Centralisation of acute stroke services in London: Impact evaluation using two treatment groups

Key words: Centralisation of stroke care; Health policy evaluation; Difference-in-difference models; Panel Data Analysis

1. INTRODUCTION

Policy makers have focussed considerable efforts on improving healthcare quality and its efficient provision at the hospital-level (Scott, 2009). One effective intervention for triggering change is the introduction of centralised treatment centres, where the bundling of clinical expertise translates into enhanced service delivery, characterised by efficiently applied processes and improved clinical outcomes. Successful centralisations are documented in cancer care (Lemmens et al., 2011; Gooiker et al., 2011), with specialist units leading to reduced 30-day mortality and overall costs, mainly because of decreases in length of stay (Lemmens et al., 2011; Gooiker et al., 2011). The primary theory underlying centralisation is the physician/unit-volume effect (Schmidt et al., 2010; Freeman et al., 2012; Svendsen, Ehlers, Ingeman and Johnsen, 2012; Halm, Lee and Chassin, 2000), whereby clinical staff enhance their ability to perform specialist tasks through continuous repetition, which leads to better patient outcomes. While the effectiveness of centralisation for surgical interventions is well documented, little is known about its effectiveness in acute settings, such as stroke (Kanhere, Kanhere, Cameron and Maddern, 2012).

Stroke is the leading cause for mortality and disability in developed countries (Mathers, Boerma and Ma Fat, 2009). The high incidence combined with potentially life changing clinical effects imposes a significant burden on society and health care providers (Smith et al., 2012; Di Carlo, 2009; Fattore et al., 2012; Persson, Ferraz-Nunes and Karlberg, 2012). The direct treatment costs in England total £3-4.4 billion (Houses of Parliament, 2014) and outcomes and long-term recovery from a stroke is highly variable (Reistetter et al., 2014). Apart from clinical severity, it is highly influenced by the management of stroke pathways and provision of high quality of care (Clarke and Forster, 2015). This includes the capacity to respond to early symptoms, for example providing immediate access to specialist thrombolytic drugs for eligible patients (Lecouturier et al., 2010).

Since 2010, all acute stroke patients in London are expected to receive treatment within one of eight Hyper Acute Stroke Units (HASUs) that cover the first 72 hours of the acute stroke episode. Post-policy implementation, twenty-six hospitals were meant to cease the provision of acute stroke care, and centralising services intended to offer equal and accessible high quality procedures, bundling clinical expertise and to subsequently improve patient outcomes (Healthcare for London, 2008). Previous impact evaluations found positive associations between stroke care centralisation and improvements in processes and outcomes

(Liu, Rudd and Davie, 2011; Hunter et al., 2013; Fulop et al., 2013; Morris et al., 2014; Ramsay et al., 2015).

Despite clear structuring of stroke pathways in London, descriptive statistics of patient flow show that some London non-HASU Trusts continued treating stroke patients after the implementation of the centralisation policy. Approximately 15 per cent of all London stroke patients still received stroke care in non-HASUs in 2012, with the number of stroke admissions to non-HASUs decreasing gradually (see Figure 1). This appears contrary to the intention of the centralisation policy and has been disregarded by previous research. While estimations of an overall area-level treatment effect provide insights into changes across a pooled group of healthcare providers, findings disguise the heterogeneity in treatment effects within provider groups. This is of particular concern with regards to stroke care in London, because approximately 350 patients still receive care in non-HASU trusts every quarter.

The innovative contribution of this study is to assess the impact of centralised stroke care in London on seven process and outcome indicators, separately for patients admitted to HASUs and for patients admitted to non-HASUs. We apply a difference-in-difference analysis with two treatment groups to all English stroke patients recorded in the Hospital Episode Statistics database (HES) from April 2006 to April 2014. This methodology provides a tool to investigate potentially systematic differences between patients receiving care in London trusts that can result from lower levels of clinical engagement or limited availability of equipment to provide stroke specific processes, which is disguised by a one treatment group methodology.

2. BACKGROUND

In 2010, the two largest metropolitan areas in England, London and Greater Manchester, performed a reorganisation of stroke care aimed at streamlining stroke services through service centralisation. Prior to the policy introduction, 30 London hospitals provided acute stroke services across the city, of which 26 were expected to terminate service provision following the introduction of the policy in April 2010. Eight trusts were converted into HASUs in London, with the objective of improving stroke processes and outcomes, as well as saving costs in the long run (Healthcare for London, 2008). The identification of trusts that should become HASUs followed a modelling exercise (Fulop et al., 2013), addressing not only population need and configuration requirements, but also an ambulance travelling time of maximum 30 minutes to the closest facility, given any possible stroke

patient location within the London catchment area. All HASUs are equipped with stroke-specialised staff that provides 24/7 stroke care for patients, covering the first 72 hours of the acute stroke episode. Following 72 hours, stroke patients will either be directed to another stroke unit based on the locality of their residence, which in many cases is located in a non-HASU trust, or will be discharged depending on their level of recovery.

Several empirical studies investigated the effectiveness of centralised stroke care in England (Liu, Rudd and Davie, 2011; Hunter et al., 2013; Fulop et al., 2013; Morris et al., 2014; Ramsay et al., 2015). Early effects showing increased thrombolysis rates (12 per cent), discharge to home rates (35 per cent), and reductions in 30-day mortality rates (6 per cent) were reported by Liu, Rudd and Davie (2011), and interpreted as a direct effect of centralisation. The method used in the study was a before and after comparison of crude rates that were not adjusted for patient case-mix and based on data from one HASU trust. Further methodological limitations relate to the isolation of policy effects from general improvements in stroke care and non-adjustment for pre-policy performance heterogeneity between trusts. In particular, some trusts that eventually transformed into HASUs already provided leading stroke services, *e.g.* thrombolysis treatments in the King's College London trust, whereas other HASUs had to be newly built and subsequently showed low levels of pre-policy engagement in similar processes. As a result, the observed jump in thrombolysis rates and mortality could be more prominent in trusts that had lower baseline experiences.

Hunter et al. (2013) conducted a before and after cost-effectiveness analysis of the stroke policy in London, with a particular focus on time trends in mortality and length of stay. The study used Cox Proportional hazards and Weibull survival analysis to evaluate changes in outcome and cost. According to the findings of the study, the reorganisation led to improved survival rates illustrated by Kaplan-Meier survival curves, fewer overall deaths, and a cost reduction per stroke patient of £811. A variety of datasets were used, capturing a sub-section of stroke patient in London. Data sources included the South London Stroke Register, which holds information on patients consented to the collection and storage of their information, and data from two hospitals based in North London. Similar to Liu et al. (2011), findings are therefore not representative of the treatment effect on the whole stroke population in London.

Morris et al. (2014) provided the first impact evaluation on the centralisation approach implemented in London as well as Greater Manchester. Difference-in-difference

regression methods were used to compare trends in outcomes between London, Greater Manchester and the rest of England. The method accounted for time trends and was conducted at the hospital-level, using patient-level records from the HES database, and focussed on all urban-living stroke patients in England admitted to a hospital within the study period. The study compared area-wide changes in the whole of London to changes that occurred in the rest of England, and findings supported previously established improvements in outcomes, with significant decreases found for 30-day mortality rates (-1.3 per cent) and length of stay (-1.4 days). However, the study has limitations. The use of the classical difference-in-difference design averages provider performance in London and compares it to changes in the average performance within the rest of England. Morris et al. (2014) failed to address the differential impact on stroke patients in London, given that non-HASUs continued to provide acute stroke care. Even though the applied method allowed for estimates of the area-wide impact of the policy, it provided no insight into heterogeneity of implementation practice between providers. In fact, deviation from guidelines by some providers could undermine efforts of quality improvements and subsequently dilute previously reported area-level treatment effects.

Past research failed to consider the impact of possible policy deviation by non-HASUs that continued to provide acute stroke treatment to stroke patients. To understand the potential impact of differential treatment received by stroke patient in London, an impact evaluation with two treatment groups is required. The methodological expansion in this study provides policy makers with a crucial insight into the performance variation between HAUSs and non-HASUs in London.

3. DATA

The study covers the period from April 2006 to April 2014, providing a panel of 16 quarters before and 16 quarters after policy introduction in April 2010. The dataset contains patient information from a total of 224 English NHS trusts that have been treating stroke patients across the study period, including trusts that have merged or dissolved. To capture the potential impact of trust status change, we include a dummy variable for all London trusts that have merged with other trusts, hence absorbed another trust or dissolved.

The eight HASUs are situated in hospitals belonging to eight NHS trusts. Over the observation period, mergers between HASU trusts and non-HASU trusts occurred, *e.g.* Whipps Cross University Hospital NHS Trust integrated into Barts Health and the London

NHS Trust, in 2012. We assume that after a trust merger, stroke patients were recorded under the new trust code, with the original trust disappearing from our analysis and hence coded as a missing value.

We include all trusts that treated at least one patient per quarter. For some trusts and quarters we have missing values in our dataset, *i.e.* zero patients or missing values for some variables, which may be an indication of no stroke patients being treated or potentially poor coding practice that could impact our results. As a response we estimate an unbalanced panel. To avoid that the control group, rest of England, is driven by any changes that occurred through the area-wide stroke policy framework in Greater Manchester, eight trusts located in the Greater Manchester catchment area are excluded from this study. Additionally, we exclude the Epsom and St. Helier University Hospital NHS Trust, because of their location on the periphery of Greater London and subsequent limitation in assigning it to either the HASU, or control group.

We use trust-level data, aggregated from the patient-level for all patients with a primary diagnosis of stroke, which was obtained from the HES database. Our final dataset was based on 'super-spells', *i.e.* linked continuous inpatient spells that hold information on patient demographics and treatment for the period between hospital admission and discharge. By definition, 'super-spells' are constructed from 'spells' that are separated by less than two days, which avoids double counting of patients in case of repatriation to a regular stroke unit in a non-HASU trust following an acute care 'spell' at a HASU trust. Stroke was defined based on ICD-10 (International Classification of Disease, 10^{th} revision) codes – I61 (intracerebral haemorrhage), I62 (other non-traumatic intracranial haemorrhage), I63 (cerebral infarction), and I64 (stroke, not specified as haemorrhage or infarction). Patients with a primary diagnosis of subarachnoid haemorrhage are excluded, as this diagnosis was not part of the implemented hyper acute stroke care pathway in London.

We focus on seven stroke specific processes and outcome measures, chosen to cover different critical points in the quality of stroke care along the medical pathway. The measures are based on findings of Palmer et al. (2013), which investigated the feasibility of using HES to derive measures for an evaluation of quality of stroke care at the trust-level. Assessed process and outcome measures are 24 hour brain scan rate; thrombolysis treatment rate; rate of patients suffering from hospital acquired aspiration pneumonia; 7-day and 30-day in-hospital mortality rate; rate of patients discharged to their usual place of residence within 56

days of admission; and 30-day emergency readmission rates. Table I includes a definition of measures and Table II summary statistics.

We control for average trust-specific covariates, patient age, Charlson index, gender ratio and hospital transfers rate. The transfer rate describes the proportion of patients coming from another A&E department before receiving acute stroke care. Time invariant regional variation of dependents is captured with dummy variables for seven separate English regions (North East, North West, Yorkshire and the Humber, East Midlands, West Midlands, East of England, South East Central, South Central, and South West).

Insert Table I Here

Insert Table II Here

4. ECONOMETRIC FRAMEWORK

To evaluate the intervention, we use a difference-in-difference analysis (Ashenfelter and Card, 1985) - a widely used tool for estimating causal inference of health policies (Wooldridge, 2002; Propper, Whitnall, Sutton and Windmeijer, 2008). We estimate a difference-in-difference model that uses two-treatment groups, HASUs and London non-HASUs (Marini, Miraldo, Jacobs and Goddard, 2008). We assume a constant difference between the two treatment groups and trusts in the rest of England given the absence of an intervention, as well as parallel trends in the process and outcome variables before the policy intervention. We tested for differences in pre-treatment trends of the treatment and comparison group. The main model of our difference-in-difference regression analysis is specified as:

$$Y_{jt} = \beta_0 + \beta_1 * N_j + \beta_2 * H_j + \beta_3 * T_t + \beta_4 * N_j T_t + \beta_5 * H_j T_t + \beta_6 * W_{jt} + \beta_7 * M_j + \beta_8 * R_j + \varepsilon_{jt} + \mu_j \quad (1)$$

The dependent variable Y_{jt} represents one of seven process or outcome indicators, in quarter t and trust j. For the first treatment group, N_j takes the value of one if the trust is a non-HASU in London, and zero otherwise. For the second treatment group, H_j takes the value of one if the trust is a HASU, and zero otherwise. Both variables are time invariant and capture systematic permanent differences between either the first or second treatment group and the control group, and the other treatment group. The coefficient estimate of β_1 presents the differences in outcomes of non-HASU trusts in London compared to the rest of England

and HASU trusts, whereas β_2 indicates the differences in outcome of HASUs compared to the rest of England and non-HASU trusts, for reasons unrelated to the reorganisation. Time dummy T_t captures the time varying impacts on the dependent variable that affects both treatment and control groups, and takes the value of one for quarters after the reorganisation (17 to 32), and zero before (1 to 16). From quarter 17, the interaction term $N_j T_t$and $H_j T_t$ is one for non-HASUs and HASUs, respectively. The coefficient estimates for β_4 and β_5 captures the impact of the reorganisation purged from the effects of other time varying and time invariant observed and unobserved impacts on the dependent variable. Time varying covariates, such as average age and gender rate, are represented in vector W_{jt}. We further include a time invariant merger dummy M_j, and regional dummies R_j. The time invariant error μ_j captures unobserved random variations in processes and outcome across trusts that are stable over time; and the normally distributed error ε_{jt} captures unobserved random shocks.

We estimate alternative model specifications. The first replicates the analysis conducted by Morris et al. (2014) to compare changes in 30-day mortality rates and length of stay for all London trusts (HASUs and non-HASUs) to the control group, rest of England, using random effects. We acknowledge that previous findings may not be fully replicable due to several reasons. First, Morris et al. (2014) performed analysis at the hospital-level using patient-level data, whereas our analysis is restricted to aggregate data at the trust-level. Second, we estimate the treatment effect of centralisation in London compared to a control group comprising of all patients admitted to trusts within the rest of England, but excluding Greater Manchester, whereas the previous evaluation confined to patients living in urban areas. Finally, our study uses in-hospital mortality data derived from patient records, whereas Morris et al. (2014) used mortality data on all deaths including those occurred outside of hospital. In combination these differences can potentially lead to significant variations in replicating previous results. The difference-in-difference model is specified as:

$$Y_{jt} = \beta_0 + \beta_1 * L_j + \beta_2 * T_t + \beta_3 * L_j T_t + \beta_4 * W_{jt} + \varepsilon_{jt} + \mu_j \qquad (2)$$

where the dummy variable L_j takes the value of one if the trust is located in London, and zero otherwise. The time dummy T_t is one after the reorganisation (April 2010 to March 2012), and zero before (January 2008 to March 2010). The coefficient estimates of $L_j T_t$ show

the policy effect on the dependent variable Y_{jt}, namely 30-day mortality and length of stay. Time varying covariates are represented in vector W_{jt}.

We assess the validity of the control group with a specification that compares HASUs and non-HASUs in London to a control group containing trusts of seven English metropolitan areas (Birmingham, Bristol, Leeds, Liverpool, Sheffield, Southampton, and Newcastle). We assume systematic differences in the provision of health care services between rural and urban areas (Smith, Humphreys and Wilson, 2008) that could impact the time-to-treatment for patients and possibly lead to worse health outcomes (QualityWatch, 2014). We further perform Hausman model specification tests.

5. RESULTS

We identify 678 968 patients with a primary diagnosis of stroke in England, over the observation period. The number of quarterly recorded strokes increased throughout, and is 12.4 per cent higher in quarter 32 compared to quarter 1. As shown in Figure 1, the proportion of London stroke patients admitted to trusts with HASU post-reorganisation and trusts with non-HASUs post-reorganisation is evenly split at approximately 50 per cent before the implementation of the centralisation policy. Immediately after the policy introduction, admission rates started to diverge and we observe a gradual increase in admissions to HASUs and a decrease in admissions to non-HASUs. Our data shows a levelling effect that occurred in quarter 23, beyond which admissions to HASUs account for about 85 per cent of all stroke admissions in London.

Insert Figure 1 Here

Appendix A illustrates plotted weighted time trends of dependent variables over the study period. We find that stroke processes and outcome measures improved across England. In London, weighted rates closely follow the time trend of HASUs, indicating that the performance in HASUs is the main driver for performance observed in the London area.

Results from main model specification (1)

Table III provides estimates of the difference-in-difference analysis using two treatment groups and comparing them to performance recorded in trusts based in the rest of England and the other treatment group, respectively. The number of observations used per analysis was 5147. For some outcome measures we reject the random effect specification

based on the Hausman test. For the estimations of a panel data model with fixed effects, all time invariant variables were omitted. We present results of the fixed effect specification for the models that failed the Hausman test in Appendix B.

Insert Table III Here

According to the coefficient estimate of T_t, we find an improvement in stroke care over time that is unrelated to the reorganisation. Across all English trusts, stroke processes were higher in the quarters after the reorganisation, with 22.9 per cent more patients scanned within 24 hours of hospital admission, and 4.3 per cent more patients receiving thrombolysis. 7-day mortality and 30-day mortality was significantly lowered by 1.5 per cent and 3.7 per cent, respectively. The rates for aspiration pneumonia, discharge to usual place of residence and 30-day emergency readmission were significantly higher in quarter 16 to 32 compared to the pre-policy period. An additional 0.8 per cent of patients experienced aspiration pneumonia, 6.8 per cent more patients were discharged to their usual place of residence, and 2 per cent more patients were readmitted within 30-days of discharge.

Based on the coefficients of dummy N_j and H_j we cannot generally identify underlying time-invariant differences in processes and outcomes between the treatment groups, HASUs and non-HASUs, and the control group, except that non-HASUs have 4.7 per cent higher aspiration pneumonia rates across all quarters. No other underlying differences between HASU, non-HASU, and the rest of England are found.

Following the assumption of heterogeneous policy effects, *i.e.* non-HASUs continued the provision of care for a small proportion of the stroke population, the DiD coefficient of interest, DiD (non-HASUs) is significantly smaller for both processes, aspiration pneumonia and discharge to usual place of residence, and significantly larger for both mortality rates and readmission rates, in the period post-reorganisation. Our findings indicate that 24-hour scan rates are lower by 14.7 per cent in non-HASUs compared to HASUs and trusts in the rest of England; however, our estimates highlight no policy effect for HASUs when compared to trends in non-HASUs in London and the rest of England. Thrombolysis treatment rates show an opposing effect for HASUs and non-HASUs, with a significant decrease of 3.9 per cent in non-HASUs and a significant increase of 4.3 per cent in HASUs. Further policy effects for patients admitted to non-HASUs are a 1.9 per cent rise in 7-day mortality rate, a rise in 30-day mortality rate by 2.3 per cent, a 2.3 per cent decrease in aspiration pneumonia rates and 7.6 per cent decrease in rates of discharge to usual place of residence. Except for one

indicator, there is no effect for HASUs, but importantly there are negative effects on outcomes and processes for non-HASUs. This finding suggests that the reorganisation of stroke care led to significant different policy effects for patients admitted to HASUs and London non-HASUs. The estimates of the regional dummies show significant variation for 7-day mortality rates across English regions.

Alternate specifications and sensitivity analyses

Our results confirm reduction in length of stay previously stated by Morris et al. (2014) (see Appendix C); however, we find no significant effect of centralisation on 30-day in-hospital mortality. This is likely to be caused by limitations of our data, namely the use of aggregate-level data, inclusion of all patients regardless of whether their place of residence is in rural or urban areas, and the use of 30-day in-hospital mortality, as compared to mortality that includes deaths outside the hospital.

Results from sensitivity analysis, comparing changes in London HASU and non-HASU trusts to a control group that comprises of seven English metropolitan areas show no significant policy effects on 7-day or 30-day in-hospital mortality for HASUs and non-HASU trusts in London (Appendix D). Furthermore, the centralisation of stroke care led to a 10.10 per cent increase in 24-hour scan rates in HASU trusts

6. DISCUSSION AND POLICY IMPLICTIONS

The intention of stroke care centralisation in London was to increase provision of stroke processes and improve outcomes, while containing costs (Healthcare for London, 2008). Our results show that this policy objective was partly achieved by increased rates of thrombolysis treatment for patients admitted to HASUs. However, we find that approximately 15 per cent of patients still receive acute stroke care in London non-HASU trusts and estimates of the difference-in-difference analysis suggests that those patients are less likely to receive stroke-specific processes and are experiencing worse outcomes. This is the first study to evaluate the impact of stroke service centralisation in London, addressing heterogeneity in provider performance that was masked by previous studies.

The objective of centralised stroke care in London was to provide acute stroke services for the first 72 hours to patients in eight dedicated London HASUs, leading to the expectation of a reduction in patients receiving treatment in London non-HASU trusts. Our findings could be explained by four factors. First, variation in coding practice and in particular the wrong

coding of acute and rehabilitation stroke patients within HES. In fact, recorded stroke patients in non-HASUs could be rehabilitation patients who naturally would not receive processes, and are also more likely to experience worse health outcomes as they tend to be sicker compared to patients that are discharged after their acute episode. Second, while non-HASUs have no financial incentive in treating stroke patients, our results may indicate selection bias at non-HASU level due to unobservable differences in patient complexity. For example, non-HASUs in London could end up treating sicker patients with multiple life threatening conditions, which are not observable in our data, and may preclude transfer to a HASU. Further, stroke cases treated in non-HASUs could be diagnosed with delay, because sometimes strokes present in complex multi-morbid patients and symptoms are difficult to read. Depending on the length of the delay, patients may not be suitable for transfer into a HASU upon diagnosis. Despite adjusting for comorbidities by using the Charlson index, age and other indicators of patient complexity, HES does not allow adjusting for severity of stroke. This may have explained whether some patients were treated in non-HASU trusts because they were considered clinically unfit for transportation. Lastly, and keeping the above alternative explanations in mind, our results could indicate differences in quality of care received at London HASU and non-HASU trusts. Poorer quality of care, potentially resulting from factors such as lower availability of specialist stroke staff, led to patients treated in London non-HASU trusts being less likely to receive stroke specific processes, 24h brain scans (-14.78) and thrombolysis treatment (-3.90), and being more likely to die within 7-days (1.94) and 30-days (2.35).

Our study has limitations. The use of HES data relies largely on the consistency of good quality coding practice. A previous study has shown that up to 16 per cent of all stroke patients are missed when compared to independent hospital stroke registers (Barer and Cassidy, 2014). However, the same study also found that the Stroke Improvement National Audit Programme (SINAP) omitted 30 per cent of all stroke patients, highlighting that of the two widely used sources for stroke policy evaluations, HES may be the more appropriate data source. In a recent study by Li and Rothwell (2016), systematic variation in coding practice of stroke patients between the weekday and weekend was highlighted. Even through the study has limited generalizability to the whole population due to its use of data from nine general practices, it flags up potential issues surrounding the quality of administrative datasets and its biases that could affect our estimates in unknown magnitude and direction. However, our study uses a tighter definition of stroke and we restricted our analysis to

emergency admissions, which may help to reduce bias. In this study we were not able to adjust for the type of stroke, which could bias performance of thrombolysis treatment rates and be a predictor for stroke outcomes. However, previous studies reported high inconstancies in stroke coding across English hospitals (Britton et al., 2012), which could introduce an additional bias into the analysis provided the type of stroke is coded wrongly. Last, policy makers have linked payments to performance targets based on clinical processes, which led to substantial investments into improving coding practices at the hospital-level. This might partly explain the estimated increase in 24-hour brain scan rates and thrombolysis treatment rates across the whole of England.

As shown by previous studies, the centralisation of stroke care in London led to a step change in quality improvement, with processes and outcomes across London as a whole being consistently favourable to rates observed in the rest of England. The provision of centralised stroke care in London is therefore leading in the country, and improvements in London may have translated into learning for other service centralisations. However, while the majority of stroke patients received care in the anticipated clinical pathway, our findings show that the London stroke model would benefit from further exploration into reasons for why approximately 15 per cent of stroke patients still received care within London non-HASU trusts and causes of poorer processes and outcomes for those patients. For example, one opportunity could be the revision of the London hub-model performance through joint collaboration between the three London Sustainability and Transformation Plans, and to develop strategies on how to drive further improvements in London and derive learning that could benefit other areas. An in-depth revision of the long-term impact of the London stroke model would also be of particular importance to policy makers when deciding whether a rigid area-wide policy is the appropriate tool for triggering a continuous long-term improvement, or whether locally driven, bottom-up initiatives could offer more flexibility to providers and hence better value in the long-term. Future research could explore the effectiveness of small scale local policies, which will help to develop an understanding of initiatives that could run in parallel to current efforts and potentially trigger further improvements of stroke care on a national scale.

In this study, we found evidence to suggest underlying heterogeneity in processes and outcomes between providers following the introduction of an area-level centralisation of acute stroke care services in London, but we are not able to fully determine the reasons underlying such variation. Although the provision of stroke care has improved significantly

across the whole of England, with services in London remaining one of the best in the country, a renewed policy engagement into the London stroke model could lead to further improvements in processes and outcomes, ultimately affecting peoples lives.

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Table I: Definitions of selected process and outcome measures

Stroke measure	Definition	Inclusion Criteria	Exclusion Criteria
24 hour brain scan rate	Proportion of patients receiving a CT or MRI brain scan within 24 hours of admission	OCPS codes = U05.1, U05.2, U21.1 or U05.2 with Z01.9	Death on day of admission
Thrombolysis rate	Proportion of patients receiving clot-busting drug treatment	OPCS codes = X83.3	Patients excluded from license agreement (<18 and >80)
Aspiration pneumonia rate	Proportion of patients contracting aspiration pneumonia	ICD-10 codes = J69.0, J69.8 recorded as primary or secondary diagnosis	Exclusion if episode is prior to stroke episode
7-day in-hospital mortality rate	Proportion of patients dying within 7-days of admission	HES discharge method = 4 if length of stay <= 7 days	None
30-day in-hospital mortality rate	Proportion of patients dying within 30-days of admission	HES discharge method = 4 if length of stay <= 30 days	None
Discharge rate to usual place of residence within 56 days	Proportion of patients discharged to their usual place of residence within 56 days of index admission	HES discharge destination = 19 if length of stay <= 56 days	Spell ending in death
30-day emergency readmission rate	Proportion of patients readmitted within 30-days following discharge from an index admission	HES admission method = 21, 22, 23, 24, 25 or 28 a nd admission < disdate(index) + 30 days	None

Note: Definitions and inclusion/exclusion criteria are adopted from Palmer at al (2013).

Table II (A): Summary statistics for London and rest of England trusts

	All trusts in London				All trusts in rest of England			
	Before (N=404)		After (N=388)		Before (N=2125)		After (N=2230)	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Number of admissions	95.49	59.88	111.70	120.17	129.54	73.11	133.85	85.46
Female patients (%)	47.91	14.30	47.95	14.89	51.78	15.94	51.62	15.08
Age (average)	71.01	6.41	71.81	6.03	75.03	4.88	75.49	5.02
Charlson Index (average)	5.90	2.37	7.97	2.41	5.32	2.35	7.14	2.72
Length of stay (average)	14.11	11.82	9.37	8.62	14.49	17.49	12.59	16.32
Admission from home (%)	84.38	28.07	80.85	28.31	91.31	21.18	87.38	25.94
Admission from hospital (%)	14.75	27.54	18.34	27.46	7.62	19.73	11.90	25.40
Scan rate (%)	37.47	22.69	51.56	22.95	30.16	20.48	51.89	25.08
Thrombolysis treatment rate (%)	0.91	2.62	4.23	6.44	0.64	1.72	4.72	6.11
7-day death rate (%)	7.81	4.93	7.17	10.19	10.44	10.35	8.20	9.09
30-day death rate (%)	15.97	10.54	13.64	12.01	20.49	14.91	15.77	12.54
Discharge to usual place of residence rate (%)	55.79	14.95	57.76	16.97	50.76	16.79	57.43	18.12
30-day readmission rate (%)	9.59	9.51	12.74	9.53	7.31	7.06	9.57	8.91
Aspiration pneumonia rate (%)	6.66	8.11	5.75	5.94	5.14	7.23	5.84	8.07

Note. Before: Quarters 1 to 16; After: Quarters 17 to 32.

Table II (B): Summary statistics for HASU trusts and non-HASU trusts

	All HASU trusts				All non-HASU trusts			
	Before (N=128)		After (N=114)		Before (N=276)		After (N=259)	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Number of admissions	150.65	58.89	271.75	63.80	69.91	39.74	33.57	26.13
Female patients (%)	47.09	6.03	48.35	3.82	48.29	16.80	47.96	17.79
Age (average)	70.00	4.36	72.49	2.14	71.47	7.12	71.58	7.15
Charlson Index (average)	5.58	1.45	7.68	1.18	6.05	2.68	8.04	2.79
Length of stay (average)	11.50	3.62	5.63	2.61	15.32	13.93	11.09	9.58
Admission from home (%)	88.03	18.63	92.19	15.15	82.69	31.39	78.94	29.52
Admission from hospital (%)	10.44	17.77	7.47	14.53	16.75	30.87	20.25	28.88
Scan rate (%)	44.34	15.23	72.03	10.28	34.29	24.80	41.98	21.10
Thrombolysis treatment rate (%)	1.86	3.95	10.80	6.94	0.47	1.50	1.07	3.08
7-day death rate (%)	8.06	2.69	6.00	1.75	7.69	5.68	7.77	12.37
30-day death rate (%)	14.94	4.52	11.99	2.96	16.45	12.35	14.56	14.45
Discharge to usual place of residence rate (%)	55.70	7.04	62.39	5.87	55.83	17.46	56.03	19.42
30-day readmission rate (%)	8.54	2.95	11.29	2.38	10.08	11.30	13.42	11.47
Aspiration pneumonia rate (%)	5.22	2.93	5.85	2.21	7.33	9.55	5.70	6.97

Note. Before: Quarters 1 to 16; After: Quarters 17 to 32.

Table III: Panel data model using two treatment groups

Independent variables	24 hour brain scan **(fixed effect)**	Thrombolysis treatment **(fixed effect)**	Death within 7 days **(random effect)**	Death within 30 days **(random effect)**	Aspiration pneumonia **(random effect)**	Discharge to usual place of residence **(fixed effect)**	30-day emergency readmission **(fixed effect)**
London non-HASUs	-	-	4.88	-4.35	4.74**	-	-
London HASUs	-	-	4.23	-8.96	2.45	-	-
T	**22.91*** **	**4.26*** **	**-1.53*** **	**-3.72*** **	**0.82*** **	**6.84*** **	**2.08*** **
DiD (non-HASUs)	**-14.78*** **	**-3.90*** **	**1.94** **	**2.35** **	**-2.32*** **	**-7.61*** **	**1.39***
DiD (HASUs)	3.52	**4.32*** **	-0.75	0.08	-0.59	0.13	0.86
Merger dummy	-	-	0.40	-3.02	-0.01	-	-
Average age	0.00	-0.01	**0.23*** **	**0.51*** **	0.03	**-0.51*** **	**-0.04***
Average Charlson Index	**0.93*** **	**0.10*** **	**-0.16*** **	**-0.22*** **	0.06	**0.55*** **	-0.02
Gender	0.02	**0.01*** **	0.00	**-0.03*** **	**-0.02*** **	**0.03** **	**-0.01***
Hospital transfers	**-0.05*** **	0.00	**-0.06*** **	**-0.11*** **	**-0.03*** **	**-0.09*** **	0.00
North East	-	-	6.01*	-4.19	2.85	-	-
North West	-	-	3.66	-4.73	1.68	-	-
Yorkshire and Humber	-	-	4.91	-6.27	1.46	-	-
East Midlands	-	-	**8.22** **	-3.80	3.88	-	-
West Midlands	-	-	4.99	-5.28	2.44	-	-
East of England	-	-	**7.99** **	-3.27	3.15	-	-
South East Central	-	-	**6.81***	-0.62	4.64*	-	-
South Central	-	-	3.98	-6.71	2.37	-	-
South West	-	-	**8.99*** **	-2.49	1.83	-	-
Constant	**24.36*** **	0.35	**-11.25*** **	-8.08	2.16	**85.48*** **	12.27
N	5147	5147	5147	5147	5147	5147	5147
R-squared	0.20	0.21	0.04	0.08	0.02	0.12	0.03
Hausman test (Prob>chi2)	0.00	0.00	0.20	0.51	0.52	0.00	0.00

Note: [1]*** indicates that the variable has robust impact on dependent variable at 1% significance level, ** for 5%, and * for 10%; [2] The Hausman test was used to determine the preferred model effect; [3]Fixed effect models ommit time invariant variables.

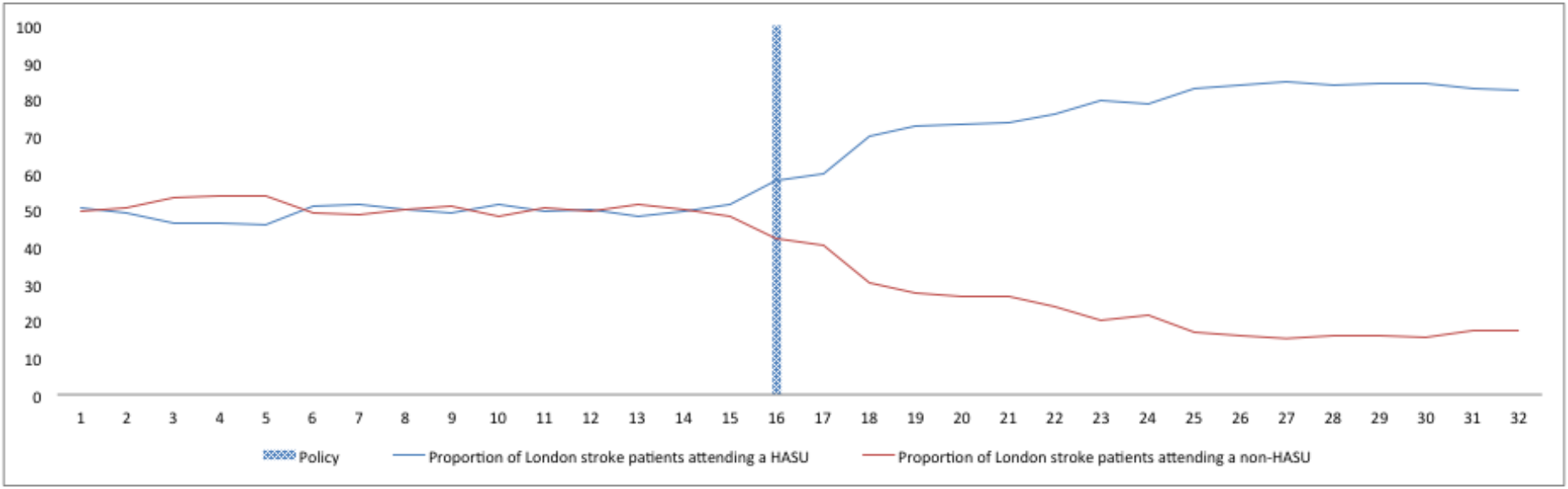
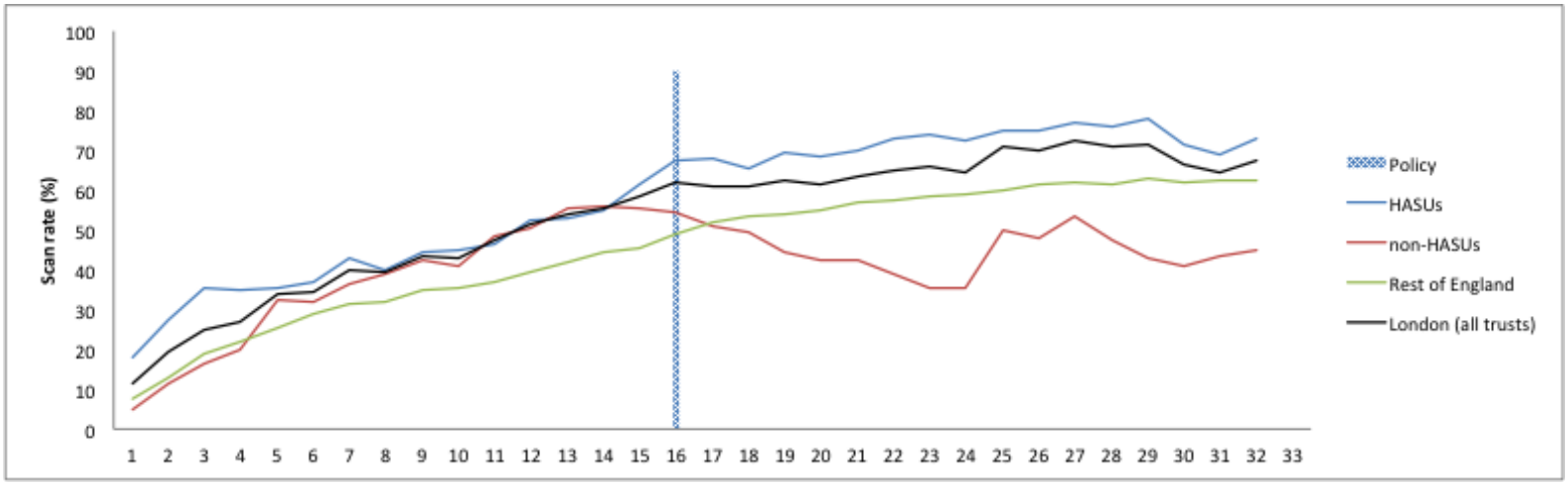


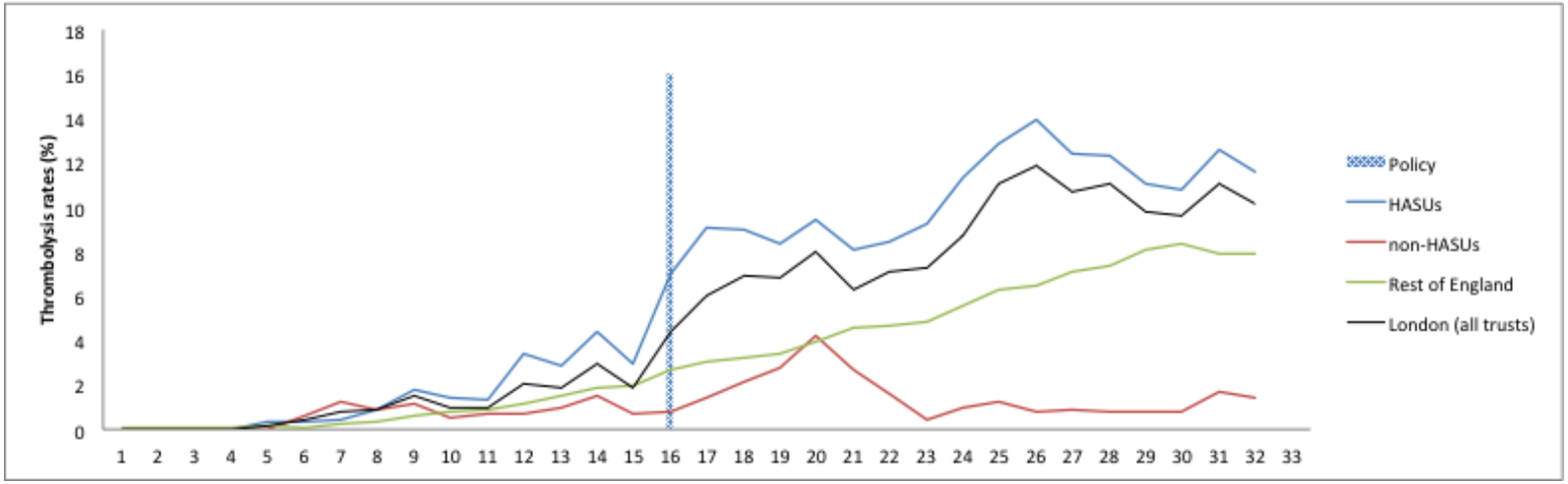
Figure 1: Proportion of stroke admissions divided by London Hyper Acute Stroke Unit trusts and London non-Hyper Acute Stroke Unit trusts

Appendix A: Trends in stroke specific process and outcome measures weighted by the number of admission

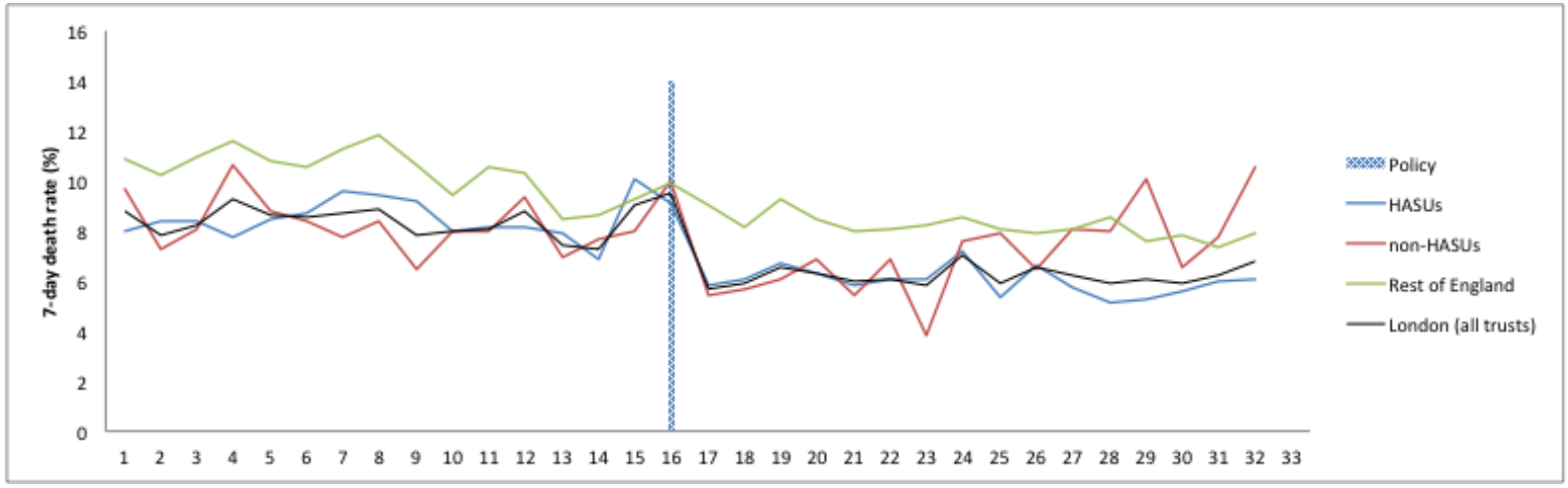
I)



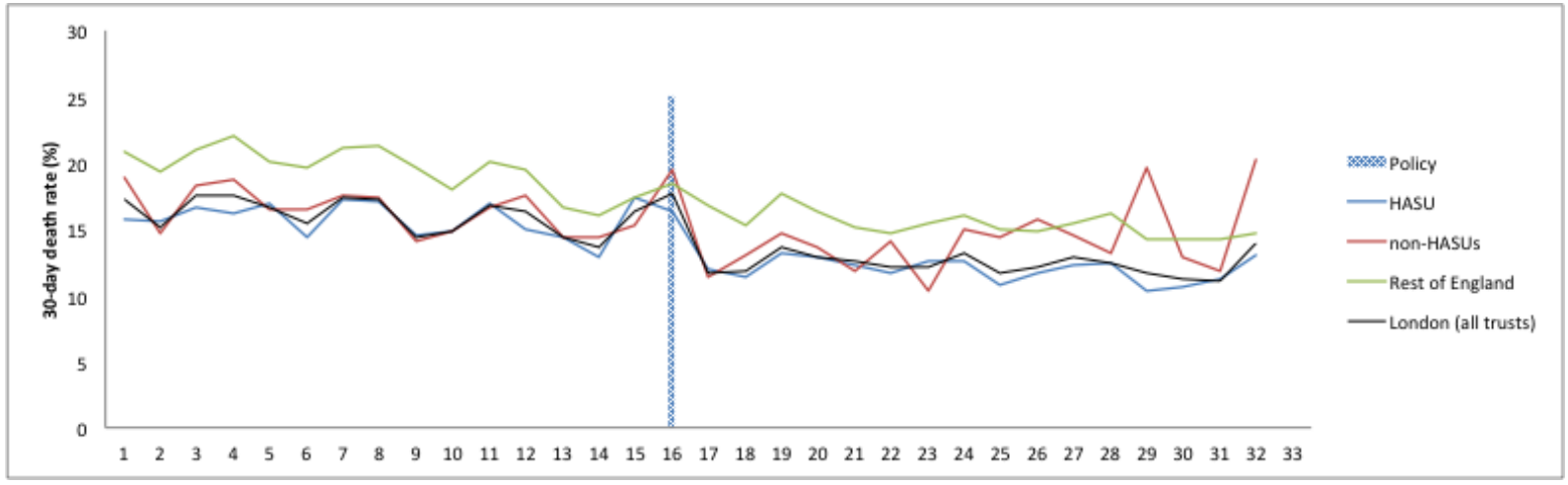
II)



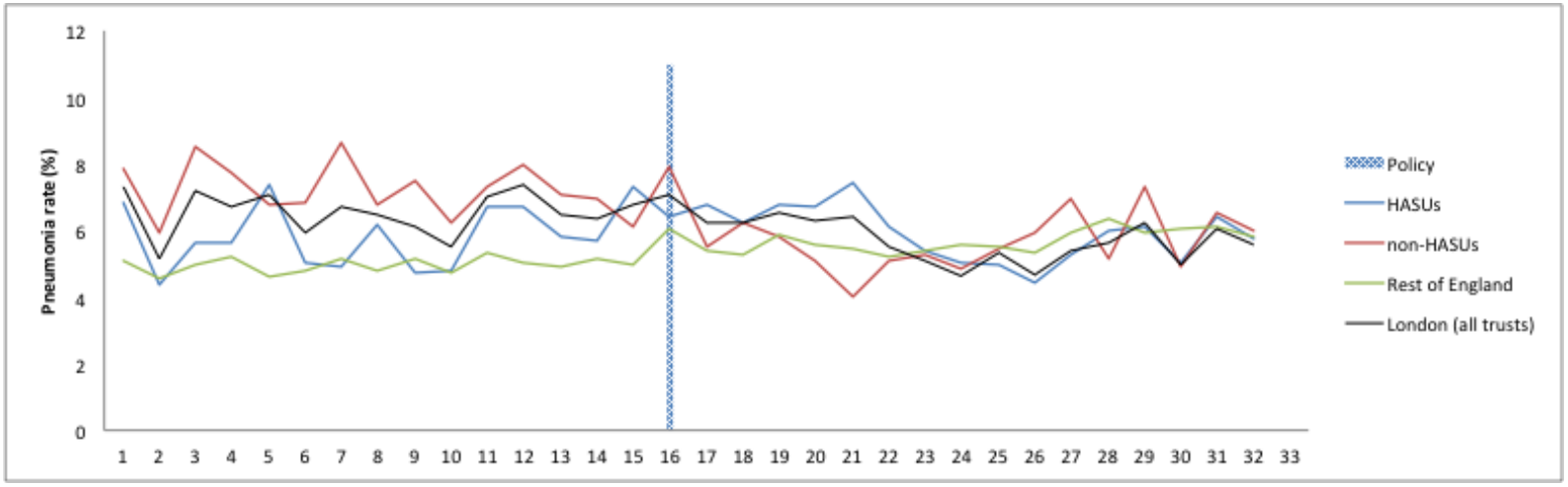
III)


7-day death rate (%)
0
2
4
6
8
10
12
14
16
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33
Policy
HASUs
non-HASUs
Rest of England
London (all trusts)

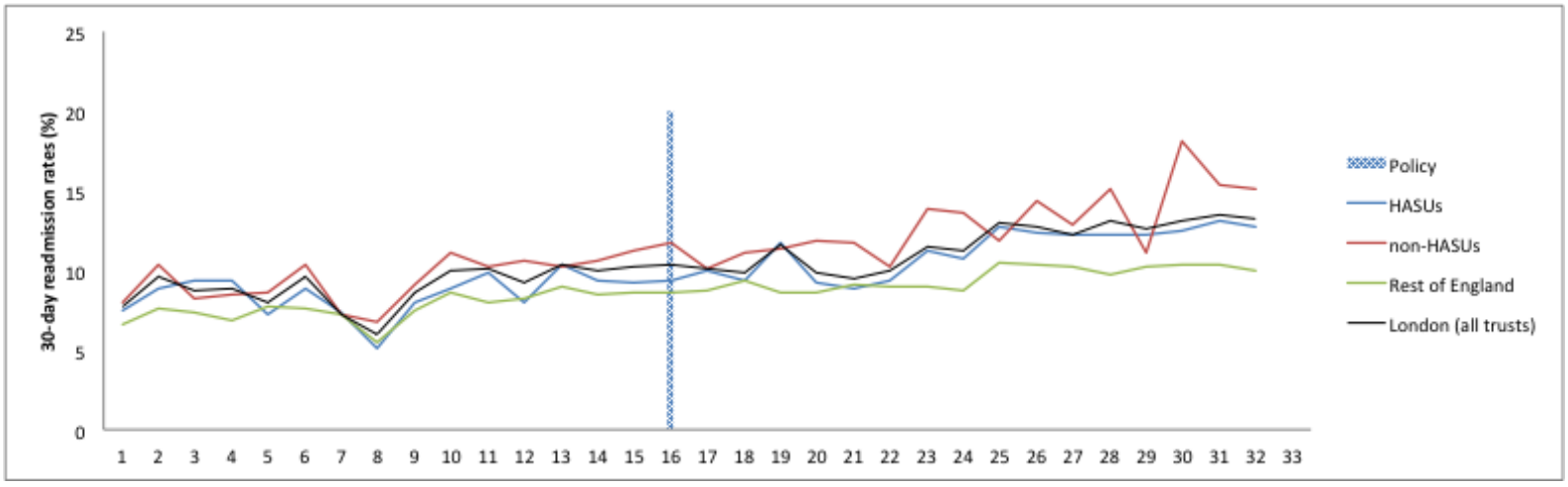
IV)


30-day death rate (%)
0
5
10
15
20
25
30
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33
Policy
HASU
non-HASUs
Rest of England
London (all trusts)

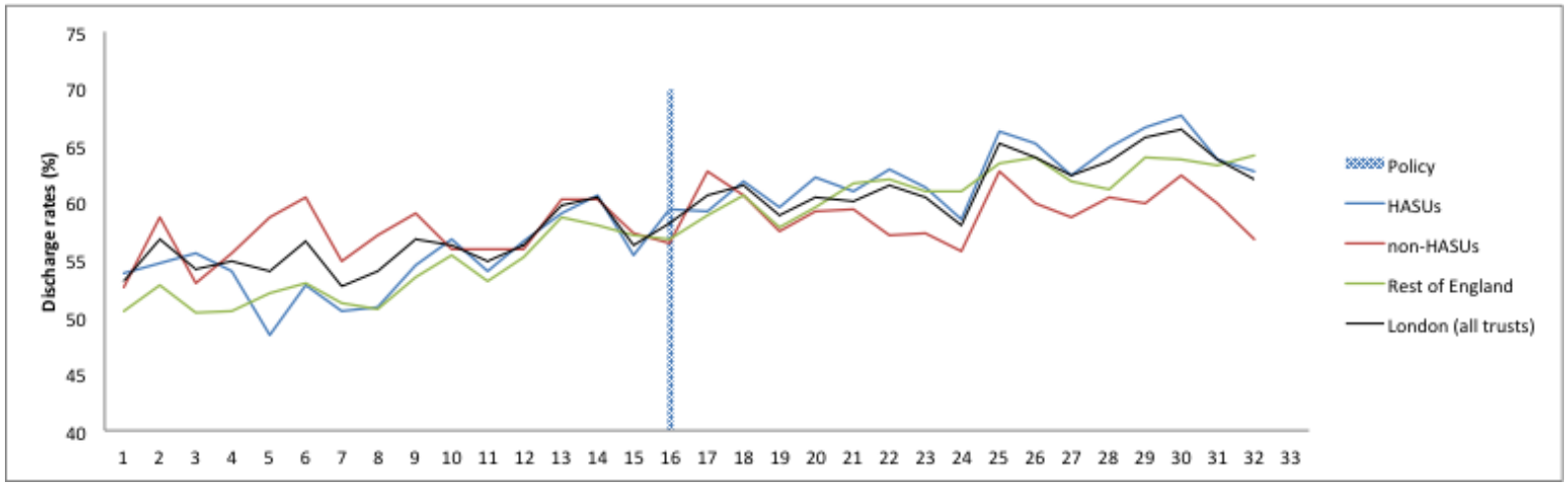
V)


Pneumonia rate (%)
0
2
4
6
8
10
12
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33
Policy
HASUs
non-HASUs
Rest of England
London (all trusts)

VI)


30-day readmission rates (%)
0
5
10
15
20
25
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33
Policy
HASUs
non-HASUs
Rest of England
London (all trusts)

VII)


Discharge rates (%)
75
70
65
60
55
50
45
40
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33
Policy
HASUs
non-HASUs
Rest of England
London (all trusts)

Appendix B: Fixed effect model versus random effect models (Two treatment groups)

Independent variables	24 hour brain scan (fixed effect)	24 hour brain scan (random effect)	Thrombolysis treatment (fixed effect)	Thrombolysis treatment (random effect)	Death within 7 days (fixed effect)	Death within 7 days (random effect)	Death within 30 days (fixed effect)	Death within 30 days (random effect)	Aspiration pneumonia (fixed effect)	Aspiration pneumonia (random effect)	Discharge to usual place of residence (fixed effect)	Discharge to usual place of residence (random effect)	30-day emergency readmission (fixed effect)	30-day emergency readmission (random effect)
London non-HASUs	-	**11.77***	-	**2.33****	-	4.88	-	-4.35	-	4.74**	-	**22.09*****	-	0.66
London HASUs	-	**25.92*****	-	**4.27*****	-	4.23	-	-8.96	-	2.45	-	**24.41*****	-	-0.78
T	**22.91*****	**22.81*****	**4.26*****	**4.18*****	**-1.55*****	**-1.53*****	**-3.73*****	**-3.72*****	**0.85*****	**0.82*****	**6.84*****	**6.69*****	**2.08*****	**2.11*****
DiD (non-HASUs)	**-14.78*****	**-14.64*****	**-3.90*****	**-3.78*****	**1.95****	**1.94****	**2.27****	**2.35****	**-2.34*****	**-2.32*****	**-7.61*****	**-7.50*****	**1.39***	1.31*
DiD (HASUs)	3.52	**3.77***	**4.32*****	**4.41*****	-0.74	-0.75	0.04	0.08	-0.58	-0.59	0.13	0.08	0.86	0.89
Merger dummy	-	**14.55***	-	**2.49****	-	0.40	-	-3.02	-	-0.01	-	9.30	-	0.78
Average age	0.00	-0.06	-0.01	-0.02	**0.22*****	**0.23*****	**0.50*****	**0.51*****	0.01	0.03	**-0.51*****	**-0.52*****	**-0.04***	**-0.07*****
Average charlson index	**0.93*****	**0.91*****	**0.10*****	**0.11*****	**-0.13****	**-0.16*****	**-0.18****	**-0.22*****	0.06	0.06	**0.55*****	**0.66*****	-0.02	-0.03
Gender	0.02	0.02	**0.01*****	**0.01*****	0.00	0.00	**-0.03*****	**-0.03*****	**-0.02*****	**-0.02*****	**0.03****	**0.03*****	**-0.01***	-0.01
Hospital transfers	**-0.05*****	**-0.08*****	0.00	-0.01	**-0.06*****	**-0.06*****	**-0.12*****	**-0.11*****	**-0.03*****	**-0.03*****	**-0.09*****	**-0.10*****	0.00	0.00
North East	-	9.28	-	**1.89****	-	6.01*	-	-4.19	-	2.85	-	**18.28*****	-	0.80
North West	-	10.31	-	**3.48*****	-	3.66	-	-4.73	-	1.68	-	**18.91*****	-	-2.62
Yorkshire and Humber	-	5.58	-	**1.82***	-	4.91	-	-6.27	-	1.46	-	**20.52*****	-	-1.63
East Midlands	-	12.03	-	**2.63****	-	**8.22****	-	-3.80	-	3.88	-	**11.12***	-	-2.10
West Midlands	-	3.84	-	**2.88*****	-	4.99	-	-5.28	-	2.44	-	**17.41*****	-	-2.49
East of England	-	11.40*	-	**3.41*****	-	**7.99****	-	-3.27	-	3.15	-	**15.09*****	-	-0.31
South East Central	-	**14.58****	-	**3.07*****	-	**6.81***	-	-0.62	-	4.64*	-	**14.85****	-	-2.15
South Central	-	10.31	-	**3.06*****	-	3.98	-	-6.71	-	2.37	-	**21.33*****	-	-1.94
South West	-	3.58	-	**3.42*****	-	**8.99*****	-	-2.49	-	1.83	-	**17.05*****	-	-3.27
Constant	**24.36*****	**17.26****	0.35	**-2.34***	**-5.38****	**-11.25*****	**-14.32*****	-8.08	**5.75*****	2.16	**85.48*****	**63.84*****	12.27	**15.19*****
N	5147	5147	5147	5147	5147	5147	5147	5147	5147	5147	5147	5147	5147	5147
R-squared	0.20	0.25	0.21	0.24	0.04	0.04	0.08	0.08	0.01	0.02	0.12	0.13	0.03	0.03

Note: [1]*** indicates that the variable has robust impact on dependent variable at 1% significance level, ** for 5%, and * for 10%; [2]Fixed effect models ommit time invariant variables.

Appendix C: Panel data model using fixed effects and replicating Morris et al. (2014)

Independent variables	Death within 7 days	Death within 30 days	Length of hospital stay
X_t	-	-	-
T	-0.95***	-2.37***	-1.64***
DiD	-1.08	-0.37	-2.16*
Average age	0.13***	0.36***	-0.39***
Average charlson index	-0.09	-0.20	-0.16
Gender	-0.02	-0.03*	0.03*
Hospital transfers	-0.05***	-0.08***	0.21***
Constant	1.57	-5.46	40.75***
N	2372	2372	2372
R-squared	0.05	0.09	0.15

Note: *** indicates that the variable has robust impact on dependent variable at 1% significance level, ** for 5%, and * for 10%.

Appendix D: Panel data model comparing London HASUs and London non-HASUs to seven English metropolitan areas as control a group

	24 hour brain scan **(fixed effect)**	Thrombolysis treatment **(fixed effect)**	Death within 7 days **(random effect)**	Death within 30 days **(random effect)**	Aspiration pneumonia **(random effect)**	Discharge to usual place of residence **(fixed effect)**	30-day emergency readmission **(fixed effect)**
Independent variables							
London non-HASUs	-	-	2.06	2.89	2.63	-	-
London HASUs	-	-	1.34	-0.36	0.31	-	-
T	**17.26*****	**4.18*****	-0.33	**-1.91***	**1.42****	**5.20*****	**1.67****
DiD (non-HASUs)	**-8.46*****	**-3.69*****	0.60	0.46	**-2.84*****	**-5.30*****	0.84
DiD (HASUs)	**10.10*****	**4.44*****	-1.73	-1.70	-1.33	2.73	0.43
Merger dummy	-	-	-0.42	-1.79	-0.90	-	-
Average age	-0.05	0.01	**0.09****	**0.56*****	**0.17*****	**-0.63*****	-0.03
Average charlson index	**0.54****	0.07	-0.11	**-0.30****	0.00	0.27	**0.35*****
Gender	**-0.06***	0.00	-0.01	**-0.06*****	**-0.10*****	**-0.08*****	0.00
Hospital transfers	-0.01	0.00	**-0.06*****	**-0.04****	-0.02	**-0.10*****	**0.04*****
Constant	**37.99*****	-0.38	1.78	**-18.91*****	-2.06	**104.40*****	**8.37****
N	1286	1286	1286	1286	1286	1286	1286
R-squared	0.14	0.39	0.02	0.07	0.06	0.06	0.02

Note: [1] *** indicates that the variable has robust impact on dependent variable at 1% significance level, ** for 5%, and * for 10%; [2] Controls are Trusts in Birmingham, Bristol, Leeds, Liverpool, Sheffield, Southampton and Newcastle.