the employment of cardiothoracic surgeons. We provide evidence of the substitution between CABG and the other cardiac interventions undertaken by these workforce group. Whether this increase in volume of other treatments reflects a compensating induced mechanism in the form of supplier-induced demand by the cardiothoracic surgeons or merely the ability of these surgeons to address pent-up demand in other treatment areas is something our analysis does not address.

Little is known about the substitution of workforce across the health care sector, and there is little knowledge relating to the technology-labour substitution. If technology is, as seems to be the case, a major driver of health care expenditure growth the aggregate, examining general impacts of new technology up-take on staffing levels and composition is key to understand future workforce planning. Further research is required to check whether our findings are replicated across other areas of technology, and across a wider range of staffing categories. Data restrictions on staffing levels prevented investigation of the latter in our case.

Overall, our results suggest that, at least in this area of health care, new technology up-take and diffusion does affect the skill mix of the medical workforce as the technology matures. While our results are confined to specific highly prevalent technologies, it appears that the complex regulation of staffing and specialty mix is even further complicated once account is taken for the impact of new technology on the hospital production process. Skilled staff appear to be able to substitute into new tasks adjusting to exogenous technology change.

# References


Acemoglu, D. (2002), 'Technical change, inequality, and the labor market', *Journal of Economic Literature* **40**(1), 7–72.

Acemoglu, D. & Finkelstein, A. (2008), 'Input and technology choices in regulated industries: Evidence from the health care sector', *Journal of Political Economy* **116**(5), 837–880.

Arellano, M. & Bond, S. (1991), 'Some tests of specification for panel data: Monte carlo evidence and an application to employment equations', *The Review of Economic Studies* **58**(2), 277–297.

Autor, D. H., Katz, L. F. & Krueger, A. B. (1998), 'Computing inequality: have computers changed the labor market?', *The Quarterly Journal of Economics* **113**(4), 1169–1213.

Autor, D. H., Levy, F. & Murnane, R. J. (2003), 'The skill content of recent technological change: An empirical exploration', *The Quarterly Journal of Economics* **118**(4), 1279–1333.

Baker, L. C. (2001), 'Managed care and technology adoption in health care: evidence from magnetic resonance imaging', *Journal of Health Economics* **20**(3), 395–421.

Baker, L. C. & Phibbs, C. S. (2000), Managed care, technology adoption, and health care: the adoption of neonatal intensive care, Technical report, National Bureau of Economic Research.

Bech, M., Christiansen, T., Dunham, K., Lauridsen, J., Lyttkens, C. H., McDonald, K., McGuire, A. & Investigators, T. (2009), 'The influence of economic incentives and regulatory factors on the adoption of treatment technologies: a case study of technologies used to treat heart attacks', *Health Economics* **18**, 1114–1132.

Bekman, E., Bound, J. & Machin, S. (1998), 'Implications of skill-biased technological change: international evidence', *The Quarterly Journal of Economics* **113**(4), 1245–1279.

Blundell, R. & Bond, S. (1998), 'Initial conditions and moment restrictions in dynamic panel data models', *Journal of Econometrics* **87**, 115–143.

Bond, S. (2002), 'Dynamic panel data models: a guide to micro data methods and practice', *Portuguese Economic Journal* **1**(2), 141–162.

Chandra, A. & Skinner, J. (2012), 'Technology growth and expenditure growth in health care', *Journal of Economic Literature* **50**(3), 645–80.

Chandra, A. & Staiger, D. O. (2007), 'Productivity spillovers in health care: evidence from the treatment of heart attacks', *Journal of Political Economy* **115**(1), 103–140.

Clemens, J. & Gottlieb, J. D. (2014), 'Do physicians' financial incentives affect medical treatment and patient health?', *American Economic Review* **104**(4), 1320–49.

Coscelli, A. & Shum, M. (2004), 'An empirical model of learning and patient spillovers in new drug entry', *Journal of Econometrics* **122**(2), 213–246.

Crawford, G. S. & Shum, M. (2005), 'Uncertainty and learning in pharmaceutical demand', *Econometrica* **73**(4), 1137–1173.

Cutler, D. M. & Huckman, R. S. (2003), 'Technological development and medical productivity: the diffusion of angioplasty in new york state', *Journal of Health Economics* **22**(2), 187–217.

Cutler, D. & McClellan, M. (2001), 'Is technological change in medicine worth it?', *Health Affairs* **20**, 11–29.

David, G., Helmchen, L. A. & Henderson, R. A. (2009), 'Does advanced medical technology encourage hospitalist use and their direct employment by hospitals?', *Health Economics* **18**(2), 237–247.

Dranove, D., Garthwaite, C., Li, B. & Ody, C. (2015), 'Investment subsidies and the adoption of electronic medical records in hospitals', *Journal of Health Economics* **44**, 309–319.

Gray, A. & McGuire, A. (1989), 'Factor input in nhs hospitals', *Applied Economics* **21**(3), 397–411.

Gray, H., Swanton, R., Schofield, P., Murray, R., Brooksby, I., Venn, G., Perrins, J., deBelder, M., Smith, L., Hall, R. & Cumberland, D. (2000), 'Coronary angioplasty: guidelines for good practice and training?', *Heart* **83**, 224–235.

Ho, C.-Y. (2008), 'Investment-specific technological change and labor composition: Evidence from the us manufacturing', *Economics Letters* **99**(3), 526–529.

Imison, C. & Bohmer, R. (2013), 'NHS and social care workforce: meeting our needs now and in the future', *London: The Kings Fund* .

Lamiraud, K. & Lhuillery, S. (2016), 'Endogenous technology adoption and medical costs', *Health Economics* **25**, 1123–1147.

Lammers, E. (2013), 'The effect of hospital–physician integration on health information technology adoption', *Health Economics* **22**(10), 1215–1229.

McClellan, M., McNeil, B. & Newhouse, J. (1994), 'Does more intensive treatment of myocardial infarction reduce mortality?', *Journal of the American Medical Association* **272**, 859–866.

McGuire, A., Raikou, M., Windmeijer, F. & Serra-Sastre, V. (2010), 'Technology diffusion and health care productivity: Angioplasty in the UK', *LSE Health Working Paper Series in Health Policy and Economics, The London School of Economics and Political Science* .

Molina, J. A. & Heng, B. H. (2009), 'Global trends in cardiology and cardiothoracic surgery – an opportunity or a threat?', *Ann Acad Med Singapore* **38**(6), 541–545.

Morrison Paul, C. J. & Siegel, D. S. (2001), 'The impacts of technology, trade and outsourcing on employment and labor composition', *Scandinavian Journal of Economics* **103**(2), 241–264.

Newhouse, J. P. (1992), 'Medical care costs: how much welfare loss?', *The Journal of Economic Perspectives* **6**(3), 3–21.

Okunade, A. & Murthy, V. (2002), 'Technology as a major driver of health care costs: A cointegration analysis of the newhouse conjecture', *Journal of Health Economics* **21**, 147–159.

Roodman, D. (2009), 'A note on the theme of too many instruments', *Oxford Bulletin of Economics and statistics* **71**(1), 135–158.

Serra-Sastre, V. & McGuire, A. (2013), 'Information and diffusion of new prescription drugs', *Applied Economics* **45**(15), 2049–2057.

Skinner, J. & Staiger, D. (2015), 'Technology diffusion and productivity growth in health care', *Review of Economics and Statistics* **97**(5), 951–964.

Smith, S., Newhouse, J. P. & Freeland, M. S. (2009), 'Income, insurance, and technology: why does health spending outpace economic growth?', *Health Affairs* **28**(5), 1276–1284.

Tu, J., Pashos, C., Naylor, C., Chen, E., Normand, S., N. J. & McNeil, B. (1997), 'Use of cardiac procedures and outcomes in elderly patients with myocardial infarction in the US and Canada', *The New England Journal of Medicine* **336**, 1500–1505.

# Appendix

Table A1: Variables Definition and Descriptive Statistics (2000-2012)

| Variable | Definition | Source | N | Mean | St.Dev |
|---|---|---|---|---|---|
| v_ptca | PTCA volume | HES | 870 | 643.732 | 657.997 |
| v_cabg | CABG volume | HES | 870 | 250.537 | 324.417 |
| p_emergency | % emergency operations | HES | 870 | 0.31 | 0.281 |
| p_males | % male patients | HES | 870 | 0.732 | 0.160 |
| age | Age patients | HES | 870 | 64.23 | 49.62 |
| comorbidities | Comorbidities patients (0-3) | HES | 870 | 0.802 | 0.357 |
| imdi | Index of Multiple Deprivation (IMD) income | HES | 870 | 0.138 | 0.050 |
| charlson | Charlson Comorbidity Index | HES | 870 | 4.418 | 2.33 |
| ftrust | =1 if provider has FT status | HES | 870 | 0.317 | 0.466 |
| teaching | =1 if teaching status | ERIC | 870 | 0.323 | 0.468 |
| occuprate | Overnight bed occupancy rate | NHS England | 869 | 85.066 | 5.44 |
| #sites | # sites the trust occupies for services delivery | ERIC | 868 | 6.987 | 8.889 |
| estatescost | Annual revenue cost (£000,000) to provide the whole of the Estate services | ERIC | 858 | 17 | 18.8 |
| Pop45 | % population aged 45 and above 45 by PCT | ONS | 870 | 38.467 | 6.694 |
| Admissionspop | total admissions adjusted by population | ONS | 870 | 321.348 | 213.372 |
| dptcacabg | =1 if provider has high volumes (above 50) of PTCA and CABG | HES | 870 | 0.424 | 0.495 |
| dptca | =1 if provider has high volumes (above 50) of PTCA and low CABG volumes | HES | 870 | 0.576 | 0.495 |
| C | # FTE doctors performing PTCA | HES | 870 | 13.969 | 10.608 |
| CS | # FTE doctors performing CABG | HES | 870 | 3.326 | 3.977 |
| C: | # FTE cardiologists | ESR | | | |
| c_consultant | Consultants | | 870 | 7.387 | 4.674 |
| c_specialist | Specialists | | 870 | 8.081 | 7.34 |
| c_trainees | Trainees | | 870 | 2.840 | 3.802 |
| CS: | # of FTE cardio surgeons | ESR | | | |
| cs_consultant | Consultants | | 870 | 3.502 | 4.624 |
| cs_specialist | Specialists | | 870 | 4.463 | 6.555 |
| cs_trainees | Trainees | | 870 | 0.895 | 2.009 |
| statins | Number of items prescribed (2008-2013) at PCT level | NHS Digital | 363 | 501569.4 | 284118.6 |
| v_otherCSint | Volume other CS interventions K25-K29 & E54 | HES | 870 | 106.349 | 142.297 |
| Distance P75 | Distance from GPs to provider | HES | 766 | 21.043 | 10.782 |
| No. GPs | Number of GPs referring patients to each provider | HES | 766 | 142.704 | 128.288 |

*Notes*: p_males, imdi, charlson, p_emergency, age and comorbidities are averages over patients treated by hospital $i$ in year $t$. HES (Hospital Episodes Statistics). ONS (Office for NAtional Statistics) ESR (Electronic Staff Records). ERIC (Estates Return Information Collection) from Hospital Estates and Facilities Statistics.

Table A2: Workforce Elasticity - IV - Other Distance Measures

| Dep. Var: Log C/CS | (1) 2SLS Distance Mean | (2) 2SLS Distance Median | (3) 2SLS Distance P90 | (4) 2SLS Distance Mean | (5) 2SLS Distance Median | (6) 2SLS Distance P90 |
|---|---|---|---|---|---|---|
| Log PTCA/CABG | 0.217** | 0.186 | 0.370*** | 0.0453 | 0.0763 | 0.295* |
| | (0.105) | (0.128) | (0.0537) | (0.168) | (0.154) | (0.154) |
| First stage - Instrument | 0.071*** | 0.048*** | 0.059*** | 0.076*** | 0.045*** | 0.033** |
| | (0.019) | (0.014) | (0.009) | (0.028) | (0.013) | (0.013) |
| F statistic | 37.579 | 24.523 | 105.167 | 31.32 | 27.904 | 23.646 |
| No. Hospitals | 79 | 79 | 79 | 29 | 29 | 29 |
| N | 755 | 755 | 755 | 360 | 360 | 360 |
| Provider FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Time FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Controls Patients | Yes | Yes | Yes | Yes | Yes | Yes |
| Controls Providers | Yes | Yes | Yes | Yes | Yes | Yes |
| $R^2$ | 0.541 | 0.517 | 0.606 | 0.259 | 0.277 | 0.320 |
| Years | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 |

*Notes:* See *Notes* in Table 1. Robust standard errors in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1. F Statistic on exclusion restrictions.

Table A3: Workforce Elasticity - Distance IV - 37km and 30% referral

| Dep. Var: Log C/CS | (1) 2SLS Mean | (2) 2SLS Median | (3) 2SLS P75 | (4) 2SLS P90 | (5) 2SLS No. GPs | (6) 2SLS Mean | (7) 2SLS Median | (8) 2SLS P75 | (9) 2SLS P90 | (10) 2SLS No. GPs |
|---|---|---|---|---|---|---|---|---|---|---|
| Log PTCA/CABG | 0.193 | 0.119 | 0.341*** | 0.330*** | 0.305*** | 0.0614 | 0.213 | 0.0530 | -0.325 | 0.0305 |
| | (0.155) | (0.228) | (0.0684) | (0.0577) | (0.0552) | (0.199) | (0.144) | (0.305) | (0.465) | (0.167) |
| First stage - Instrument | 0.056** | 0.034** | 0.076*** | 0.076*** | 0.011*** | 0.096*** | 0.057*** | 0.041** | 0.033 | 0.005* |
| | (0.022) | (0.017) | (0.015) | (0.011) | (0.002) | (0.036) | (0.014) | (0.018) | (0.021) | (0.002) |
| F Statistic | 18.447 | 9.64 | 68.52 | 111.059 | 113.466 | 23.129 | 21.502 | 9.951 | 9.637 | 52.784 |
| No. Hospitals | 79 | 79 | 79 | 79 | 79 | 29 | 29 | 29 | 29 | 29 |
| N | 755 | 755 | 755 | 755 | 755 | 360 | 360 | 360 | 360 | 360 |
| Provider FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Time FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Controls Patients | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Controls Providers | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| $R^2$ | 0.524 | 0.455 | 0.600 | 0.597 | 0.589 | 0.269 | 0.320 | 0.264 | -0.171 | 0.250 |
| Years | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 | 2000-2012 |

*Notes:* See *Notes* in Table 1. Robust standard errors in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.1. F Statistic on exclusion restrictions.