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ABSTRACT

Immigration, Workforce Composition, and Organizational Performance: The Effect of Brexit on NHS Hospital Quality*

Restrictive immigration policies may force firms to abruptly change their workforce composition. But how does this impact the performance of these organizations? We study the effects of the 2016 Brexit referendum, which led to a drop in the share of EU nationality nurses in English hospitals. Using high-quality administrative patient-level data and a continuous difference-in-differences design which exploits the different pre-referendum hospital exposure to the shock, we estimate the causal effect of the workforce composition changes on hospital quality of care. We find that, in the post-referendum period, emergency patients admitted to NHS hospitals with a mean pre-referendum share of EU nurses faced an increase in mortality risk, equivalent to about 1,485 additional deaths per year. These findings are consistent with a theory model that predicts a decrease in the quality of newly hired hospital workers to avert labour shortages. We provide empirical evidence in support of this mechanism by showing that the foreign joiner nurses hired in the post-referendum period were assigned to lower salary grades than those hired prior to the referendum, indicating lower levels of skills and job experience.

JEL Classification: J45, J61, J68, I11, C26

Keywords: labour supply, worker mobility, migration, patient care, hospital quality, Brexit

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1 Introduction

The shortage of skilled labour is one of the main bottlenecks which is expected to harm the growth of Western economies in the upcoming decades. For the past few years, the US and European Union (EU) member states have been experiencing an insufficient labour supply of skilled workers in many professions such as construction, healthcare, or manufacturing, and face hiking job opening rates (U.S. Bureau of Labor Statistics, 2023; European Labour Authority, 2023; Eurostat, 2023*a*). In many countries, this pattern will persist, and likely be reinforced, in light of the currently ageing demographic trends. In the EU, the working-age population is predicted to decline by 6% until 2040 (Eurostat, 2023*b*), and OECD countries are foreseen to lose on average 10% of their working-age population by 2060 (OECD, 2021).

Policymakers have been trying to tackle this critical economic challenge by acting on several policy levers, for example by increasing and facilitating labour market participation, incentivizing longer working hours or later retirement, and by improving the quality of job matches between employers and employees. Although the adoption of the aforementioned policies is usually beneficial, reducing the labour shortages in many sectors of Western economies might be still difficult without attracting migrant workers from other countries. However, immigration policies trigger an open dilemma for policymakers, who face the trade-off between increasing the labour supply needed to raise aggregate productivity at national level and the implied cost of immigration, such as the rise of populistic movements and parties (Rodrik, 2021; Guriev and Papaioannou, 2022). While there is a vast economics literature on the effects of labour supply expansions achieved through increases in the foreign labour force (e.g., Friedberg and Hunt 1995; Friedberg 2001; Card 2001; Borjas 2003; Dustmann et al. 2013; Peri 2012, 2014; Peri et al. 2015, among many others), robust evidence on the effects that immigration barriers can produce on outputs of economic interest, such as organizational performance, is much scanter.[1]

With this paper we contribute to fill this evidence gap, by investigating the effects on organizational performance and consumer outcomes caused by a change in the labour supply of skilled migrant workers. To do so, we exploit the outcome of the Brexit referendum as a persistent and large-scale, negative labour supply shock to an exceptionally tight labour market: the labour market for nurses in English public hospitals. In this market, vacancy rates have been persistently at 10% and employment of foreign-trained nurses has been 2.5 times as high as the OECD average (OECD, 2017), mainly due to a lack of domestic workers.[2] In this paper, we show that the change in the workforce composition of skilled migrant

[1] As an exception, see (Lee et al., 2022).

[2] The shortage of skilled nurses and healthcare workers is not unique to England. In the EU, the occupation

nurses joining English National Health Service (NHS) hospitals had a negative impact on the health outcomes of hospital patients.

To identify the causal effect of this labour supply shock on hospital organization performance and patient health outcomes, we exploit quasi-experimental variation in the degree of pre-shock exposure of NHS hospital organizations to the employment of EU nurses within their workforce and, hence, to the reduced immigration of EU nurses following the victory of the vote to leave the EU. Across English NHS hospitals, the pre-referendum share of EU nurses, among all nurses employed, ranged from 0.5 to 22%. As the Brexit vote was unanticipated, hospitals could not strategically plan for their workforce needs in advance, allowing us to compare patient health outcomes – in particular, in-hospital mortality and unplanned emergency readmissions – and other hospital organization performance indicators before and after the Brexit referendum, using a continuous treatment difference-in-differences design based on the differential exposure to the Brexit shock due to heterogenous pre-referendum workforce composition.

The English NHS institutional setting is ideal to answer this research question. Hospitals within the English NHS are subject to identical institutional regulations (such as pay agreements and financial rules) and clinical guidelines, both set at national level, making these organizations rather homogeneous in their service delivery model and, hence, more suitable to compare than firms in other productive sectors. Nevertheless, NHS hospitals have complete autonomy in the hiring decisions of clinical staff such as nurses and doctors; thus, different hospital organizations might have reacted heterogeneously to labour supply shortages of nurses and doctors. Moreover, hospitals offer highly-valuable labour-intensive services to consumers, because health care is a basic need. Finally, 'quality' of healthcare service is more objectively and unambiguously defined and measured than the quality of consumable products and durable assets, where consumer preferences' heterogeneity is greater.

The main analyses of this study are based on the linkage of three high-quality and rich datasets, covering the period from 2012 to 2019: the administrative payroll records of all English NHS hospitals provide us with information on the monthly composition of its clinical workforce; we gather patient-level mortality and readmissions indicators, as well as other covariates such as patient age, sex and comorbidities, from the universe of patient admission records at English NHS acute care hospitals; and we capture the nurses' job satisfaction with the quality of services provided to patients, by employing large-scale NHS staff surveys collected every year at the nurse level. We focus our analysis on the health outcomes of

of 'nursing professionals' is the number one field for which most EU member states report labour shortages (European Commission, 2020).

emergency hospital patients, as in the NHS they typically cannot choose which hospital to be admitted to (Gaynor et al., 2013), given the emergency nature of their health condition(s). This approach prevents endogeneity problems associated with the patient self-selection into hospitals (Moscelli et al., 2021) with expected higher quality or lower changes in workforce composition, and also limits violations of the Stable Unit Treatment Value Assumption required to give a causal interpretation to our difference-in-difference estimates.

The core result of our empirical analysis is that hospital quality of care was negatively impacted by the change in the hospital staff composition, caused by the success of the referendum to leave the EU. After the Brexit referendum, for emergency patients admitted to a hospital with a mean pre-referendum share of EU nurses, the risk of in-hospital mortality increased by 5.31%, and the risk of unplanned emergency readmission increased by 2.28%. The estimate translates to about 4,454 additional hospital deaths in England during the post-referendum period and about 8,777 additional unplanned hospital readmissions.[3]

We show that hospital organizations substituted the missing EU nurses by hiring non-European nurses after the referendum, also because of the 2018 relaxation of the cap on healthcare workers' visas for non-EU migrants (Portes, 2022), so that no absolute nurse shortage arose. Most importantly, however, we show that the missing inflow of EU nurses, and the implied change in the hospital nursing workforce composition, is the main mechanism through which hospital care performance was affected. In particular, our analysis suggests that the NHS hospitals changed the workforce composition of new joiner nurses: newly hired nurses after the referendum were employed in lower salary bands, which can be interpreted as a sign of lower qualifications, experience and skills (Cortes and Pan, 2015). We also rationalize the decreasing quality of newly joining workers through a theoretical model of hospitals' optimal hiring rule. Our model predictions are consistent with the empirical patterns we document and provide a skill selection mechanism linking the Brexit referendum outcome to changes in hospital quality. Confirming our proposed mechanism, we further provide suggestive evidence that nurse satisfaction with the care quality they offered to patients fell after the referendum in the more exposed hospital organizations. Importantly, we also investigate and rule out alternative economic mechanisms. On the demand side, we show that the number of hospital patients, either prospective or treated, did not change with the intensity of the shock. On the supply side, we collect and put together publicly-available NHS hospital organization balance sheet data, showing that hospital expenditures and rev-

[3]Similarly to increases in hospital-related mortality, unplanned emergency readmissions to hospital are a known indicator of poor hospital care quality (Gruber and Kleiner, 2012; Moscelli et al., 2018, 2021; Friedrich and Hackmann, 2021).

enues from reimbursements of patient treatments were unaffected by the exposure to the migration shock. We ensure that the drop in hospital quality was not induced by capacity constraints, such as a lack of staff rather than a human capital loss. For example, we find no evidence of a productivity decrease in the hospital organizations more exposed to the shock, as the post-treatment share of occupied beds did not show any significant decrease.

Our work contributes to several lines of research in health, labour, organization and political economics. First, we provide evidence that public migration policies directly impact organizational performance. Most of the existent literature in this research area has investigated the effects of high-skilled migration policies and their impact on firm performance and innovation (Choudhury et al., 2022; Doran et al., 2022; Kerr and Lincoln, 2010; Peri et al., 2015; Hornung, 2014; Mitaritonna et al., 2017; Ottaviani et al., 2018; Terry et al., 2023). Only a little work exists on migrant workers' labour market effects in nursing markets (Furtado and Ortega, 2023; Grabowski et al., 2023), and, to our knowledge, none in the hospital sector except for Schlenker (2024) and our investigation. Our work also contributes to literature on the effects of return migration (Adda et al., 2022; Borjas and Bratsberg, 1996; Dustmann and Görlach, 2016) and migration barriers (Lee et al., 2022), by originally investigating how the reverse migration policy shock due to the Brexit referendum vote induced the withdrawal of skilled migrants, as well as its effects on end-consumers, that is, hospital patients.

We contribute to the literature investigating the effects of staff turnover, and in particular the workers' substitutability, on firm performance. Other papers studying worker exit on firm or institutional performance either examine only short-run, transitional effects (Bertheau et al., 2022; Kuhn and Lizi, 2021), temporary absences such as parental-leave programs (Brenoe et al., 2023; Gallen, 2019; Ginja et al., 2023; Huebener et al., 2022), look at small entities (Becker et al., 2017; Brenoe et al., 2023; Gallen, 2019), or explicitly deal with productivity spillovers between workers (Jones and Olken, 2005; Huber et al., 2021; Waldinger, 2010, 2012). Instead, we exploit a large-scale employment shock that affected sizeable organizations – NHS hospital organizations – rather than using as a source of identification single exogenous layoffs or deaths in small groups of workers.

To our knowledge this is also the first paper to quantify one channel – that is, immigrant hospital workers – through which the outcome of the Brexit vote has causally impacted public health in the United Kingdom. This adds to the literature on the (unintended) economic effects of the recent deglobalization and nationalistic trends, and Brexit in particular (Born et al., 2019; Hantzsche et al., 2019; Fetzer and Wang, 2020; Davies and Studnicka, 2018; Breinlich et al., 2020, 2022). While these papers mainly focus on macroeconomic implications, we provide microeconomic evidence on healthcare services, with possible effects on all UK citizens and their daily lives. The effects of the Brexit referendum on public health are of particular interest from a political economy perspective, given that it has been found that regional heterogeneity in NHS performance was a driver of 'Leave' votes (Alabrese et al., 2019; Becker et al., 2017) and Brexit campaigners, including the former Prime Minister Boris Johnson, claimed that Brexit would have improved substantially the English NHS funding.

Furthermore, our work contributes to the literature that identifies the economic value of nurse and physician labour supply for patient health (among others: Fetzer et al. 2024; Foster and Lee 2015; Furtado and Ortega 2023; Gruber and Kleiner 2012; Chan Jr. and Chen 2023; Schlenker 2024). Within the English NHS context, Propper and van Reenen (2010) exploit regional differences in the outside-option wage to control for unobservable factors affecting hospital nurse quits and nurse quality; whereas Friedrich and Hackmann (2021) exploit a parental leave program in Denmark, which led to a short-run decline in nursing, and find a mortality increase in retiree care homes. Rather than exploiting an absolute deficit of workers in some hospitals or care homes, our investigation makes use of an original identification setting, the sudden drop in the inflow of EU nurses after the Brexit referendum, which is a persistent shock that changed the hospital workforce composition.

Last, but not least, our study contributes to a number of studies documenting the effects of immigration in the United Kingdom (Dustmann et al., 2005; Manacorda et al., 2012; Dustmann and Frattini, 2014; Ottaviani et al., 2018).

The empirical and theoretical results of our work are informative for policymakers, and provide the following take-away message: prospective migrants, and especially high-skilled workers like nurses, are responsive to expected changes in immigration legislation and cultural hospitality of prospective host countries. Moreover, abrupt shocks to skilled workers' labour supply can affect an organization's productivity (in our case, the quality of hospital care provided). Therefore, countries whose labour markets rely on the inflow of foreign skilled workers, such as the US, the UK and many other OECD member states, have to carefully weigh which labour market signal they relay to prospective migrant workers when more stringent immigration laws are proposed or approved.

The remainder of the paper is organized as follows. Section 2 describes the Brexit referendum history, the NHS workforce, and the data sources we used. Section 3 provides our theoretical framework. Section 4 presents the empirical strategy. Section 5 reports the main descriptive and estimation results. Section 6 investigates the mechanisms driving the main findings. Section 7 concludes.

2 Background

2.1 The Brexit referendum

The Brexit referendum (BR) was announced on 20th February 2016 and took place on 23rd June 2016. On this date, British, Irish and Commonwealth adult citizens residing in the UK or Gibraltar were asked whether the UK should remain a member or leave the European Union. The BR was the culmination of a series of failed negotiations between the UK and the EU regarding the terms of the EU membership for the UK, especially with respect to policy matters like immigration and national sovereignty. The referendum had consultative nature, i.e. its outcome was not meant to be binding for the UK government. However, the British government of the time committed to implement the referendum result.

The BR had a 72.21% turnout, with 17,410,742 people (corresponding to 51.9% of the actual voters) voting in favour of leaving the EU. The official exit from the EU was dated 31 January 2020, but the UK remained a member of the European Single Market for a transition period lasting until the end of the year, which served to finalize the terms of the withdrawal and favour a smoother exit from the European Union. Starting from 1st January 2021, EU laws did not apply to the UK anymore, including the freedom of movement of persons and workers, which holds compulsorily within EU country members, as established by the 1992 Treaty of Maastricht, and allows any EU national to freely move and seek a job in another member state of the European Single Market (European Parliament, 2023). Thus, only from 1st January 2021 EU citizens willing to settle in the UK have been subject to the same migration rules of non-EU citizens and needed a visa to work in the UK. Between the BR date and 1st January 2021 there was no change in the immigration rules for EU workers moving to the UK, compared to the pre-BR regulation. Moreover, EU citizens already resident in the UK before the end of the transition period retained their pre-Brexit immigration rights under the so-called "EU settlement scheme", a dedicated scheme for EU nationals designated by the UK Home Office (House of Commons Library, 2020).

2.2 The NHS Workforce and Staff Recruitment From Abroad

The English NHS employs around 1.5 million people overall and it is one of the largest employers worldwide. It provides tax-funded, free at the point of use healthcare services to the general population, across more than 1,000 hospital sites grouped into 219 healthcare organizations called "Trusts". Nurses and doctors represent the core of the hospital workforce and account for more than one third of the total number of English NHS employees. As of January 2014 (2018), the English NHS employed 52,452 (59,253) hospital senior doctors and

338,333 (346,941) nursing and midwivery staff (NHS Digital, 2023*a*).

In order to work as a doctor or nurse for the English NHS, one must hold a relevant medical or nursing degree recognized by accredited bodies. Medical graduates who wish to become fully qualified doctors have to register with the General Medical Council (GMC) and undergo an in-hospital training programme to specialize in a given medical area. Junior medical workers account for approximately half of the total doctor workforce. Instead, nursing graduates can be hired immediately by English NHS hospitals as fully qualified nurses, upon registration with the Nursing and Midwifery Council (NMC).[4]

International medical and nursing graduates wishing to join the English NHS from abroad have to show respectively the GMC and the NMC that they possess a valid qualification and competence to practice. They also have to prove their knowledge of the English language. Foreign doctors' medical skills are evaluated by the so-called Professional and Linguistic Assessments Board (PLAB), consisting of a multiple choice test (PLAB1) and an objective structured clinical exam (OSCE) to be taken only in the UK. Similarly, foreign nurses' clinical skills get screened first through a computer-based test (CBT) and then by a practical OSCE competency test. Conditional on passing the PLAB1 (CBT), prospective doctors (nurses) can apply through one of the designated visa routes and enter the UK territory to take the second test. The successful completion of the OSCE exam provides the final clearance for joining the English NHS.

Starting from January 2021, the accreditation process described above applies to all international doctors and nurses, regardless of the foreign country in which they obtained their professional qualification. Instead, until the end of the Brexit transition period, EU laws automatically allowed doctors and nurses trained in a country of the European Economic Area (EEA) to practice as healtcare professionals in the English NHS, without the need to take either the PLAB or the CBT and OSCE exams. However, starting from January 2016 all nurses from the EEA willing to join the English NHS were required to present an English language proficiency certificate, which is a requirement in place since 2005 for international nurses trained in non-EEA countries. In June 2014, a similar language requirement for international doctors was extended to doctors trained in the EEA area.

2.3 Data Sources

We combined multiple data sources to create a unique patient- and nurse-level dataset which stretches from June 2012 to May 2019, namely the seven years around the Brexit referen-

[4] Alternative, although less popular, routes to become a nurse in the English NHS are through the completion of a registered nurse degree apprenticeship (RNDA) directly offered by English NHS organizations or by joining the nurse workforce as a nursing associate.

dum date. We abstract from years before this time window due to a major organizational restructuring and merger wave among NHS organizations, which took place mainly until early 2012. Years after 2019 are dropped due to the onset of the COVID-19 pandemic in March 2020, which represented a major shock on the English NHS (Fetzer et al., 2024). Overall, our analysis sample comprises 131 acute care providers which consistently admitted patients over our period of study, thus excluding mental health providers or organisations undergoing any (potentially confounding) hospital consolidation event close to the Brexit referendum date.[5]

Electronic Staff Records. We use Electronic Staff Records (ESR) data, an administrative monthly worker-level payroll database, whose records on the universe of NHS hospital nurses and doctors include rich information on these clinical workers' demographics (e.g. age, nationality, sex) and employment-related variables, such as hours worked, earnings, staff grade and role, date of joining the NHS, and hospital organization of employment. We use the ESR data to compute inflows and outflows of NHS hospital nurses for different nationality groups, i.e. EU, British, non-EU nurses (and doctors), at the hospital organization level. To allocate nurses into nationality groups, we exploit the panel nature of the ESR data and rely on the first non-missing nationality record of each individual nurse. Based on their ethnicity background (e.g. White/Black British, White/Black Asian, White Irish, White European), we also impute the broad nationality group of almost all those residual nurses who never present a valid nationality information.[6] We define the hospital-level exposure to the Brexit shock based on the distribution of the shares of EU, British and non-EU foreign nurses of each hospital organization in the pre-referendum period. Moreover, we use the salary grades observed in the ESR records to track hiring decisions at hospital organization level before and after the Brexit referendum, and to proxy for nurse 'quality' – that we intend as a mixture of skills, experience and qualifications – when joining the NHS as new hires.

Hospital Episodes Statistics. We use Hospital Episodes Statistics (HES) Admitted Patient Care (APC) data to compute patient-level health outcomes that are frequently used as hospital quality indicators, such as the occurrence of death and unplanned readmissions, and other hospital-level indicators (e.g., the number of admitted patients). HES APC is an administrative database containing the universe of patient admissions to NHS acute care hospitals; its records provide rich information on patients' demographics, e.g. age, sex, date

[5]The information on mergers and acquisition events among NHS hospital organisations comes from the NHS Workforce Statistics Data Quality Annex regularly published by NHS England.

[6]In our sample, only 4.2% of the total number of nurses has a missing nationality record.

of admission, method of admission, medical conditions, income deprivation of the patient residence at small area level. We exploit this information to create binary indicators at patient level for in-hospital death and unplanned emergency readmissions within 30 days from the index hospital admission, as well as the Charlson index (Charlson et al., 1987), a known indicator of patient health risk due to pre-existing comorbidities. We also compute a binary indicator for patient mortality anywhere (in and outside the hospital) within 30 days from the index hospital admisison, by linking patient-level HES APC records to the Office for National Statistics (ONS) Civil Registration Deaths dataset, which holds information on the exact date of death of patients admitted to NHS hospital organizations.

NHS Staff Surveys. The NHS Staff survey collects the self-reported assessments of NHS hospital workers with respect to several dimensions of their jobs. Its records consists of several hundred thousands NHS workers participating on an annual basis to this repeated survey, which is the largest longitudinal survey of a healthcare workforce in the world. We observe the occupation and the tenure of each worker matched with their answers. This allows us to identify the self-reported changes in quality of care and working environment conditions perceived by nurses employed in NHS hospital organizations with a different exposure to the Brexit referendum shock.

Hospital Trusts Financial Accounts. To test how the Brexit referendum affected the accounts and finances of NHS hospital organizations, we collected publicly available data on the annual financial reports of NHS hospital organizations.[7] This data includes the aggregate monetary £ pound value of healthcare expenditures related to operative hospital costs, which are mostly due to patient admissions.

Summary statistics. The sample includes 131 acute care NHS hospital organizations with an overall number of 9.5 million emergency patients and 17.6 million emergency admissions in the pre-referendum period. *Panel a* of Appendix Table A.1 provides the summary statistics on the health outcomes and covariates of the emergency patients in our sample.[8] The average in-hospital mortality risk, within 30 days from the index admission to hospital, was 3.3% in the pre-referendum period (June 2012 to May 2016) and 3% in the post-referendum period (June 2016 to May 2019). The risk of unplanned emergency readmission within 30 days from the index emergency hospital discharge, was 15.2% in the pre-referendum period and

[7]This data is available at `https://www.england.nhs.uk/financial-accounting-and-reporting/nhs-providers-tac-data-publications/`.

[8]The analogous information for all emergency and non-emergency hospital patients is reported in Appendix Table A.2.

16.1% in the post-referendum period. *Panel b* of Appendix Table A.1 provides an overview of the clinical workforce composition of the hospital organizations. On average, in our pre-referendum sample, the acute care NHS hospital organizations employed approximately 1,661 nurses, out of which 98 (221) were foreign EU (non-EU) nurses, and 316 senior doctors, out of of which 27 (70) were foreign EU (non-EU) doctors. In the post-referendum period, the average acute care NHS hospital organization employed approximately 1,751 nurses, out of which 147 (246) were foreign EU (non-EU) nurses, and 359 senior doctors, out of of which 36 (88) were foreign EU (non-EU) doctors.

3 Conceptual Framework

We develop a simple conceptual framework to understand how the Brexit referendum might affect workforce composition and hospital quality in the NHS. This model also allows us to formalize and study the heterogeneous effects of Brexit across occupations and hospital organizations with different exposures to the shock.

Setup. Consider a hospital organization that wants to fill a mass $M < 1$ of vacancies. Suppose there is a unit mass of prospective workers, each deciding whether to apply for a job at the NHS. Each prospective worker might be from two possible origins $j \in \{e, r\}$, where e denotes "European Union" (EU nationals) and r the "rest of the world", with $\mu \in (0, 1)$ denoting the share of EU nationals. A worker i from origin j gets utility u_{ij} if they join the NHS and v_{ij} if they stay in their home country.[9]

The utility gain from joining the NHS is assumed to be

$$u_{ij} - v_{ij} = \omega_j + \gamma_j - \varepsilon_i,$$

where $\omega_j \in \mathbb{R}$ denotes the average expected present value wage gain and $\gamma_j \in \mathbb{R}$ other expected non-wage benefits of joining the NHS when coming from region j, while $\varepsilon_i \in \mathbb{R}$ denotes a mean-zero idiosyncratic preference shock.[10]

We assume that each worker i has a skill level $\theta_i \in \mathbb{R}$ that affects the quality of care as defined later. We impose that $(\theta_i, \varepsilon_i)$ are independent of each other, i.i.d. across workers, admit a continuous probability density function, and have finite first moments. We denote

[9] The insights of the model hold regardless whether the r group includes British workers. For simplicity, we keep the main analysis with only two groups: EU and non-EU nationals.

[10] The non-wage benefits γ_j may include monetary and non-monetary benefits, such as access to a pension scheme, stability at work, gains from moving to the UK, or an intrinsic value for the job.

by F (by f) the cumulative distribution (probability density) function of ε_i and by G (by g) the one of θ_i. To stress that our results are not given by exogenous differences across worker groups, we assume the same skill and preference shock distributions irrespective of the worker origin.[11]

If hired, each worker's type provides a quality of care $q(\theta)$, where $q : \mathbb{R} \to \mathbb{R}$ is strictly increasing. The hospital organization then decides what share of workers of each type to hire. The total quality of care provided by the newly hired workers is

$$Q(h, a) = \int q(\theta)h(\theta)a(\theta)d\theta,$$

where $h : \mathbb{R} \to [0, 1]$ denotes the share of the applicants of a given type the hospital hires, and $a : \mathbb{R} \to \mathbb{R}_+$ denotes the number of applicants of each type θ.

A potential worker of origin j applies to the NHS if $u_{ij} - v_{ij} \geq 0$, or equivalently if $\varepsilon_i \leq \omega_j + \gamma_j$. Therefore, the mass of applicants of each type is

$$a(\theta) = \Big[\mu F\big(\omega_e + \gamma_e\big) + (1-\mu)F\big(\omega_r + \gamma_r\big)\Big]g(\theta).$$

We assume the total mass of applicants would be sufficient to cover vacancies if all were accepted, that is, $M < \int a(\theta)d\theta$.

The hospital's problem. The hospital observes the set of applicants and wants to maximize the total quality of care subject to the constraint that they can hire at most a mass M of workers. The hospital solves

$$\max_{h:\mathbb{R}\to[0,1]} \int q(\theta)h(\theta)a(\theta)d\theta. \tag{1}$$

subject to

$$\int h(\theta)a(\theta)d\theta \leq M. \tag{2}$$

Lemma 1. *The hospital accepts all applicants with type above the cutoff* $\theta^* := max\{\theta_0, \tilde{\theta}\}$, *where* θ_0 *and* $\tilde{\theta}$ *are defined as*

$$\theta_0 := inf\{\theta \in \mathbb{R} : q(\theta) \geq 0\} \text{ and } M = \int_{\tilde{\theta}}^{+\infty} a(\theta)d\theta.$$

Lemma 1 shows that the hospital hires the most skilled workers until they fill all their

[11] The results remain qualitatively unchanged if different origins are associated with different skill or preference shock distributions.

vacancies or reach a minimum acceptable skill level. Any worker with skill $\theta < \theta_0$ negatively impacts the quality of care. Hence, we refer to them as unqualified for the job. If there are enough qualified applicants, the hospital uses all its budget for new hires, and the hiring skill cutoff is $\tilde{\theta}$. Otherwise, the hospital hires all applicants with skills above θ_0 but fails to fill all the vacancies.

Brexit referendum. We model the Brexit referendum effects as a decrease in the EU nationals' future discounted expected payoff from moving to the UK. This decrease stems from potential EU national movers' revised expectations about direct future monetary and non-monetary losses the Brexit enforcement regulation might cause to EU national workers based in the UK. For example, they include increased costs for travels, visa, recognition of overseas-acquired qualifications, settlement hurdles as EU-migrants to the UK (UK Government, 2020), as well as the immediate disutility related to an increase in the anxiety and uncertainty about the future (Frost, 2020; Teodorowski et al., 2021) in terms of employment-related, political and civil rights.[12] Formally, we say that $\gamma_e^{pre} > \gamma_e^{post}$. We then denote by θ^*_{pre} and θ^*_{post} the hiring skill cutoff pre and post-referendum and study how the BR affected hospitals' hiring cutoff, quality of care, and prevalence of worker shortages.

Proposition 1. *Suppose that $\theta^*_{pre} > \theta_0$ and $\gamma_e^{pre} > \gamma_e^{post}$. Then, in the post-referendum*

1. *the hiring skill cutoff decreases;*
2. *the EU-worker joining rate decreases;*
3. *the quality of care decreases;*
4. *worker shortages do not occur unless $(\gamma_e^{pre} - \gamma_e^{post})$ is sufficiently high.*

Proposition 1 delivers several insights about the referendum's effects on the workforce composition and the quality of care. First, it shows that the decrease in the non-wage gains of joining the NHS for EU nationals reduces the overall supply of workers, and to fill all their vacancies a NHS hospital organization needs to decrease its hiring standards. Second, it shows that simultaneously with a decrease in the hiring standard, one also observes a decrease in the share of EU workers and a decrease in the overall quality of care. Finally, Proposition 1 shows that a decrease in the quality of care occurs even when there is no increase in worker shortages: a NHS hospital organization might be able to fill all its vacancies, yet the decrease in the UK attractiveness to EU nationals harms the selection of skilled workers regardless of their country of origin and thus reduces quality of hospital care.

It is important to note that the resulting hiring skill cutoff θ^* is the same for EU and non-EU workers pre and post-referendum. The decrease in the quality of care stems from

[12] See also KPMG (2017), Nursing Times (2018), The Guardian (2019) and Financial Times (2019).

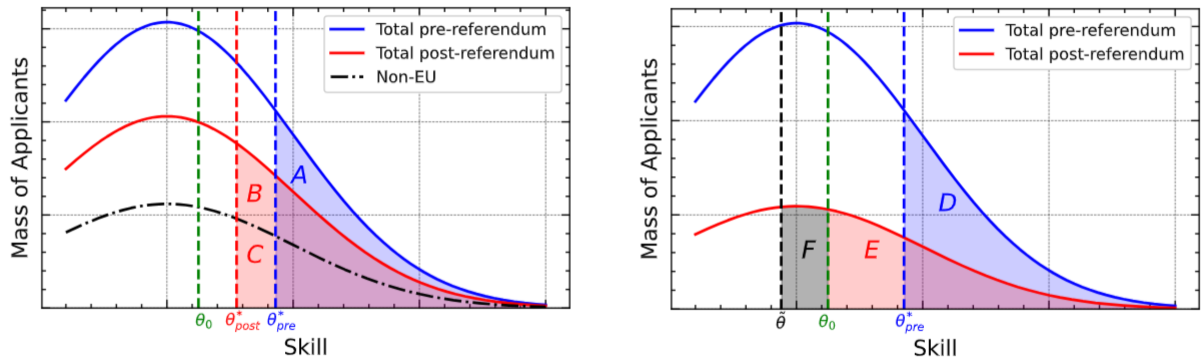
substituting higher-skill EU workers with lower-skill workers of any origin, i.e. Europeans, non-Europeans, and British. Figures 1 and 2 illustrate this substitution pattern when we observe worker shortages and when we do not, as well as across low and high-exposure hospitals (low vs. high μ).

Figure 1a describes the effects of a reduction on γ_e that does not cause an increase in worker shortages. The solid blue (red) line denotes the pre(post)-referendum total number of applicants with a given skill level, while the dash-dotted black line plots the number of non-EU applicants. The difference between the solid blue (red) and dash-dotted black line denotes the number of EU applicants pre(post)-referendum. The area shaded in blue (red) represents all the hired workers pre(post)-referendum. Area A — the area in-between the blue and red solid lines — denotes the mass of higher-skill workers who would apply prior to the referendum but do not after it, while B and C display the mass of workers who are hired after the referendum but would have not been hired if the hiring skill cutoff had not decreased. When comparing the workforce composition pre and post-referendum, there is a substitution from higher-skill workers (area A) to lower-skill workers (area $B + C$), which reduces the quality of hospital care. Moreover, note that the higher-skill workers who no longer apply (area A) are all EU nationals, while the new hires below the pre-referendum hiring skill cutoff are from both EU (area B) and non-EU (i.e., British and non-EU nationals; area C) countries of origin. Consequently, the quality of care and the share of new EU joiners simultaneously decrease.

Figure 1b displays the changes in the workforce composition of a reduction in γ_e that instead causes also worker shortages. When the decrease in the attractiveness of the NHS for one group of prospective workers is big enough, the NHS hospital organizations are unable to find a sufficiently large number of qualified workers (with $\theta \geq \theta_0$) to fill all of their vacancies. The hiring cutoff then becomes the minimum qualification standard θ_0. Area D represents the mass of higher-skill workers that stopped applying after the decrease in γ_e, area E denotes the newly hired workers that would not have been hired absent the reduction in the hiring skill cutoff, and area F is the size of the shortage, meaning the mass of vacancies that remain unfilled.

The next result compares how different hospitals are affected by the same shift in γ_e. Proposition 2 shows that hospitals that have a larger share of EU national potential applicants (higher μ) are more affected by the referendum's result, as long as the average utility gains from moving to the UK to work for the NHS are larger for workers coming from the rest of the world than from EU countries. Figures 2a and 2b illustrate the result by, respectively, plotting the effects in a low-exposure hospital (low μ) and a high-exposure hospital (high μ). The shaded area in red between θ^*_{pre} and θ^*_{post} is much smaller in the low-exposure Figure

Figure 1. Model implied applicant pool and hiring cutoffs.



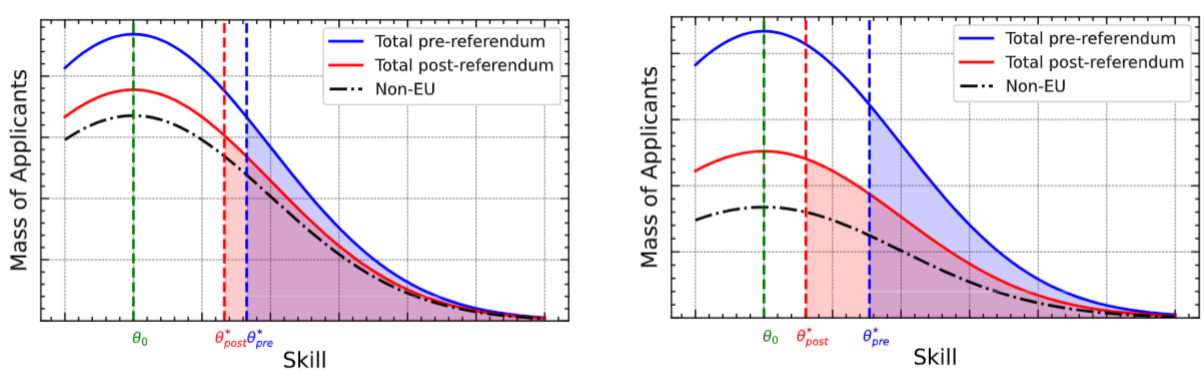
(a) No worker shortages (b) Increased worker shortages

Notes. This figure gives the effects of a change in γ_e on the workforce composition under no and increased worker shortage.

2a than in 2b. The intuition is straightforward: in high-exposure hospitals, the decrease in the supply of workers is larger, and the hospital must hire more workers with skills below its original hiring skill cutoff.

Proposition 2. *Suppose the average utility gain from joining the NHS is larger for workers from the rest of the world than from EU countries ($\omega_r + \gamma_r > \omega_e + \gamma_e$). Then, the number of unfilled vacancies plus the number of workers hired after the referendum with skills below the pre-referendum cutoff increases in the share of potential EU national applicants μ.*

Figure 2. High versus Low Exposure.



(a) Low-exposure Hospitals (b) High-exposure Hospitals

Notes. This figure gives the effects of a change in γ_e on the workforce composition for hospitals of different exposure (measured in μ).

Finally, we show that the effect of a decrease in γ_e on the set of hired workers vanishes as the *absolute* wage gains for the job increase. That is, as the ω's increase, the difference between θ^*_{pre} and θ^*_{post} goes to zero. The intuition is that the decrease in non-wage gains of moving to the UK may be similar across occupations, while the absolute monetary gains vary with each occupation's pay level. Even if all occupations receive a similar relative wage gain, meaning the same percentage increase compared to what they were paid in their country of origin, the absolute gain is much larger for the ones in high-paying jobs. This result suggests that we should observe stronger effects of the referendum for relatively lower-paid occupations, such as nurses, compared to better-paid ones, such as medical doctors.

Proposition 3. *The difference between pre and post-referendum hiring skill cutoff goes to zero as the wage gains to joining the NHS increase.*

As a quick summary of the main takeaways of our conceptual framework:
1. The quality of care decreases after the referendum, even when there are no additional worker shortages or a decrease in the total number of workers.
2. The decrease in the quality of care is driven by a decline in the skill level of newly hired workers, irrespectively of their country of origin.
3. Hospitals that more heavily relied on EU workers hire a larger number of workers below the pre-referendum skill cutoff.
4. The referendum effects vanish for sufficiently highly paid occupations.

4 Empirical Strategy

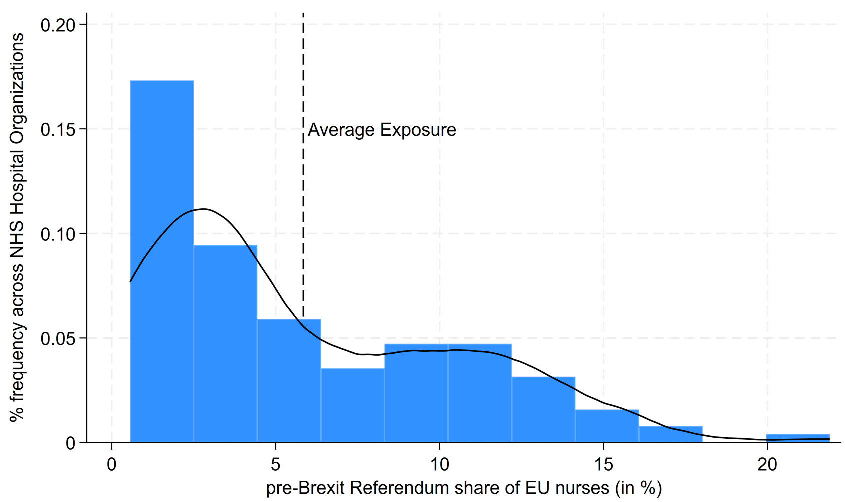
Our empirical strategy consists of three steps. In the first two steps, we evaluate the effects of the Brexit referendum on the clinical workforce composition of NHS hospitals. In particular, the first step provides descriptive evidence about any structural break in the workforce composition of both nurses and senior doctors employed in all NHS acute hospitals. The second step provides regression-based evidence on the effects of the Brexit referendum shock on nursing workforce composition only – as we show that nurses are the occupational group predominantly affected by the outcome of the Brexit vote – with respect to the final sample of 131 acute care NHS hospitals for which we measure both patient health outcomes and hospital workforce composition. Building on the previous two descriptive steps, we then estimate the causal effect of workforce composition on hospital quality (third step).

In our third step of the empirical strategy, we exploit the insight that hospital organizations that relied more heavily on EU nurses in the pre-referendum period were more exposed to the missing inflow of EU nurses after the referendum. This allows us to study whether the Brexit-induced net loss of EU nurses affected English hospital performances, as we are interested in examining the effects of the employment shock induced by the Brexit referendum on hospital care quality. To do so, we rely on the following event-study design with a continuous treatment and estimated at the patient level:

$$Y_{i,h,t} = \alpha_h + \lambda_{r,t} + \sum_{\substack{k=2012/2,\\ k\neq 2016/1}}^{2019/1} \beta_k(\mathbb{1}[t=k]_t \times \overline{EU}_h) + X_i'\theta + \epsilon_{i,h,t} \tag{3}$$

$Y_{i,h,t}$ is patient i's health outcome following admission to NHS hospital h on date t; for example, $Y_{i,h,t}$ is an indicator variable valued one if patient i died within 30 days from her admission to hospital h in month t, and zero otherwise. $\overline{EU}_h$ is our treatment exposure, the share of European nurses in hospital organization h, averaged over the four years preceding the referendum date, i.e. from June 2012 to May 2016.[13] This historical average approximates the exposure of each hospital organization to the effects of the Brexit shock, summarized in subsection 5.1. The distribution of this treatment variable at the hospital organization level is plotted in Figure 3. The 'average' hospital organization has an exposure of 5.84%, that is, about six out of 100 nurses employed are from the EU.

Figure 3. Distribution of the treatment exposure



Notes. This figure gives the hospital organization-level treatment exposure, i.e., the average share of EU nurses in the pre-referendum period of our analysis window. Mean = 5.84%; Standard Deviation = 4.58%; Minimum = 0.56%; Maximum = 21.90%.

We interact this exposure variable with half-year bins, namely dummy variables that take the value of one in each of the six-month periods around the referendum date. Indeed, because the BR took place in June 2016, we define relative half-year indicators based on

[13] Specifically, our treatment exposure measure has been computed as the four-year average of the monthly hospital share of EU nurses: $\overline{EU}_h = \frac{\sum_{m=2012/06}^{2016/05} EU_{h,m}}{48}$, where $EU_{h,m}$ denotes the share of European nurses in hospital organization h and calendar month m.

the time windows that range from June to November and December to May. We estimate Equation 3 by choosing the interaction of the treatment exposure with the relative semester right before the referendum as the reference (omitted) category.[14] α_h and $\lambda_{r,t}$ are hospital and NHS region-specific half-year fixed effects, which capture time-invariant, hospital-specific quality differences as well as regional shocks over time. The NHS region fixed effects allow for a more granular comparison of hospitals within the same region, making our approach less sensitive to heterogeneous economic reactions to the Brexit referendum outcome in space.

X_i is a rich vector of patient-level characteristics that are likely correlated with the patient outcome variable. The vector X_i includes: admission-method indicators (e.g. admission via Accident & Emergency services or via general practictioner), 19 diagnosis indicators based on the ICD-10 classification, a female indicator, seven age-bracket indicators (18-29, 39-39, 40-49, 50-59, 60-69, 70-79, 80+) and income deprivation indicators (one for each quintile of the national distribution). We also control for seasonal patterns in mortality risk through the inclusion of admission-month indicators, and for the observed patients' frailty with a polynomial of degree two in the Charlson Comorbidity Index (CCI). These covariates are standard controls in models predicting hospital patients' outcomes (Cooper et al., 2011; Gaynor et al., 2013; Moscelli et al., 2021), as they serve to account for the heterogeneity in patient-level case-mix across different hospitals (NHS Digital 2023*b*).

Identification assumptions and threats. The coefficients β_k measure how patient- and hospital organization-level outcomes evolved relative to right before the referendum date, for different levels of hospital exposure to the BR shock. More specifically, the post-referendum interaction terms indicate whether hospital organizations that were historically more reliant on EU nurses experienced, for example, a post-referendum increase in the average patient's mortality risk, relative to hospital organizations that were less reliant on EU nurses.

Two main assumptions have to be satisfied in order for Equation 3 to estimate a causal effect in the proposed framework. First, the 'parallel trends assumption' (PTA) requires that patient care quality in hospitals of heterogeneous exposure to the shock would have developed similarly had the referendum not occurred. A visual inspection of the pre-referendum interaction terms will be informative about whether such diverging trends existed or not. The absence of pre-trends will also help to rule out potential reverse causality concerns, namely the possibility that changes in hospital quality affected the pre-referendum pool of international workers and, by that, the hospital treatment status. In the presence of reverse causality, the evolution of patient outcomes over time would considerably differ between

[14]For the outcome variables on which we only observe annual data, year 2015 is the last pre-treatment time period, and as such used as the reference event-study period in the estimation.

more and less exposed hospitals, prior to the Brexit referendum and, hence, would be visible in the form of pre-trends.

Second, Equation 3 requires no treatment spillovers across hospitals of different exposure levels, also known as the 'stable unit treatment variable assumption' (SUTVA). In our setting, treatment spillovers among hospitals in the vicinity could arise. Patients could, for example, switch hospitals in response to worsening health care in a highly exposed hospital, effectively smoothing treatment across hospitals. This instance, however, would imply that Equation 3 will underestimate most of our treatment effects of interest in absolute terms. Also, we explicitly test for such patients' behavioral response through a series of robustness checks. For example, in Table A.3, we test for changes in patient composition as well as the catchment area population across hospitals of different exposures, documenting no effects in terms of key demographics and the overall number of admitted patients. Following the Brexit referendum, more exposed hospitals only seemed to have admitted less fragile patients, a potential source of downward bias which we control for through the inclusion of the comorbidity polynomial introduced above.

Moreover, our main estimation sample consists of only patients admitted to hospital for an emergency condition. Emergency patients have little to no choice over the hospital in which they are admitted, as by NHS clinical guidelines they need to be taken to the nearest hospital with capacity (Gaynor et al. 2013). Moreover, in England only NHS hospitals provide emergency care services to patients, so there is no outside option for emergency patients to be treated by private hospital providers. Given these institutional features, examining the health outcomes of emergency patients has the great advantage to limit the potential violations of SUTVA that would arise from the strategic behaviour of patients with respect to changes in hospital workforce composition and quality of care.[15]

Another possible concern is the confounding by time-varying unobservable factors that operate at hospital organization level and are correlated to, but not caused by, the labour supply shock which took place in the exposed hospitals after the Brexit referendum. To address this issue, we test a series of alternative mechanisms, such as the effects of the Brexit shock on hospital revenues, expenditures and bed occupancy rates.

Lastly, recent advances on difference-in-differences (DiD) show that DiD models with continuous treatment require a more demanding form of the parallel trends assumption (Callaway et al., 2024). For this reason, we will provide estimation results not only with our continuous measure of exposure, $\overline{EU}_h$, but also with a binary treatment indicator for

[15]As we show in Sections section 5 and section 6, we find no evidence supporting these concerns; moreover, the estimates of interest computed on the sample of both emergency and non-emergency patients are qualitatively very similar to those on emergency patients only.

hospitals that have an exposure value above the 75th percentile. This specification will identify how the quality of patient care changed after the Brexit referendum in highly exposed hospitals, relative to hospitals that belong to the first three quartiles of the exposure distribution.

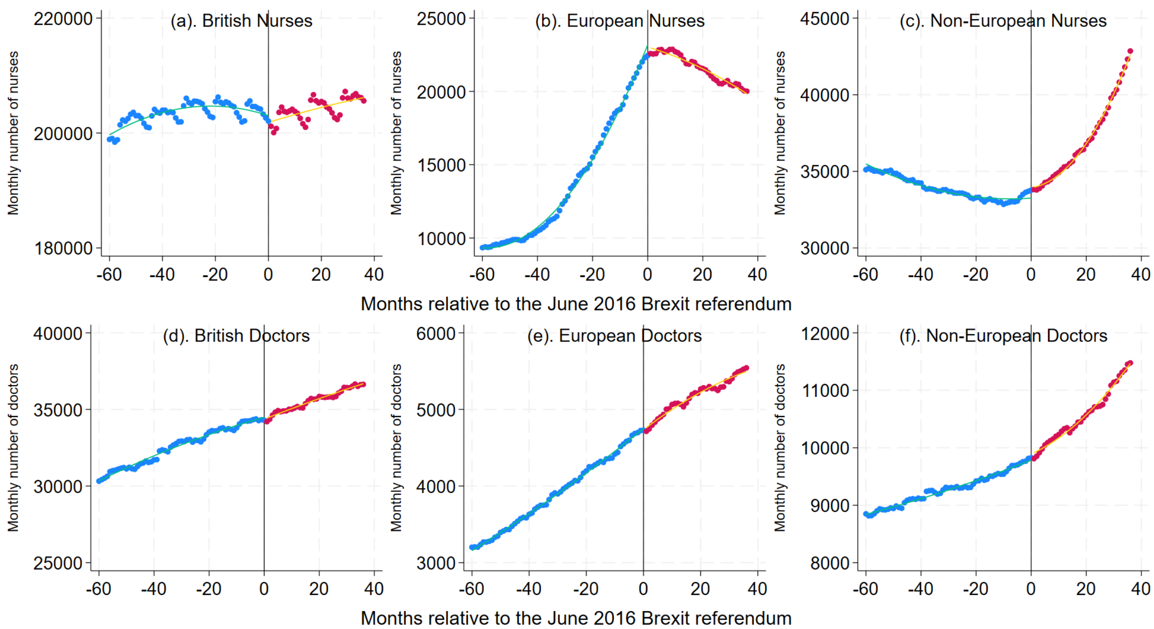
5 Results

5.1 Brexit referendum shock and NHS hospital staff composition: descriptive evidence at NHS level

In this section we examine the effects of the June 2016 Brexit referendum on the nursing and medical workforce of the entire English NHS acute care hospital sector. Figure 4 provides a breakdown by nationality groups of the staffing levels of nurses and senior doctors employed in acute care NHS hospitals. Following the Brexit referendum, the total number of EU nurses in the English NHS started to fall (*panel b*), while that of non-EU nurses started to increase sharply (*panel c*). Instead, the total number of British nurses remained roughly constant, especially in the short-term (*panel a*). Similarly, there was no substantial discontinuity in the number of doctors of any nationality group around June 2016 (*panels d, e* and *f*). These patterns are consistent with our conceptual framework, where we have shown that the referendum effects on new joiners should vanish for better-paid occupations (e.g. doctors) compared to relatively lower-paid ones (e.g. nurses).

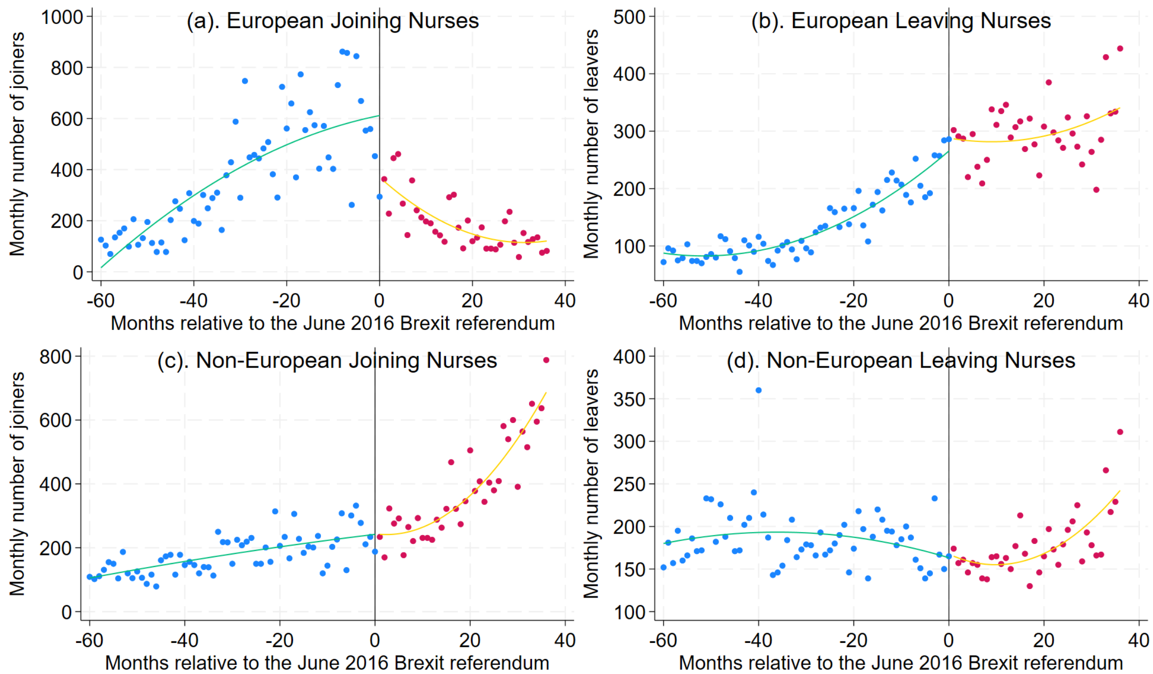
Figure 5 shows that the decrease in the overall number of European nurses and the increase in the overall number of non-European foreign nurses respectively stemmed from a marked decrease in the number of monthly joiner EU nurses (*panel a*) and a steady increase in the monthly joiner non-EU foreign nurses (*panel c*). The leaving rates of both EU and non-EU foreign nurses also increased (*panels b* and *d*), but less than the absolute changes in the number of joiners. The EU nationality workers already employed and settled in the UK prior to the BR would have made personal and professional investments, such as fostering their career within NHS hospitals, marrying, forming a household, having children; any decision to abruptly relocate outside the UK would have implied substantial divestment costs. Hence, EU nurses employed in the English NHS before the BR were likely less sensitive to the BR outcome and left the NHS at a slower pace than prospective EU nurses who choose not to move to the UK and be employed by the NHS. Moreover, Figure A.1 in the Appendix shows that the BR resulted in large decreases in the joining rates of EU non-registered nurses (*pay bands 1-4, panel a*) and EU newly registered nurses (*pay band 5, panel b*), and a smaller

Figure 4. Number of nurses and doctors employed in NHS hospitals, by nationality group



Notes. This figure shows the number of nurses and doctors employed in NHS hospitals over time with the Brexit referendum date (June 2016) in month 0. Nurses' and senior doctors' nationality is classified according to the first non-missing nationality record (if present). The EU group includes Iceland, Norway, and Switzerland, namely all countries that have access to the European Single Market although not being formal EU member states.

Figure 5. Nurses joining and leaving NHS hospitals, by nationality group



Notes. This figure gives the number of NHS monthly joiners and leavers by nationality group with the Brexit referendum date (June 2016) in month 0.

decrease in the European senior nurse joiners (*pay bands 6-9, panel c*).[16]

To summarise, the outcome of the Brexit referendum led to a substitution between European and non-European nurses in the English NHS, which was almost entirely driven by a lower number of new nurses joining the healthcare system.[17] [18]

[16]This finding chimes with evidence that the Brexit referendum had a disproportionate impact on lower-skilled and essential migrant workers (Sumption and Fernandez Reino, 2018; Fernández-Reino and Kierans, 2020).

[17]Figure A.2 reports the corresponding graphs for English NHS doctors. Consistently with Figure 4, around the Brexit referendum date there was no considerable change in the joining and leaving rates of both European and non-European doctors.

[18]We have assumed that the drop in EU nurses joining numbers was entirely due to the uncertainty triggered by the BR outcome. However, the new English language requirement imposed since January 2016 on prospective nurses from the EU (see Section 2.2) could have acted as a concomitant driver of such drop. To assess which of these two shocks was mostly responsible for the aforementioned drop, in Figure A.4 we plot the yearly percentage-point change in the monthly number of EU joiner nurses around the January and June 2016 dates. Figure A.4 shows that the sharp reduction in the number of joiner nurses from Europe started only since June 2016, and also that the introduction of the new English language requirement had little to no impact on the EU nurse joining rate. A similar case of relative irrelevance occurred for EU hospital doctors, whose NHS joining rate did not change when a similar English language requirement was introduced in June 2014 (as shown by *panel a* of Figure A.2).

5.2 Brexit referendum shock and NHS hospital staff composition: hospital-level regression-based evidence

In this section, we show how the Brexit referendum shock impacted the workforce composition of our final analysis sample of 131 acute NHS hospitals at the hospital organization instead of the aggregate level. Before 2016, NHS hospitals differed largely in their reliance on EU nurses: before the referendum in 2016, the average share of EU nurses was 5.84%, with a range between 0.56% and 21.90% and a standard deviation of 4.58% (see Figure 3). Hospitals with a larger share of EU nurses before the referendum were more exposed to the negative labor supply shock induced by the Brexit referendum, due to EU nurses either reducing their migration inflow to NHS hospitals from EU countries as new joiners, or leaving their employing NHS hospital and the UK.

In Table 1, we report the association between the share of EU nurses (with respect to all nurses employed in the NHS hospital organization) during the four pre-referendum years (our continuous treatment exposure) and the hospital-level changes in key employment variables between the pre- and post-Brexit period. *Panel a* of Table 1 reports the association between the hospital exposure to the Brexit referendum and the change in the share of nurses by nationality groups, which is computed as the change in shares between the two endpoints of our pre- and post-referendum periods (May 2019 and May 2016, respectively), in order to capture the full extent of the effects of the Brexit referendum shock on the NHS hospital nursing workforce composition, as displayed in Figure 4. Consistently with our hypothesis, hospital organizations that relied on a higher share of EU nurses before the referendum experienced a stronger decline in the share of EU nurses and a stronger growth in the number of non-EU nurses, after the Brexit referendum; the share of British nurses was unaffected, and there was no effect on total employment levels, as shown in Appendix Table A.4; these findings are robust across and within NHS health regions.

According to the estimates in Table 1 *panel b*, NHS hospital organizations substituted the 'lost' inflow of EU nurses with non-EU nurses; such substitution is particularly evident among newly hired nurses: NHS hospitals with higher pre-referendum exposure to EU nurses hired a lower share of EU nurses but a higher share of non-EU nurses, cumulatively after the referendum. Moreover, estimates in Table 1 *panel c* show that there is no association between the referendum exposure and the change in the share of NHS leavers by nationality subgroup, confirming that the changes in workforce composition occurred predominantly through a substitution between EU and non-EU joiner nurses.[19] In Appendix Table A.5, we

[19] To compute the changes in leavers used as outcomes in *panel b* of Table 1, we use the cumulative number of leavers in the whole pre- and post-referendum periods.

Table 1. Exposure to Brexit shock and changes in nurse employment shares

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Employed nurses	Δ Share of British nurses		Δ Share of EU nurses		Δ Share of Non-EU nurses	
Pre-BR share of EU nurses	-0.1066*	0.0222	-0.2196***	-0.3840***	0.3290***	0.3586**
	(0.0558)	(0.1232)	(0.0588)	(0.1164)	(0.0775)	(0.1417)
Panel B: NHS joining nurses	Δ Share of British joiners		Δ Share of EU joiners		Δ Share of Non-EU joiners	
Pre-BR share of EU nurses	-0.1373	0.7538*	-1.0850***	-1.9434***	1.2087***	1.1746**
	(0.2101)	(0.4485)	(0.2491)	(0.4566)	(0.26410)	(0.4966)
Panel C: NHS leaving nurses	Δ Share of British leavers		Δ Share of EU leavers		Δ Share of Non-EU leavers	
Pre-BR share of EU nurses	-0.0143	-0.0827	0.3727***	-0.0971	-0.3314***	0.1857
	(0.1386)	(0.3452)	(0.1060)	(0.2520)	(0.1067)	(0.2062)
NHS region FE	No	Yes	No	Yes	No	Yes

Notes. $N = 131$ acute care NHS hospital organizations. The changes in employment shares used as dependent variables in *panel A* is computed between May 2019 and May 2016, namely the two endpoints of our post- and pre-BR analysis periods. The changes in the total number of joining and leaving nurses used as dependent variables in *panels B* and *C* are computed as the percentage point changes in the cumulative number of joining or leaving nurses between the whole post-BR and pre-BR periods. Robust standard errors reported in parenthesis. Significance levels: *p<0.1; **p<0.05; ***p<0.01.

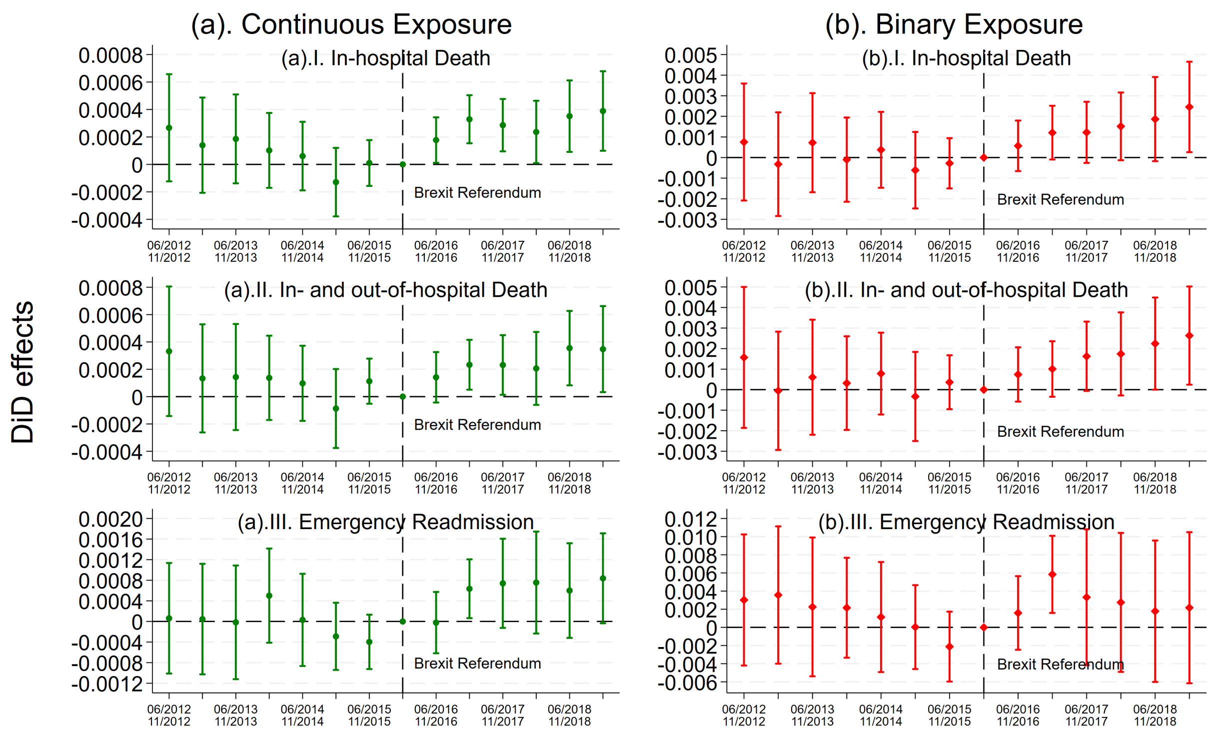
also show that the pre-treatment exposure is also associated with a loss of South European and Irish nurses and an increase in Asian nurses, primarily driven by the reduced share of South European joiners and increasing share of Asian joiners (see Appendix Table A.6).

5.3 Effects on Hospital Quality of Care

In this section, we present the main results of our analysis, that is, the causal effect of the changes in hospital workforce composition on a number of hospital care quality outcomes.

Baseline results. Figure 6 presents the event-study estimates of the impact on the health outcomes of patients admitted for an emergency condition. Emergency hospital patients represent the marginal patients with the greatest health risk, for which changes in the workforce quality and composition could be more impactful. Our event-study regressions reveal that patients admitted to hospitals with a higher exposure to the Brexit referendum shock experienced higher risks of in-hospital mortality, mortality anywhere (in- and out-of-hospital) and also unplanned emergency readmission, in the post-referendum period. These effects are persistent over time, indicating that the decrease in healthcare quality was not just transitory, and the lead effects in the pre-referendum period are not significant. The mortality effect is robust, regardless of the use of a continuous or binary treatment exposure variable (which takes the value of one if a hospital organization is in the top quartile of the exposure distribution), whereas the readmission effect is more precise using a continuous treatment exposure variable. As shown in Appendix Figure A.5 and Appendix Table A.8, we find very similar effects using the sample of hospital patients that includes also planned (non-emergency) patients.

Figure 6. Effects of Brexit exposure on Patient Health Outcomes (emergency patients)



Notes. N = 32,445,509 hospital emergency admissions. $N_{clusters}$: 131 hospital organizations. This figure gives the dynamic treatment effects of the Brexit referendum on patient-level health outcomes by estimating Equation 3 with the continuous and the binary (i.e., below/above 75th percentile exposure) exposure. Robust standard errors clustered at hospital organization level; bands: 95% confidence intervals. The joint Wald test F-stat values, and their related p-values, testing the null hypothesis that all the leads effects are equal to zero, are reported in Appendix Table A.7.

Implied magnitude of the effects. For the event-study based on the continuous exposure measure, the left axis of the event study plot provides the effects of a 1 percentage point (p.p.) increase in the Brexit shock exposure on the in-hospital mortality risk (within 30 days from hospital admission). Thus, for a hospital with mean exposure to the treatment (equal to 5.84%, see Figure 3), the in-hospital mortality risk increased by 5.31%, in- and out-of-hospital mortality risk increased by 3.45%, and the unplanned emergency readmission risk increased by 2.28%.[20]

[20] Each value is obtained as the product of the mean pre-referendum exposure variable (5.84) and the average of the post-referendum semestral effects on patient health outcomes using the continuous treatment event-study specifications (columns 1-3, Table A.7), divided by the average pre-referendum health outcome risk (as reported in Table A.1). Thus, respectively: $0.00029667 \times 5.84/3.26\%$ (in-hospital mortality); $0.00025167 \times 5.84/4.26\%$ (in- and out-of-hospital mortality); $0.00059333 \times 5.84/15.2\%$ (unplanned emergency readmissions).

These effects on patient health outcomes are equivalent, over the entire post-BR period, to 34 additional in-hospital deaths and 67 additional readmissions in hospitals with a mean pre-BR exposure measure (5.84%), for a total of 4,454 additional deaths and 8,777 additional readmissions.[21] To put things into perspective, the yearly magnitude of our estimated effects of the Brexit shock on in-hospital deaths (about 1,485 additional deaths per annum) is about half of the impact of the COVID-19 pandemic on non-COVID-related excess mortality (3,050 deaths) throughout the first twelve months of the COVID pandemic, as estimated by Fetzer et al. (2024). Given a decline in the number of EU nurses employed by the NHS acute care hospitals in our sample equal to 2,047 workers within the first three years after the referendum (see also Figure 4), the 'loss' of each EU nurse is associated with approximately 2.18 extra in-hospital patient deaths during our post-referendum period.[22] Considering an average age of 78.85 years for the hospital patients dying in our sample, an average life expectancy of 81.26 years in the UK in 2018 according to the World Bank, and assuming that the value of one year in full health is worth £60,000 (Glover and Henderson, 2010; Cutler and McClellan, 2001; Ryen and Svensson, 2015), the implied monetary life value 'lost' due to the Brexit shock was worth £644,048,400 (that is: £$60,000 \times 4,454 \times (81.26 - 78.85)$).[23]

Similarly, considering an average expenditure of £2,100 per each unplanned hospital readmission (Billings et al., 2012), the implied cost of the Brexit shock translates into additional £18,431,700 (that is: £$2,100 \times 8,777$) for NHS hospitals, or £140,700 for each of the 131 NHS hospital organizations in our analysis. Therefore, based on the 2016 regulated NHS nurse salary scales, the NHS hospital sector could have afforded hiring an additional number of either 841 (Pay Band 5) nurses, or 700 (Pay Band 6) senior nurses, or 587 (Pay Band 7) advanced nurses, if the £18.4 millions extra costs for the unplanned hospital readmissions caused by the Brexit referendum shock was averted.[24]

Heterogeneity by patient characteristics. We investigate how the effects on mortality outcomes differed by patient age, gender and income deprivation, by estimating fully-interacted models in terms of these patient characteristics (see Appendix Figures A.6, A.7,

[21]Our estimates have been obtained by multiplying the average post-treatment effects displayed in Table A.7 (respectively equal to 0.00029667 for in-hospital mortality and 0.00059333 for unplanned emergency readmissions) by 113,247.5, which is the average number of patient emergency hospital admissions in the post-referendum period for the 131 hospital organizations in our sample, based on a total of 14,835,419 post-referendum patient emergency hospital admissions.

[22]In March 2016 (2019), there were 19,720 (17,643) EU nurses employed across the NHS hospital organizations in our sample, with an average of 150.53 (134.91) EU nurses employed per NHS hospital organization.

[23]For the life expectancy in the UK, see the World Bank data at: `https://datacommons.org/tools/timeline#&place=country/GBR&statsVar=LifeExpectancy_Person`.

[24]Respectively: £18,431,700 divided by either £$21,909$ (Pay Band 5), or £$26,302$ (Pay Band 6) or £$31,383$ (Pay Band 7), according to `https://www.rcn.org.uk/employment-and-pay/NHS-pay-scales-2016-17`.

A.8). The workforce composition shock affected both younger and older patients, although the effect for elderly patients was about three times larger. Female and male patients are both negatively affected, and in a similar scale, by the workforce shock. We find no remarkable differences in the mortality effects for least and most deprived patient.

Furthermore, in order to examine the heterogeneity of the effects of interest by diagnosis type, we also estimated 19 separate static DiD versions of Equation 3, one for each of the 19 large patients' subgroups identified by the patient main diagnosis for hospital admission.[25] The results, reported in Appendix Figures A.9, and A.10 and Appendix Table A.9), show that the mortality effects appear to be driven by an increase in deaths for respiratory systems diseases, as well as neoplasms and blood diseases. As respiratory infections require care-intensive treatments by nurses rather than doctors (Fetzer et al., 2024; Friedrich and Hackmann, 2021), it is not surprising that shocks to the nurse workforce composition may be particularly harmful for these patients.

Heterogeneity by share of 'Leave' votes in Brexit referendum. Exploiting the large variation in the share of 'Leave' votes across English counties, ranging from around 20% to 70%, we also investigate the heterogeneity of the in-hospital mortality effects for hospital organizations located in areas with a lower or higher share of 'Leave' votes in the Brexit referendum. We split NHS hospital organizations in 'Remain' and 'Leave' areas (identified by a share of 'Leave' votes respectively below or above 50%) based on the headquarter postcodes of NHS hospital organizations. Given the rather evenly split result of the referendum (52% votes in favour of 'Leave'), there were respectively 47 and 84 NHS hospital organizations in the 'Remain' and 'Leave' areas. Figure A.11 shows that the effects on in-hospital mortality were quite similar for NHS hospital organizations in 'Remain' and 'Leave' areas, although the mortality effects in 'Leave' areas are more precise, probably due to the stronger decline in the share of EU nurses in regions with a high 'Leave' share (see Figure A.12).

5.4 Robustness Checks

Exclusion of London hospitals. London is an outlier in the exposure measure, due to a high density of EU nurses before the referendum, thus the inclusion of London hospitals in the sample may pose a risk to the generalizabity of our main findings. Moreover, the London hospital patient composition might have changed after the referendum vote, given the large number of EU nationals in London. Therefore, as a first robustness analysis we re-estimate our event-study model on a sample of only non-London NHS hospital organiza-

[25] The 19 subgroups are created based on the International Classification of Diseases 10$^{\text{th}}$ Revision (ICD-10) chapter of the main diagnosis code in HES APC.

tions. When London hospitals and their patients are excluded from the sample (Appendix Table A.10), the effects on mortality (in-hospital or anywhere) are similarly precise but even larger in magnitude, showing that our main findings are not driven by a London-driven hospital workforce composition effect.

Exposure variable measured in the pre-referendum year only. We re-estimate our model on hospital care quality with an exposure variable defined according to the nurse nationality distribution in the last pre-referendum year only, rather than the entire pre-referendum time period. Our results remain substantially unchanged (see Appendix Figure A.13 and Appendix Table A.11).

Controlling for the exposure to pre-referendum share of non-EU foreign nurses. We also estimate an augmented version of Equation 3 which includes event-study terms for the pre-referendum exposure to non-EU nurses (Appendix Table A.12). This approach is indicative of whether the effect on quality was driven by the net loss of EU nurses or also by the pre-referendum exposure to a different group of non-native nurses (i.e. non-EU nurses). We show that, to the largest extent, the mortality and readmission effects exclusively depend on the pre-referendum exposure to EU nurses, so that the net loss of EU nurses is the driving force. Since the reduction in EU nurses was primarily driven by the reduction in new joiners from South European countries, we estimate four different models each having a pre-referendum exposure measure computed among nurses coming from a specific EU national subgroup. Consistently with the findings on the nurse composition changes, Appendix Figure A.14 shows that in-hospital mortality was more affected by the exposure to South European, East European and Irish nurses, and never by the pre-referendum share of North European nurses, which was largely unaffected by the Brexit vote shock.

Controlling for the exposure to pre-referendum share of EU doctors. Furthermore, we estimate an event-study specification in which we add the pre-referendum exposure to EU senior hospital doctors – computed in the same fashion as for nurses. As there was no drop in EU doctors after the referendum, we would expect mortality effects to be caused mostly by the nurse workforce composition shock. Therefore, these results provide us also with a first useful falsification test. The estimates, displayed in Appendix Table A.13 and Figure A.15, show that the effects on patient mortality and readmission rates are clearly associated with the pre-referendum exposure to EU nurses and not EU doctors.

Falsification tests using randomization inference. Finally, we also perform a falsification exercise based on randomization inference with 300 replications. For the continuous placebo exposure variable, we simulated 300 random draws from a log-normal distribution with the same mean and variance of the original pre-referendum hospital share of EU nurses; instead, for the binary placebo exposure variable, we 300 random values from a uniform distribution and created a binary exposure indicator equal to one for uniform draws over 0.75, and zero otherwise. We assigned the aforementioned placebo exposure variables to the 131 NHS hospital organizations in our sample, and then estimate the event-study regressions as in Eq. 3 on the observed patient health outcomes and control covariates, based either on the continuous or the binary placebo exposure variables.

The complete distributions of the 13 event study pre- and post-referendum coefficients are reported in Appendix Figures A.17 and A.18: the distribution of each estimate is symmetric and centered around zero. Appendix Figure A.16, instead, shows the event-study plot obtained by reporting the average point estimates, upper and lower bounds of the 95% confidence intervals, from the distribution the 300 event-study regressions. Also in this case, the estimates of the placebo exposures are centered around zero, both before and after the referendum, providing additional evidence that our main findings are not due to chance.

6 Mechanisms

In this section, we provide empirical evidence on the possible mechanisms explaining the deterioration in care quality in hospitals exposed to the Brexit referendum shock. In the first instance, we test the mechanism proposed by our conceptual framework, that is, the hospital nurse workforce composition changes triggered by the Brexit referendum resulted in a decrease in the skill level of newly hired NHS hospital nurses. Consistently with our theoretical predictions, we show that the quality of the newly joiner nurses after the Brexit referendum is worse than that of the nurses who joined the NHS before the referendum. Subsequently, we test a series of alternative or complementary mechanisms to the skill deterioration that we proposed, and we find no evidence that they explain the quality effects of interest.

6.1 Changes in Nurses' Skills Composition

We use the first observed pay grade that foreign nurses are assigned to, when they join their NHS hospital employer, as a measure to gauge the skill levels of newly hired foreign nurses by NHS hospitals, before and after the referendum.[26] This strategy is based on the following

[26]Using the observed pay grade variable reported in ESR records has several advantages: it is an objective measure for the expertise of nurses, and so a plausible proxy for their skill level; it is observed (i.e., non-

facts and assumptions: i) for most job hiring decision, pay is a good indicator of workers' skills and human capital at the aggregate level, i.e. on average for a group of workers; ii) a global labour market for hospital nursing jobs existed already in the years before the Brexit referendum; iii) given the international mobility of foreign nurses, the joiner nurses, who were hired after the Brexit referendum, would have chosen to move to a different employer, or to a country different from England, if they considered the pay package offered by their NHS hospital employer too low for their skill level; iv) the existence of a different NHS 'pay policy' for foreign nurses, i.e. hiring nurses in higher (lower) pay grades before (after) the referendum, is extremely unlikely.[27]

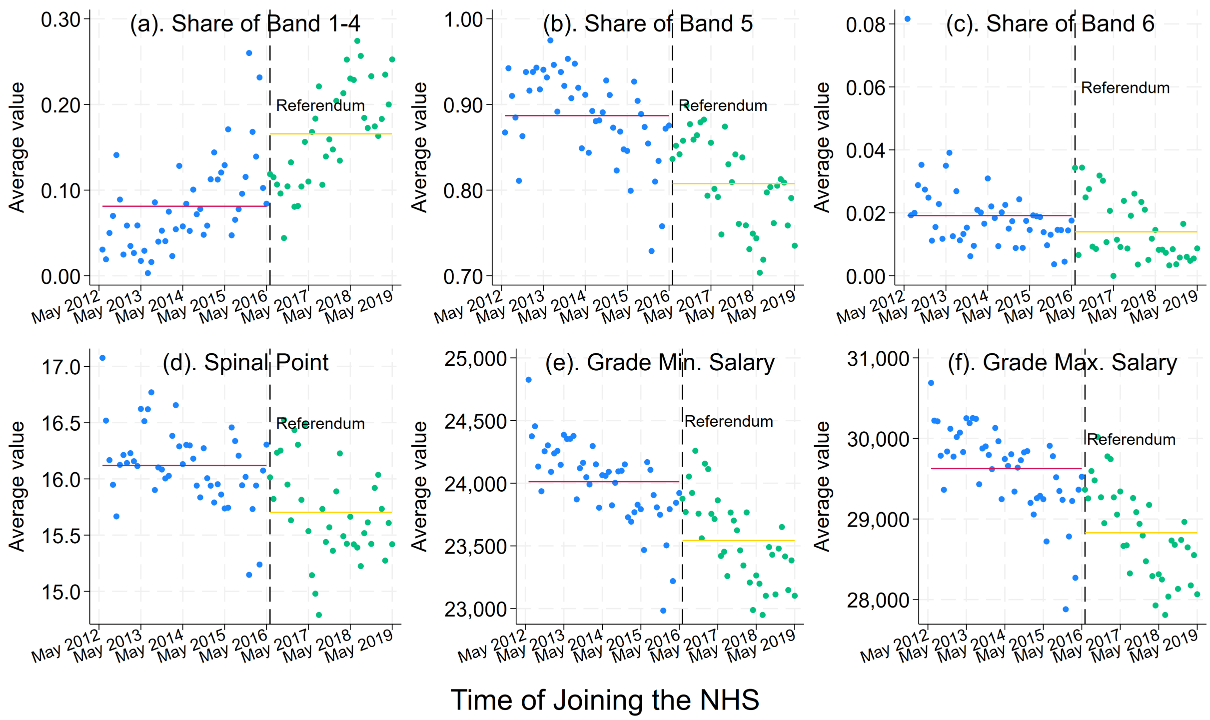
Therefore, we analyze how the pay bands of foreign newly joiner nurses changed, before and after June 2016. Higher pay bands reflect better qualifications, better employment references and a higher pre-employment tenure, that is, a greater job experience. Figure 7 shows the share of nurses being employed in wage bands 1-4 (*panel a.*), wage band 5 (*panel b.*), and wage band 6 (*panel c.*) among all newly joining, foreign nurses. After the Brexit referendum, the share of foreign joiner nurses employed in wage band 1 to 4 increased and doubled from 2016 to 2019. The share of foreign joiner nurses in the higher wage bands, proxying higher quality, decreased. ESR records also provide us with NHS hospital employees' salary spinal point, which gives the most precise measure of the nurse basic salary and pay level in a month or year; also when we use this more accurate observed pay level, with respect to pay bands, we find that the average salary spinal point (*panel d.*) of foreign newly joiner nurses fell after the referendum . Similarly, the minimum (*panel e.*) and maximum salary (*panel f.*) within the nurses' grades fell, mirroring the findings on the

missing) for all newly hired nurses; last but not least, it is not model-based, thus not prone to introduce model and/or measurement errors in this analysis. Instead, we cannot employ a Abowd-Kramartz-Margolis approach (Abowd et al., 1999) (hencefort, AKM) to measure newly hired nurses' skills, for several reasons. First, we are interested in measuring nurses' skills right at the moment of their NHS hospital entry, and not after they have acquired additional human capital through specific or general training at the NHS hospital where they are hired, but we do not have any record of the tasks, activities and qualifications that the joiner nurses possess before they are firstly employed by the a NHS hospital. Second, in HES APC there is no records of the nursing team members in charge of a given patient. Third, a hypothetical AKM strategy would require estimating separate matched nurse-hospital fixed effects regression models in the years before and after the Brexit referendum, but the estimated fixed effects risk to be biased due to the structural break induced by the Brexit referendum shock.

[27]The last assumption is justifiable according to two simple considerations. First, the NHS is highly unionized and also equal opportunity employer, so such a 'discriminatory' policy would have generated highly heated political and media debates, which we are not aware of. Secondly, such a policy would be inconsistent with labour market forces and the chain of events that we have shown: after the referendum the NHS had to cope with urgency the recruitment of foreign nurses, to avoid hospital nurse shortages due to the missing inflow of EU joiner nurses, so we should expect that highly-demanded foreign nurses should have experienced a relative increase in their wage-bargaining power, with respect to the pay grade that they were assigned to when joining NHS hospitals.

wage band structure.[28]

Figure 7. Changes in foreign joining nurse composition by pay band and salary grade



Notes. This figure gives the composition of joiners by wage group, spinal point, or minimum and maximum salary over time.

Hence, after Brexit, the composition of foreign nurses deteriorated given the increasing inflow of low-wage band nurses. This is a consequence of hiring more non-EU joiners who on average are hired at lower wage bands and lower spinal points (see Appendix Figures A.19 and A.20, and the related pre- and post-referendum averages reported in Table A.15). This matches the propositions derived in our theoretical model.

Additionally, we exploit yearly National Staff Survey data, for the years 2012 to 2019, to investigate if nurses' self-reported satisfaction with the quality of care they provide to patients and their working environment changed, based on the share of pre-referendum EU nurses. The nurse satisfaction outcome variables in the surveys are expressed on a Likert scale from 1 to 5 (e.g. strongly disagree; disagree; neither agree nor disagree; agree; strongly agree). For this reason we estimate ordered logit regressions, including hospital organization fixed effects and year-NHS region fixed effects, to mimic the event-study specification Equation 3 used

[28]The average values displayed in Panels e and f of Figure 7 measure the minimum and maximum salary levels that can be potentially earned by newly joining nurses, given their starting employment grade. Thus, the decreases highlighted by the two figures further confirms a reduction in the average employment grade among new hires.

to evaluate the effect on patient health outcomes. We provide event-study models for two samples of nurses. The first sample includes all the nurses employed in the NHS hospitals and responding to the survey; the second sample, instead, consists only of British nurses who have been employed for at least six years in a hospital, which ensures that our results are not affected by selection (e.g. joining and/or leaving EU nurses might differ from joining non-EU nurses) or the fact that nurses were directly affected by the referendum (e.g. due to worsening residence regulations).

Table 2. Effects on nurse self-reported satisfaction with provision of hospital care

	I look forward to going to work. (1)	I am satisfied with the quality of care I give to patients / service users. (2)	I am able to deliver the care I aspire to. (3)	I feel that my role makes a difference to patients / service users. (4)
Panel A: All nurses				
I(2013 NSS) * Pre-BR share of EU nurses	0.998			
	[0.975,1.021]			
I(2014 NSS) * Pre-BR share of EU nurses	1.011			
	[0.995,1.026]			
I(2016 NSS) * Pre-BR share of EU nurses	1.000	0.999	0.998	1.001
	[0.988,1.013]	[0.983,1.015]	[0.978,1.017]	[0.989,1.013]
I(2017 NSS) * Pre-BR share of EU nurses	0.990	0.977**	0.983*	0.989*
	[0.977,1.003]	[0.958,0.996]	[0.963,1.002]	[0.977,1.002]
I(2018 NSS) * Pre-BR share of EU nurses	0.994	0.987	0.988	0.990
	[0.979,1.009]	[0.967,1.007]	[0.967,1.009]	[0.977,1.003]
I(2019 NSS) * Pre-BR share of EU nurses	0.987	0.980**	0.982*	0.990
	[0.971,1.004]	[0.962,0.999]	[0.963,1.000]	[0.976,1.004]
Observations (nurse responses to NHS Staff Surveys)	398,953	333,969	333,161	333,435
Panel B: British nurses employed by at least 6 years				
I(2013 NSS) * Pre-BR share of EU nurses	0.991			
	[0.971,1.010]			
I(2014 NSS) * Pre-BR share of EU nurses	1.011			
	[0.992,1.030]			
I(2016 NSS) * Pre-BR share of EU nurses	0.994	0.997	1.000	0.998
	[0.978,1.011]	[0.978,1.016]	[0.977,1.023]	[0.983,1.013]
I(2017 NSS) * Pre-BR share of EU nurses	0.982**	0.968***	0.974**	0.982**
	[0.967,0.998]	[0.946,0.990]	[0.952,0.997]	[0.968,0.997]
I(2018 NSS) * Pre-BR share of EU nurses	0.985*	0.981	0.982	0.990
	[0.968,1.003]	[0.960,1.004]	[0.958,1.006]	[0.975,1.004]
I(2019 NSS) * Pre-BR share of EU nurses	0.977**	0.972***	0.978**	0.981***
	[0.959,0.995]	[0.952,0.992]	[0.959,0.997]	[0.968,0.994]
Observations (nurse responses to NHS Staff Surveys)	196,453	161,208	160,886	160,990

Notes. $N_{clusters}$ = 131 acute care NHS hospital organizations. Period: 2013-2019. Outcome variables: nurse responses to yearly NHS Staff Surveys, expressed on a 1–5 Likert scale. Ordinal logit odds ratios and corresponding 95% confidence intervals. Robust standard errors, clustered at the hospital organisation level. The event-study specification is based on Equation 3, using a continuous exposure to the Brexit shock. Significance levels: *p<0.1; **p<0.05; ***p<0.01.

Table 2 reports coefficients in odds ratios, and it shows that the likelihood of nurses reporting that they looked forward to going to work significantly decreased (odds ratios lower than one) in hospitals more exposed to Brexit, compared to less exposed hospitals. This effect is especially prominent among British nurses who have been employed before and after the referendum. Moreover, after the referendum the nurse satisfaction with their own quality of care, as well as the ability to deliver care as aspired, decreased more in hospitals with higher exposure to the Brexit shock. Finally, fewer British nurses felt like they made a difference to their patients. We consider the findings above as evidence that nurses employed by NHS hospitals heavily exposed to the Brexit shock perceived a deterioration in the quality of patient care they provided.

6.2 Alternative and complementary mechanisms

There could be alternative or complementary mechanisms at play that may explain the deterioration of hospital care quality that we document. Hereafter we provide evidence on four channels, either on the hospital care supply or demand sides.

Nursing workforce shortages. A first check on the hospital supply side is whether the exposure to the referendum shock had any effect on nurse labour capacity, that is, generated nurse shortages. According to Table 1, there was no effect on the number of nurses employed in the hospital – hence, no shortages of nurses in hospitals with a higher pre-2016 share of EU nurses.

Financial capacity. Another concern is whether more exposed NHS hospital organizations suffered a change in their financial conditions after the referendum. If hospital organizations more exposed to the Brexit shock also experienced a surge in patient costs or a fall in their revenues, they might have skimped on patient care and safety measures to revert their dire financial situation. To investigate this mechanism, we use the publicly available financial accounts data at NHS hospital organization level (referenced in Section 2.3) and estimate event-study specifications in which we use the natural logarithm of total hospital expenditures and revenues as dependent variables.[29] The estimates, provided in Appendix Figure A.21, show that there was no Brexit effect either on the income or the expenditures of the hospitals more exposed to the migration shock induced by the referendum.

Bed occupancy. While the overall number of nurses was unaffected, and we find no apparent evidence of nurse shortages in hospitals more exposed to the Brexit shock, it is possible that labour productivity in such hospitals decreased compared to the pre-referendum period. To test this hypothesis, we analyze how the exposure to the Brexit shock relates to hospital bed occupancy rates.[30] Appendix Figure A.22 shows that the bed occupancy rate of hospi-

[29] For several NHS hospital organizations, the published financial accounts data is unavailable in some years of the sample, and therefore missing; as such, the results of this analysis is based on an unbalanced sample consisting in 85 out 131 of the hospital organizations in the main sample.

[30] For this analysis, we use NHS bed occupancy data publicly available at: `https://www.england.nhs.uk/statistics/statistical-work-areas/bed-availability-and-occupancy/bed-data-overnight/`.

tals with a higher pre-referendum share of EU nurses suffered a modest decrease of about 0.50% in the post-referendum period, with respect to the 86.88% pre-referendum mean bed occupancy rate, but this decrease is not significant even at 10% level. Provided that the bed occupancy rate is a reliable measure of hospital productivity, these results point towards a possible weak decrease in the productivity of hospital organizations more exposed to the Brexit shock. This finding is likely consistent with changes in the hospital (nursing) workforce composition, as highlighted in Section 6.1, that might have averted labour shortages through the imperfect substitution of the missing inflow of EU nurses.[31]

Changes in hospital patient demand. Finally, we investigate whether our main effects on quality of care might be explained by changes in hospital patient demand across different English NHS hospitals. We investigate whether, across hospitals differently exposed to the shock, there were changes in the population of the NHS provider catchment area.[32] The catchment area is calculated by Public Health England based on the frequency of patient hospital utilization and admissions. If patients switched hospitals of treatment or strategically changes their residence, e.g. anticipating a lower quality of care in the hospitals more exposed to the foreign labour shock, the catchment area population would decrease. Appendix Figures A.23 and A.24 show that there was no significant change in the catchment area population for all age groups and at the aggregate level. Moreover, Appendix Table A.14 shows that the total number of patients admitted to the hospital was unaffected by the exposure variable.[33] Hence, reverse patient mobility, choice and utilization do not appear as plausible mechanisms that can explain the findings on quality of hospital care.

[31] If hospital bed occupancy rates increased in the more exposed hospital organizations after the referendum, consistently with a quality-volume trade-off mechanism, this channel would represent an alternative explanation to our preferred mechanism. However, as the sign of the (non significant) effect on the hospital bed occupancy rate is negative, our event study estimates find no empirical support in favour of this alternative mechanism.

[32] Data on the catchment area of NHS providers are publicly available at: https://app.powerbi.com/view?r=eyJrIjoiODZmNGQ0YzItZDAwZi00MzFiLWE4NzAtMzVmNTUwMThmMTVlIiwidCI6ImVlNGUxNDk5LTRhMzUtNGIyZS1hZDQ3LTVmM2NmOWRlODY2NiIsImMiOjh9.

[33] For this analysis we use the aggregate data on the volume of patients admitted to NHS hospital organization during the years of our sample period, recorded in HES APC data.

7 Conclusions

In many developed countries like the UK, several sectors of the economy are critically reliant on the immigration of skilled workers. Our work provides several insights to the existing economics literature on this matter, drawing from the relevant case of migrant nurses who are employed in the English NHS hospital acute care sector.

Skilled migrant workers like nurses are responsive to changes in the institutional settings and hospitality environment of prospective hosting countries: we document how the outcome of the 2016 Brexit referendum led to a significant change in the nursing workforce composition in NHS acute care hospitals, driven by a stark decrease in the number of EU joiner nurses. This evidence is in line with economic theory: prospective foreign workers decide whether to move to work in a given host country, form expectations based on the existing labour market conditions, and revise such expectations when big shocks to the labour market arise, as in the case of the Brexit referendum. Instead, migrant workers already employed in the host country may be much less responsive to migration policy shocks, such as the Brexit referendum outcome, for several reasons: they may have already gained settlements rights; they may postpone their reactions to the moment when the new immigration regulatory framework is clearly defined along with their settlement rights (in our case study, this would have been the approval of the 2020 European Union Withdrawal Agreement Act by the UK Government); or their reactions are smoothed over a longer time window due to the expensiveness of an otherwise abruptly quick divestment process to leave the UK.

Moreover, we find that sudden changes in the composition of skilled workers have the potential to disrupt the quality of healthcare services provided. In the case we studied, patients admitted to a NHS hospital organization with an average exposure to the Brexit referendum shock experienced a 5.31% increase in the risk of in-hospital death, and 2.28% increase in the risk of unplanned emergency hospital readmission, after June 2016. This translates into about 1,485 additional in-hospital deaths per year, in the three years after the referendum, or equivalently 2.18 extra in in-hospital deaths for each of the fewer 2,047 EU nurses employed in English NHS hospital organizations after the referendum. The size of these Brexit-related mortality effects are therefore quite large, especially when we compare them with the mortality impact of a catastrophic event such as the COVID-19 outbreak (about 3,050 non-COVID-related deaths, according to Fetzer et al. 2024): as the Brexit referendum was a scheduled political event, whereas the COVID-19 pandemic outbreak was likely unavoidable, English healthcare policy-makers could have put in place contingency plans to attenuate the Brexit shocks due to changes in the NHS hospital workforce composition, in case of a 'Leave' victory scenario at the referendum.

We also find that the risk of unplanned emergency readmission to hospital increased by about 2.78% in hospital organizations more exposed to the Brexit shock, equivalently to about 8,777 additional unplanned readmissions. Despite an unplanned emergency readmission is a much less severe event than the absorbing case of a patient death, it may be still a very stressful event for the patients' physical and mental health, and it produces extra work burden for overworked and fatigued NHS nurses and doctors; it also results in £18.4 millions extra costs for the NHS, which could have been employed to hire for one year 841 nurses, approximately equivalent to half of the nursing staff of an average size NHS hospital organization.

These empirical results can be reconciled through the lens of the theoretical framework that we provide, and the workforce composition mechanism that we test empirically: the most readily available nurses to start a job in NHS hospitals with short notice would have likely been exactly those nurses with lower reservation wages or opportunity-costs from leaving another nursing job elsewhere, in the UK or abroad. As such, the workforce composition changes in the NHS hospital nursing workforce may have prevented the insurgence of long-lasting and severe nurse shortages, but at the cost of a decrease in the quality of new hires: we find suggestive evidence supporting this mechanism by analyzing the changes in both the pay grades of new joiner nurse hired by NHS hospital, and also in the level of nurses' satisfaction with the quality of services they provide.

Overall, our investigation emphasizes the importance of high-skilled, foreign nurses in hospital care, and contribute more generally to understand the effects of workforce composition and of foreign labour supply extensive margins on the performance of labour-intensive organizations such as public hospitals. The takeaway message from this study is that, in countries relying on skilled foreign labour force, such as the US and the UK, political initiatives fostering nationalistic interests and with a relevant expected impact on immigration patterns should be carefully weighed against the potential disruptions to the labour supply chain in critical sectors of the economy, such as health care. These detrimental effects should not be underestimated in labour-intensive sectors, such as health care, also in light of the ongoing demographic changes and the ever-increasing demand for skilled (healthcare) workers in highly developed countries.

Ultimately, our research suggests that policy-makers should take informed decisions based on the willingness to move of prospective native and foreign skilled workers in the short, medium and long-term, according to different immigration scenarios. Failing to do so can critically disrupt organizational performance, at the very least in the sectors mostly exposed to immigration-related labour supply shocks.

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Appendix A. Proofs

Proof of Lemma 1. Let $h^*(\theta)$ be the hiring decision described in the Lemma's statement. That is, $h^*(\theta) = 1$ if $\theta \geq \theta^*$ and zero otherwise. Let $h : \mathbb{R} \to [0, 1]$ be an arbitrary hiring rule satisfying condition (2). We divide the proof into two cases: $\tilde{\theta} < \theta_0$ or $\tilde{\theta} \geq \theta_0$.

Case I: Suppose $\theta^* = \theta_0 > \tilde{\theta}$. The difference in total quality under h^* compared to h is

$$Q(h^*, a) - Q(h, a) = -\int_{-\infty}^{\theta_0} q(\theta)h(\theta)a(\theta)d\theta + \int_{\theta_0}^{+\infty} q(\theta)[1 - h(\theta)]a(\theta)d\theta \geq 0.$$

The first term on the right-hand-side is positive because $q(\theta) \leq 0$ for all $\theta \leq \theta_0$. The second term is positive since $q(\theta)[1 - h(\theta)]a(\theta) \geq 0$ for all $\theta > \theta_0$.

Case II: Suppose $\theta^* = \tilde{\theta} \geq \theta_0$. The difference in total quality under h^* compared to h is

$$Q(h^*, a) - Q(h, a) = -\int_{-\infty}^{\theta_0} q(\theta)h(\theta)a(\theta)d\theta + \int_{\theta_0}^{+\infty} q(\theta)[h^*(\theta) - h(\theta)]a(\theta)d\theta \geq 0.$$

The first term on the right-hand-side is positive because $q(\theta) \leq 0$ for all $\theta \leq \theta_0$. For the second term, note that $[h^*(\theta) - h(\theta)]a(\theta)$ is never strictly positive then strictly negative. Moreover, q is increasing and $q(\theta) \geq 0$ for all $\theta > \theta_0$ and $\int_{\theta_0}^{+\infty} h^*(\theta)a(\theta)d\theta = M \geq \int_{\theta_0}^{+\infty} h(\theta)a(\theta)d\theta$. Hence, the second term is also positive by the Beesack's inequality (Beesack (1957)). □

Proof of Proposition 1. We prove each of the items separately.

Item 1: Suppose for the sake of obtaining a contradiction that $\theta^*_{pre} < \theta^*_{post}$. If that is the case, then (2) must also bind after the referendum, which implies that the total mass of hired workers before and after the referendum must be the same. That is,

$$\int_{\theta^*_{post}}^{+\infty} a_{post}(\theta)d\theta = \int_{\theta^*_{pre}}^{+\infty} a_{pre}(\theta)d\theta,$$

where a_{pre} and a_{post} denote the mass of applicants of each type before and after the referendum. Note, however, that as $\gamma_e^{pre} > \gamma_e^{post}$ we have that

$$\int_{\theta^*_{post}}^{+\infty} a_{post}(\theta)d\theta - \int_{\theta^*_{pre}}^{+\infty} a_{pre}(\theta)d\theta =$$

$$\int_{\theta^*_{post}}^{+\infty} \mu \underbrace{\left[F(\omega_e + \gamma_e^{post}) - F(\omega_e + \gamma_e^{pre})\right]}_{<0} g(\theta)d\theta - \int_{\theta^*_{pre}}^{\theta^*_{post}} \underbrace{a_{pre}(\theta)}_{>0} d\theta < 0.$$

A contradiction. □

Item 2: The total number of workers hired cannot increase post-referendum since (2) was binding pre-referendum. However, the number of non-EU hired workers increases since $\theta^*_{post} < \theta^*_{pre}$. Therefore, the share of newly hired EU workers decreases. □

Item 3: Note that

$$Q(h^*_{pre}, a_{pre}) - Q(h^*_{post}, a_{post}) = \int_{\theta_0}^{+\infty} q(\theta)\Big[h^*_{pre}(\theta)a_{pre}(\theta) - h^*_{post}(\theta)a_{post}(\theta)\Big]d\theta.$$

Recall that q is increasing and $q(\theta) > 0$ for all $\theta > \theta_0$.

Moreover, $\left[h^*_{pre}(\theta)a_{pre}(\theta) - h^*_{post}(\theta)a_{post}(\theta)\right]$ single-crosses zero from below and

$$\int \left[h^*_{pre}(\theta)a_{pre}(\theta) - h^*_{post}(\theta)a_{post}(\theta)\right]d\theta \geq 0.$$

Therefore, by the Beesack's inequality $Q(h^*_{pre}, a_{pre}) > Q(h^*_{post}, a_{post})$. □

Item 4: We define worker shortages as not all vacancies being filled, or equivalently, $\theta^* = \theta_0 > \tilde{\theta}$. Note that, by Lemma 1, θ^* is a continuous and, by item 1, decreasing function of γ_e. Moreover, if $(\gamma_e^{pre} - \gamma_e^{post}) = 0$, then $\theta^*_{post} = \theta^*_{pre} > \theta_0$. Therefore, $\theta^*_{post} > \theta_0$, unless the decrease in $(\gamma_e^{pre} - \gamma_e^{post})$ is sufficiently large.□ □

Proof of Proposition 2. The mass of unfilled vacancies (if any) plus the number of workers hired after the referendum with skills below the pre-referendum cutoff is equal to the mass of prospective workers with type above θ^*_{pre} who would apply pre-referendum and no longer do (for instance, areas A and D in figures 1a and 1b). That is,

$$\begin{aligned}\int_{\tilde{\theta}_{post}}^{\theta^*_{pre}} a_{post}(\theta)d\theta &= \underbrace{\int_{\tilde{\theta}_{post}}^{\theta^*_{post}} a_{post}(\theta)d\theta}_{\text{Unfilled vacancies}} + \underbrace{\int_{\theta^*_{post}}^{\theta^*_{pre}} a_{post}(\theta)d\theta}_{\text{Hired below } \theta^*_{pre}} \\ &= \mu \int_{\theta^*_{pre}}^{+\infty} \Big[F(\omega_e + \gamma_e^{pre}) - F(\omega_e + \gamma_e^{post})\Big]g(\theta)d\theta.\end{aligned}$$

Hence,

$$\begin{aligned}\frac{d\int_{\tilde{\theta}_{post}}^{\theta^*_{pre}} a_{post}(\theta)d\theta}{d\mu} &= \int_{\theta^*_{pre}}^{+\infty} \Big[F(\omega_e + \gamma_e^{pre}) - F(\omega_e + \gamma_e^{post})\Big]g(\theta)d\theta \\ &\quad - \mu\Big[F(\omega_e + \gamma_e^{pre}) - F(\omega_e + \gamma_e^{post})\Big]g(\theta^*_{pre})\frac{d\theta^*_{pre}}{d\mu}.\end{aligned}$$

As $\gamma_e^{pre} > \gamma_e^{post}$, the first term of the right-hand-side is positive. Hence, if we show that

$d\theta^*_{pre}/d\mu < 0$ we are done. Recall that

$$M = \int_{\theta^*_{pre}}^{+\infty} \Big[\mu F(\omega_e + \gamma_e^{pre}) + (1-\mu)F(\omega_r + \gamma_r)\Big] g(\theta)d\theta.$$

Totally differentiating with respect to μ and isolating $d\theta^*_{pre}/d\mu$, we get

$$\frac{d\theta^*_{pre}}{d\mu} = \frac{\int_{\theta^*_{pre}}^{+\infty} \big[F(\omega_e + \gamma_e^{pre}) - F(\omega_r + \gamma_r)\big] g(\theta)d\theta}{\Big[\mu F(\omega_e + \gamma_e^{pre}) + (1-\mu)F(\omega_r + \gamma_r)\Big] g(\theta^*_{pre})}$$

which is smaller than zero, as $\omega_r + \gamma_r > \omega_e + \gamma_e^{pre}$ and F is strictly increasing. □

Proof of Proposition 3. Note that the hiring skill cutoff θ^* is bounded above by $\overline{\theta} := G^{-1}(1-M)$. $\overline{\theta}$ would be the hiring cutoff if all potential workers were to apply. The fewer the applicants, the smaller the hiring cutoff.

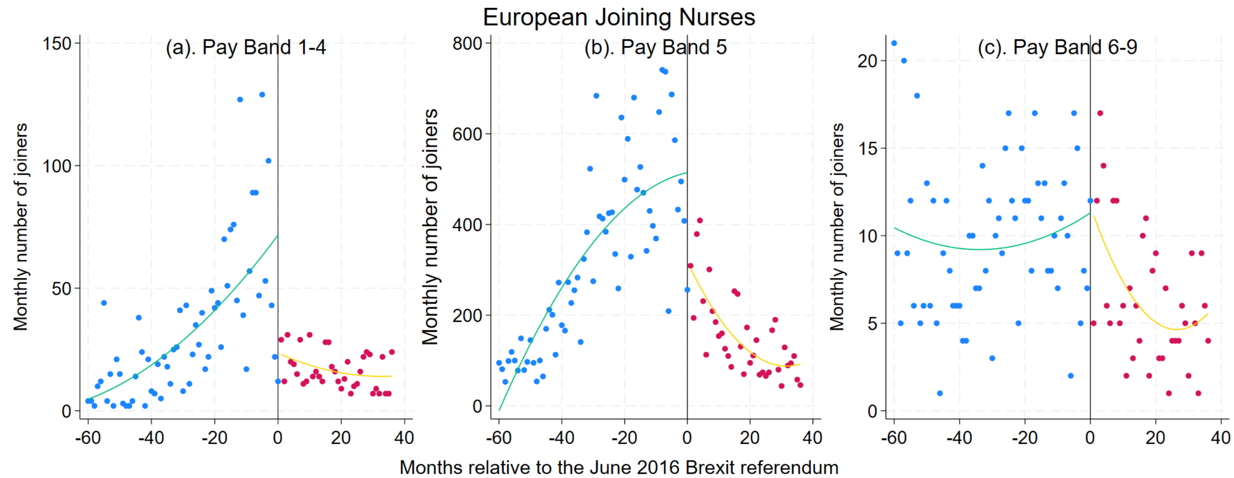
Consider now a sequence $(\omega_{e,n}, \omega_{r,n})$ where both $\omega_{e,n} \to +\infty$ and $\omega_{r,n} \to +\infty$ as $n \to +\infty$. For each $n \in \mathbb{N}$, let $\theta^*_{pre,n}$ and $\theta^*_{post,n}$ be the pre and post-referendum hiring cutoffs associated with a pair $(\omega_{e,n}, \omega_{r,n})$. Hence, for n sufficiently large and $\ell \in \{pre, post\}$ we have

$$M = \int_{\theta^*_{\ell,n}}^{+\infty} \Big[\mu F(\omega_{e,n} + \gamma^{\ell}_{e,n}) + (1-\mu)F(\omega_{r,n} + \gamma^{\ell}_{r,n})\Big] g(\theta)d\theta.$$

As n increases, both $F(\omega_{e,n} + \gamma^{\ell}_{e,n})$ and $F(\omega_{r,n} + \gamma^{\ell}_{r,n})$ converge to one. Hence, both $\theta^*_{pre,n}$ and $\theta^*_{post,n}$ converge to $\overline{\theta}$. Therefore, $|\theta^*_{pre,n} - \theta^*_{post,n}| \to 0$ as $n \to +\infty$. □

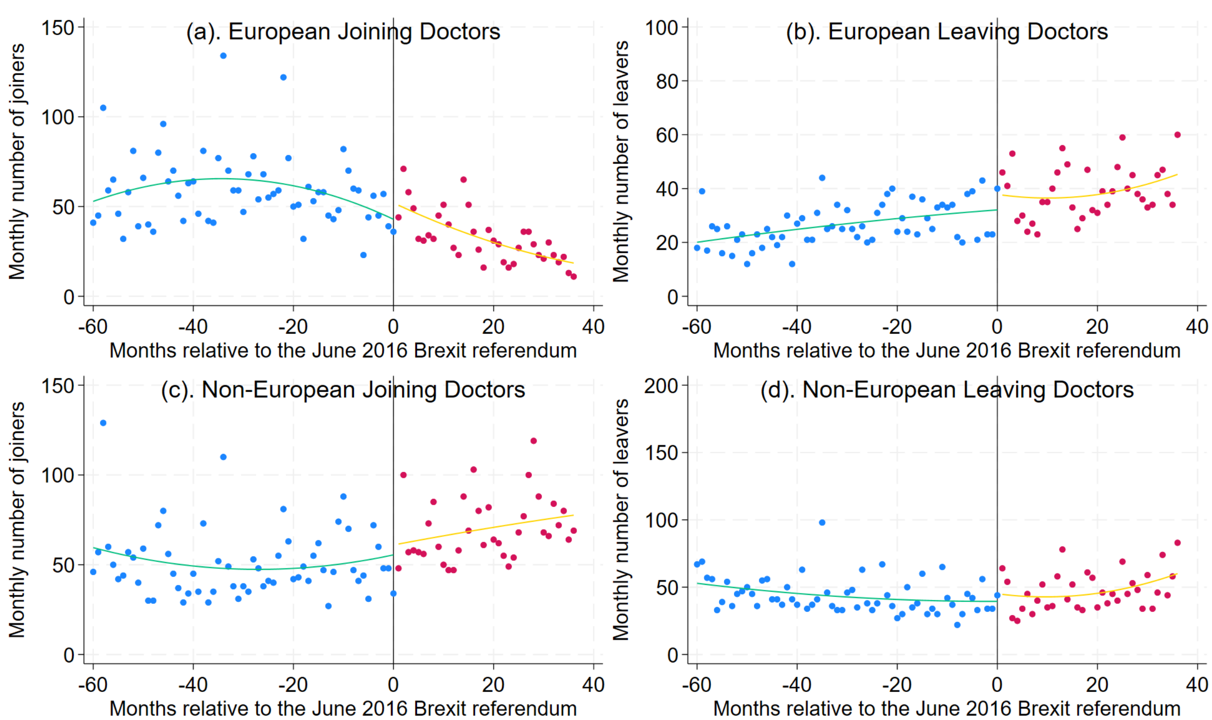
Appendix B. Additional Figures and Tables

Figure A.1. European nurses joining the English NHS by pay band section



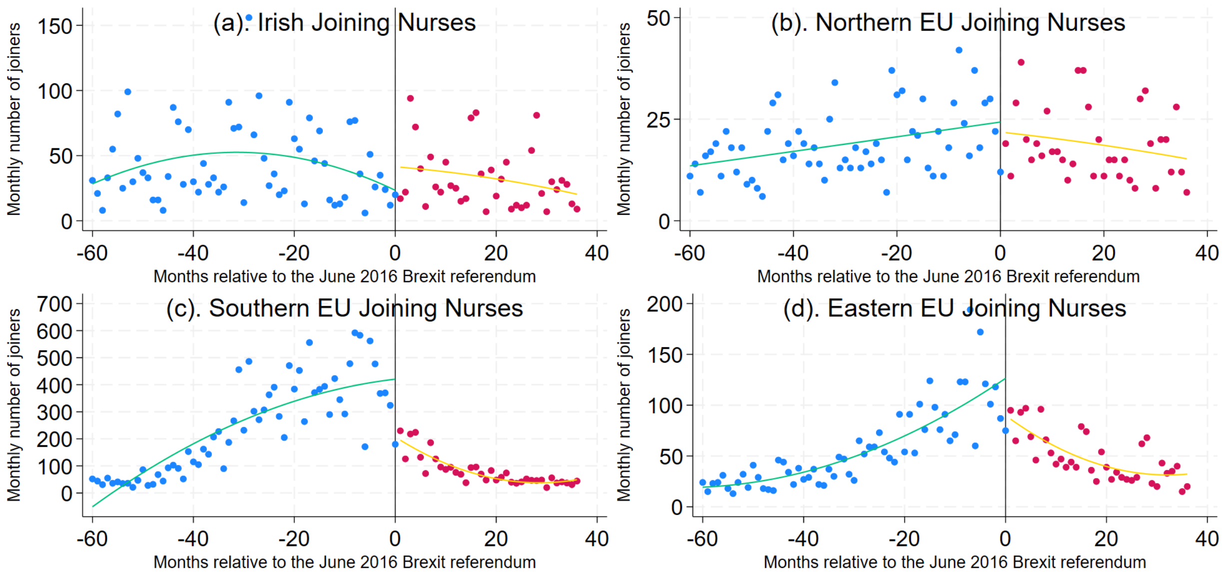
Notes. This figure gives the number of monthly European nurses joining by wage band and over time with the Brexit referendum in month 0.

Figure A.2. Senior doctors joining and leaving the English NHS by nationality group



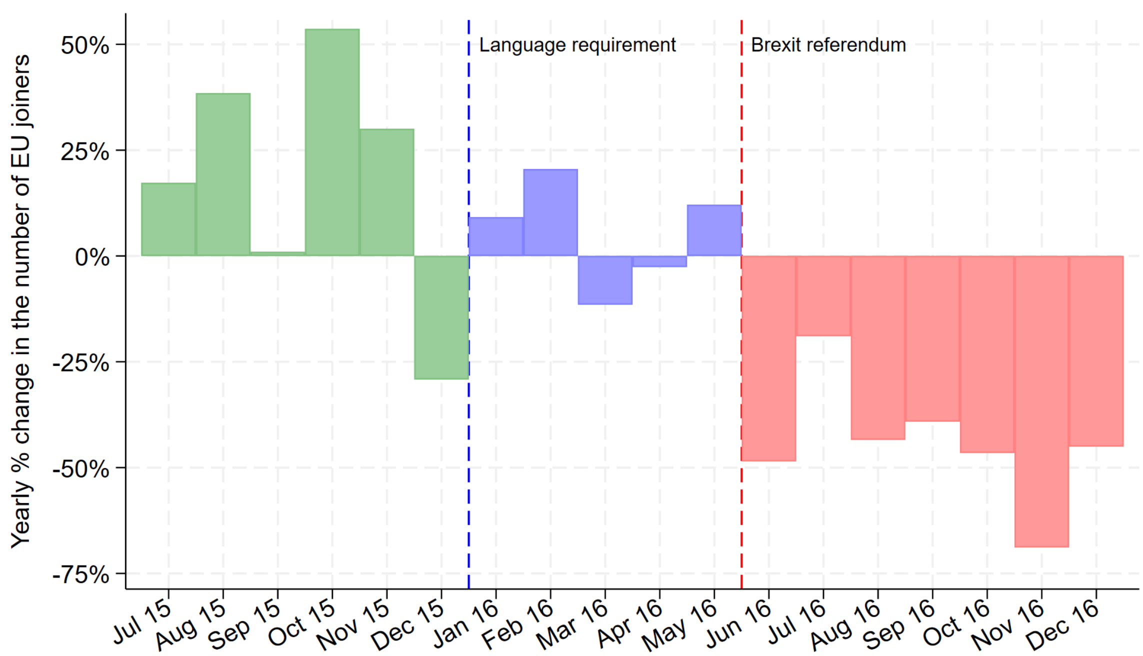
Notes. This figure gives the number of monthly European and non-European doctors joining and leaving over time with the Brexit referendum in month 0.

Figure A.3. Nurses joining the English NHS by different European nationality subgroups



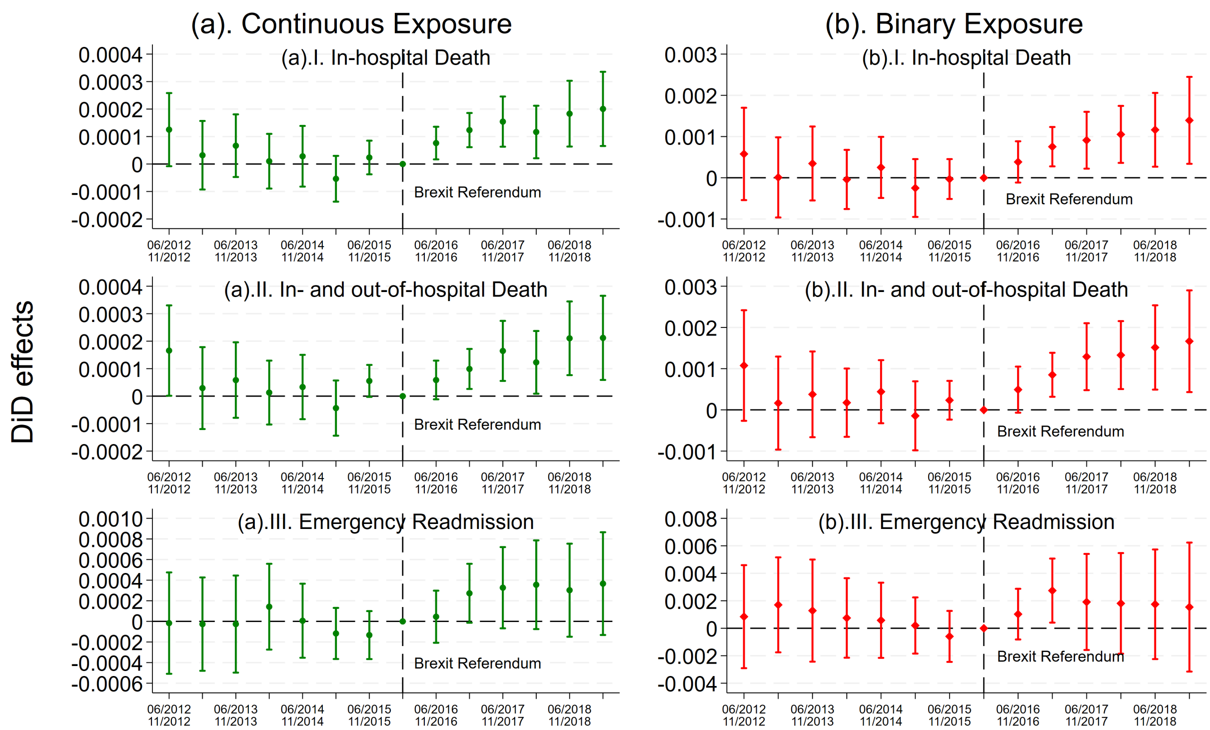
Notes. This figure gives the number of monthly joiners to the NHS over time by nationality groups of European nurses with the Brexit referendum in month 0.

Figure A.4. Yearly change in EU nurse joiners around the Brexit referendum date



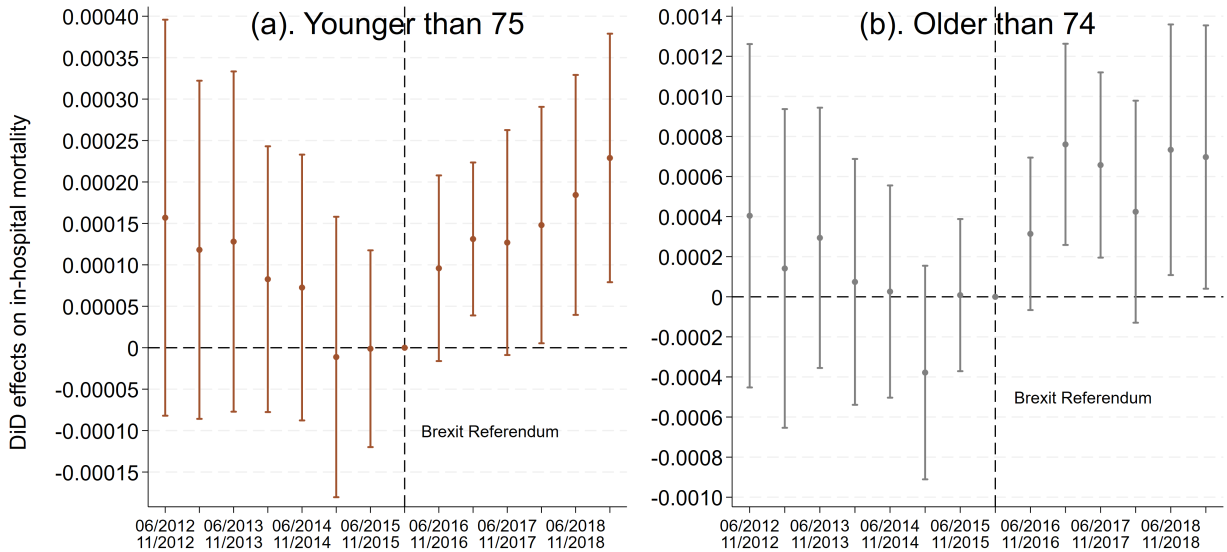
Notes. This figures gives the percentage-point change in the total monthly number of NHS nurse joiners from Europe compared to the same month of the year before.

Figure A.5. Dynamic DiD effects of Brexit referendum on Individual Health Outcomes (all patients)



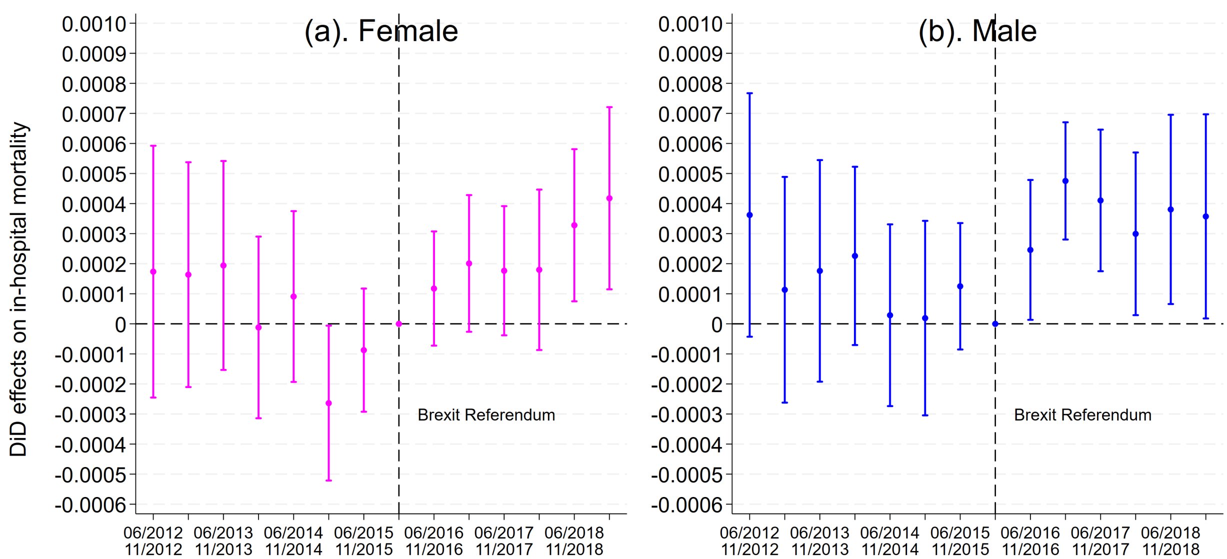
Notes. N = 89,728,352 hospital admissions (both emergency and non-emergency). $N_{clusters}$: 131 hospital organizations. This figure gives the dynamic treatment effects of the Brexit referendum on patient-level health outcomes by estimating Equation 3 with the continuous and the binary (i.e., below/above 75th percentile exposure) exposure. Robust standard errors clustered at hospital organization level; bands: 95% confidence intervals. The joint Wald test F-stat values, and their related p-values, testing the null hypothesis that all the leads effects are equal to zero, are reported in Appendix Table A.8.

Figure A.6. Dynamic DiD effects on in-hospital mortality, by emergency patients' age



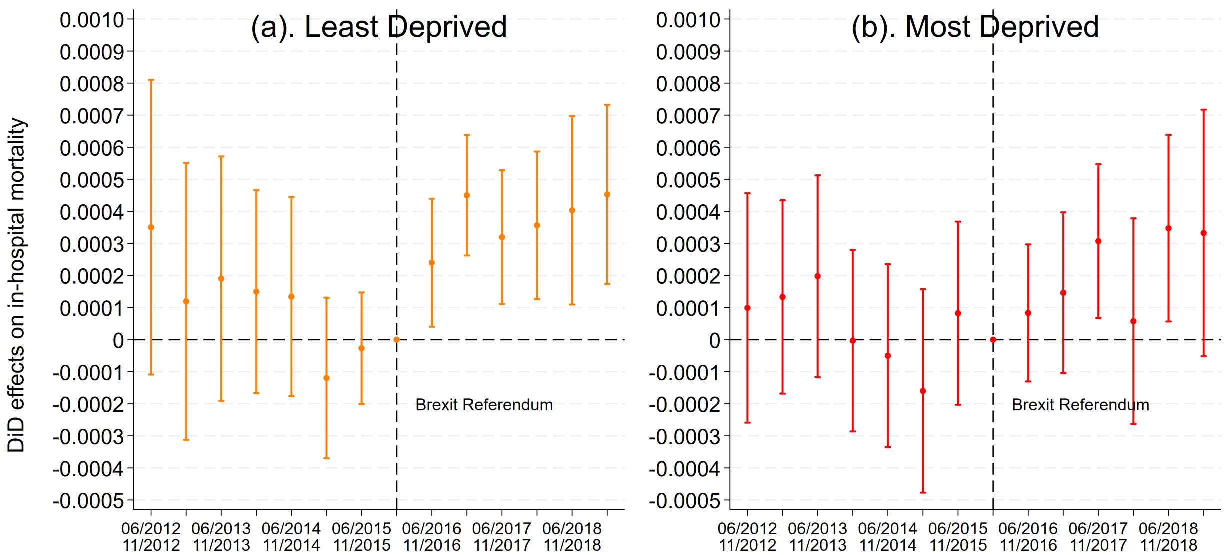
Notes. N = 32,445,509 hospital emergency admissions. $N_{clusters}$: 131 hospital organizations. This figure gives the dynamic treatment effects of the Brexit referendum on patient-level health outcomes by estimating the triple-difference version of Equation 3 with the continuous exposure interacted with a dummy whether the patient is younger than 75 (age<75) or older than 74 (age≥75). Robust standard errors clustered at hospital organization level; bands: 95% confidence intervals.

Figure A.7. Dynamic DiD effects on in-hospital mortality (emergency patients), by gender



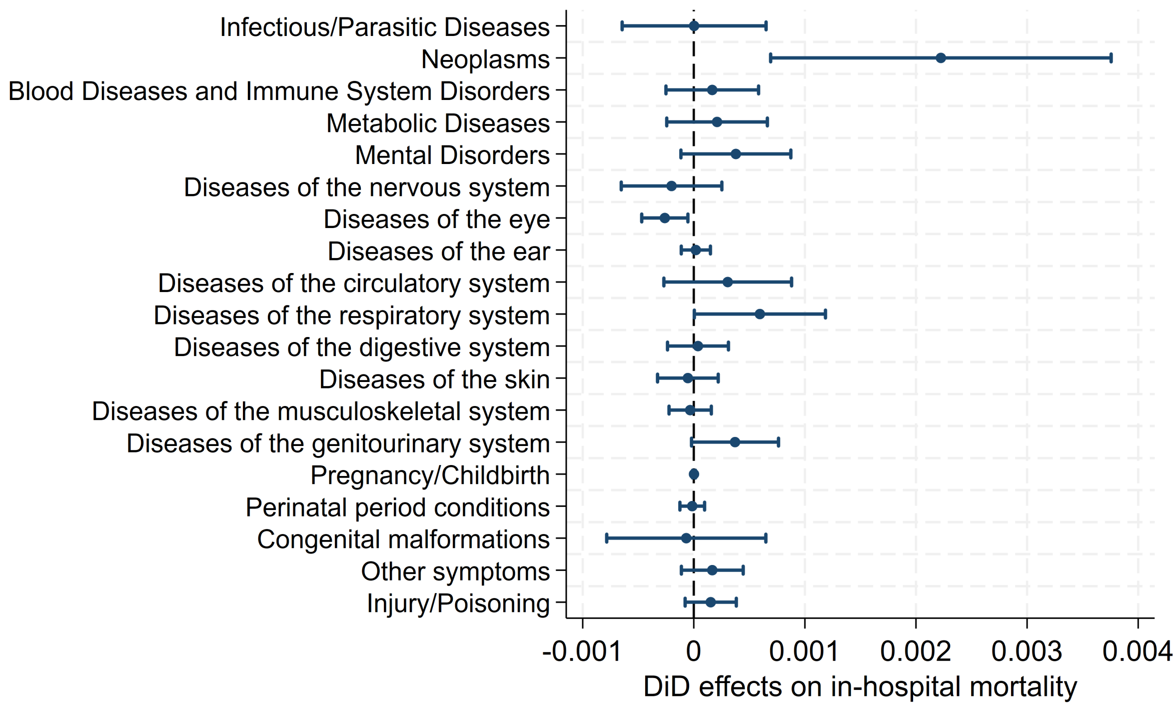
Notes. N = 32,445,509 hospital emergency admissions. $N_{clusters}$: 131 hospital organizations. This figure gives the dynamic treatment effects of the Brexit referendum on patient-level health outcomes by estimating the triple-difference version of Equation 3 with the continuous exposure interacted with a dummy whether the patient is male or female. Robust standard errors clustered at hospital organization level; bands: 95% confidence intervals.

Figure A.8. Dynamic DiD effects on in-hospital mortality (emergency patients), by income deprivation of residential area (LSOA)



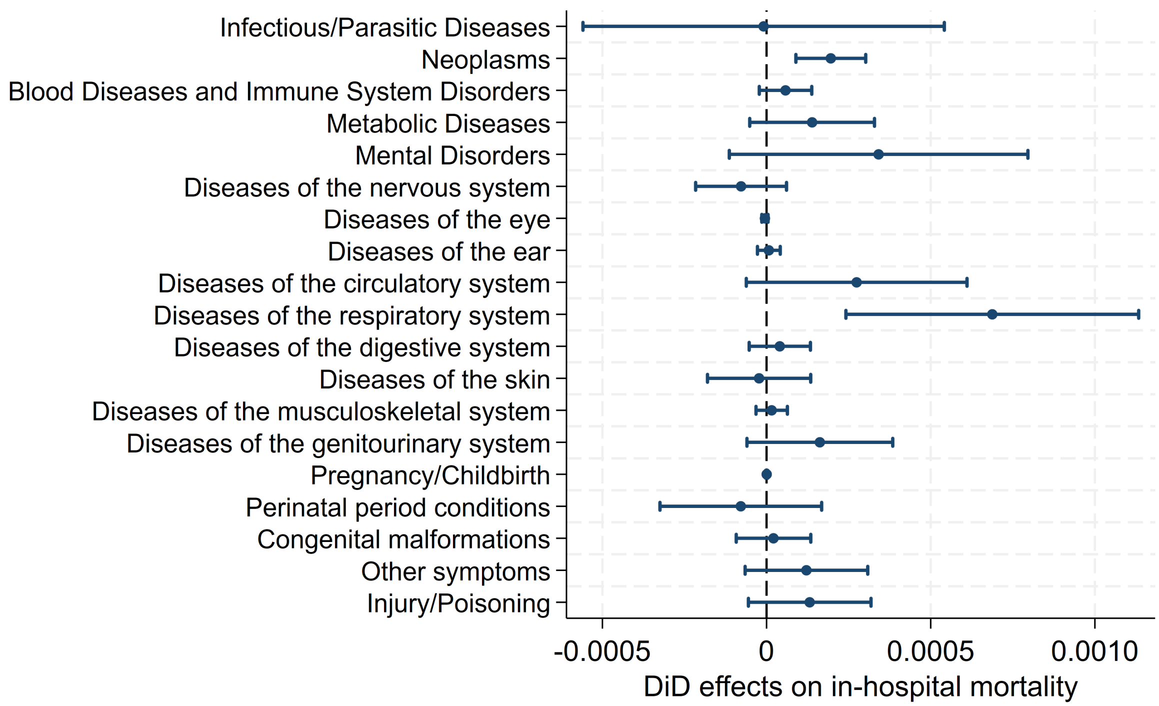
Notes. N = 32,445,509 hospital emergency admissions. $N_{clusters}$: 131 hospital organizations. This figure gives the dynamic treatment effects of the Brexit referendum on patient-level health outcomes by estimating the triple-difference version of Equation 3 with the continuous exposure interacted with a dummy whether the patient belongs to the low- or high-deprivation group. Robust standard errors clustered at hospital organization level; bands: 95% confidence intervals.

Figure A.9. DiD effects on in-hospital mortality (emergency patients), by ICD-10 diagnosis group



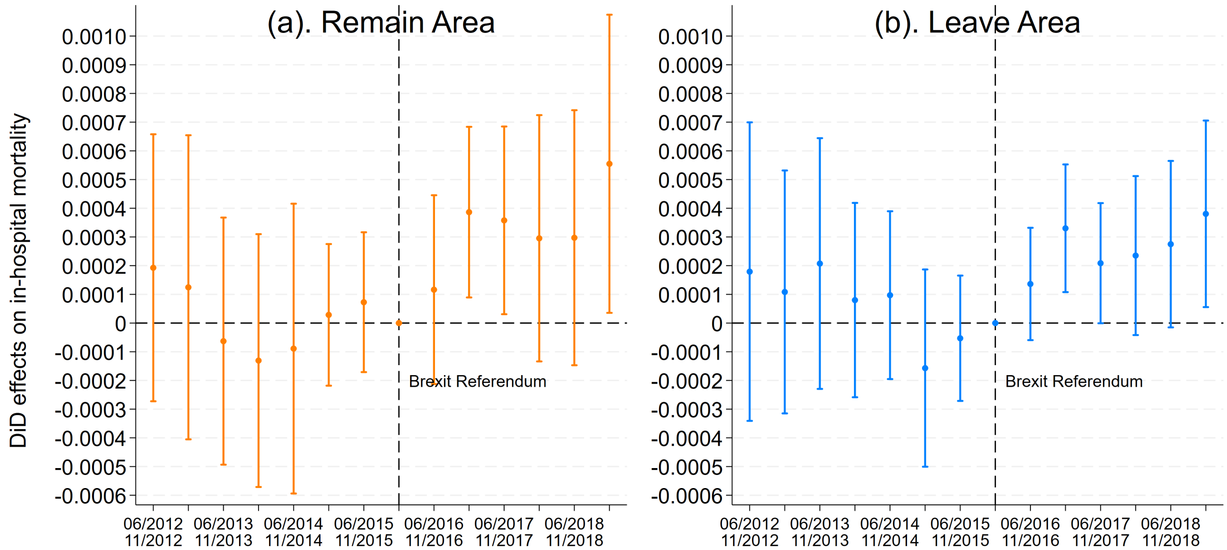
Notes. This figure gives the estimated difference-in-difference effects of the Brexit referendum on patient-level health outcomes by diagnosis by estimating Equation 3 with the continuous exposure. Robust standard errors clustered at hospital organization level; bands: 95% confidence intervals.

Figure A.10. DiD effects on in-hospital mortality (all patients), by ICD-10 diagnosis group



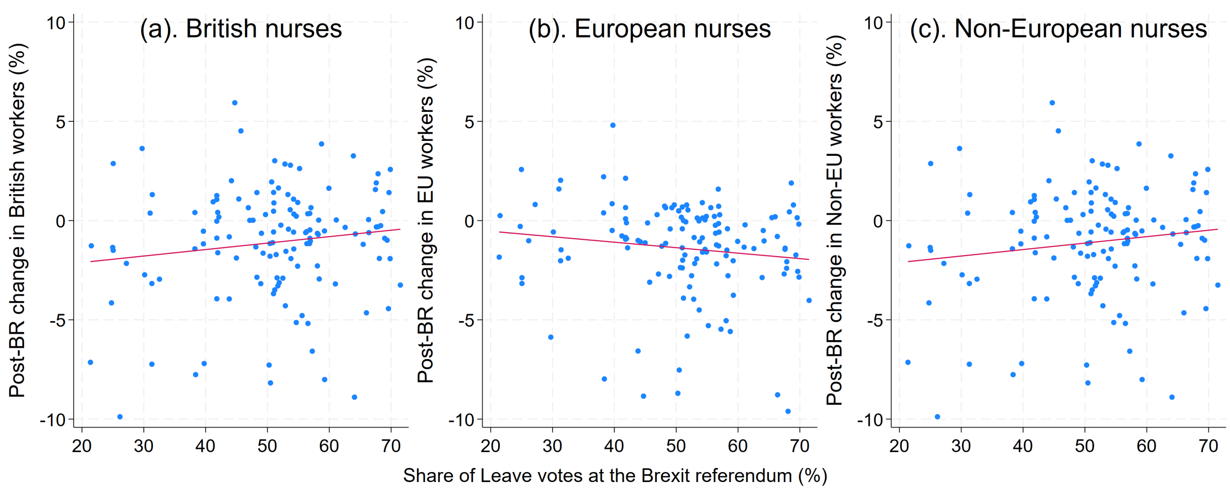
Notes. This figure gives the dynamic treatment effects of the Brexit referendum on patient-level health outcomes by diagnosis by estimating Equation 3 with the continuous exposure. Robust standard errors clustered at hospital organization level; bands: 95% confidence intervals.

Figure A.11. Heterogeneous DiD effects on in-hospital mortality, by prevalence of Brexit vote



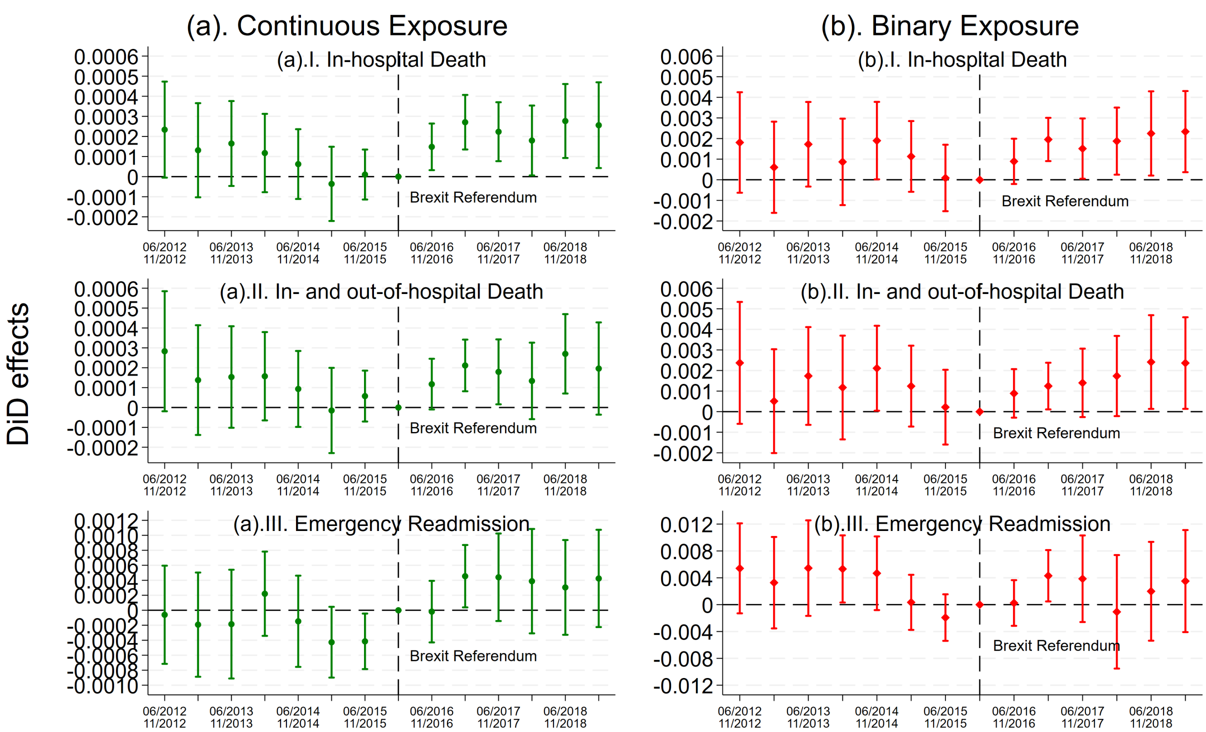
Notes. N = 32,445,509 hospital emergency admissions. $N_{clusters}$: 131 hospital organizations. This figure gives the dynamic treatment effects of the Brexit referendum on patient-level health outcomes by estimating the triple-difference version of Equation 3 with the continuous exposure interacted with a dummy whether the provider is located in a 'Remain' or 'Leave' area. Hospital Organisations are allocated into the 'Remain' or 'Leave' groups based on whether the share of votes in support of leaving the EU in the June 2016 referendum in the postcode area of the hospital headquarter was respectively lower or higher than 50%. Robust standard errors clustered at hospital organization level; bands: 95% confidence intervals.

Figure A.12. Share of Brexit 'Leave' votes and changes in the nurse workforce composition



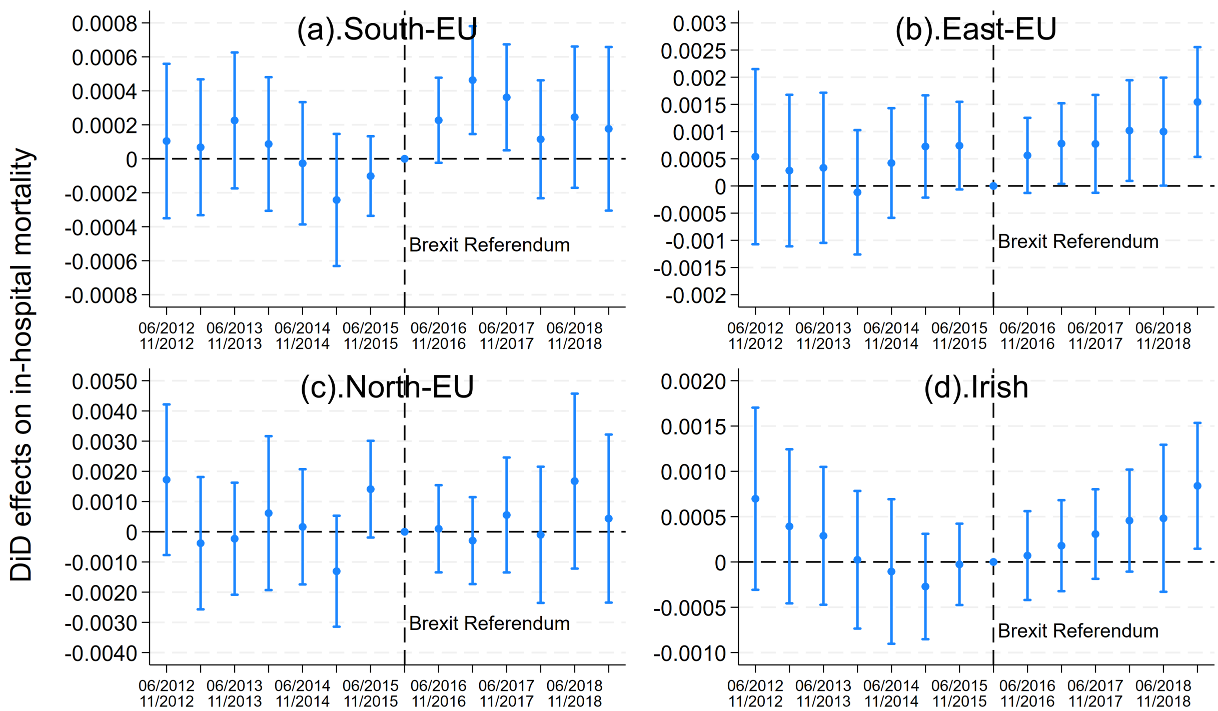
Notes. This figures correlates the hospital provider-level post-referendum changes in the share of British, European, and non-European nurses with the local share of 'Leave' votes in the Brexit referendum.

Figure A.13. Dynamic DiD effects on hospital care outcomes (emergency patients), treatment exposure based on period 06/2015-05/2016



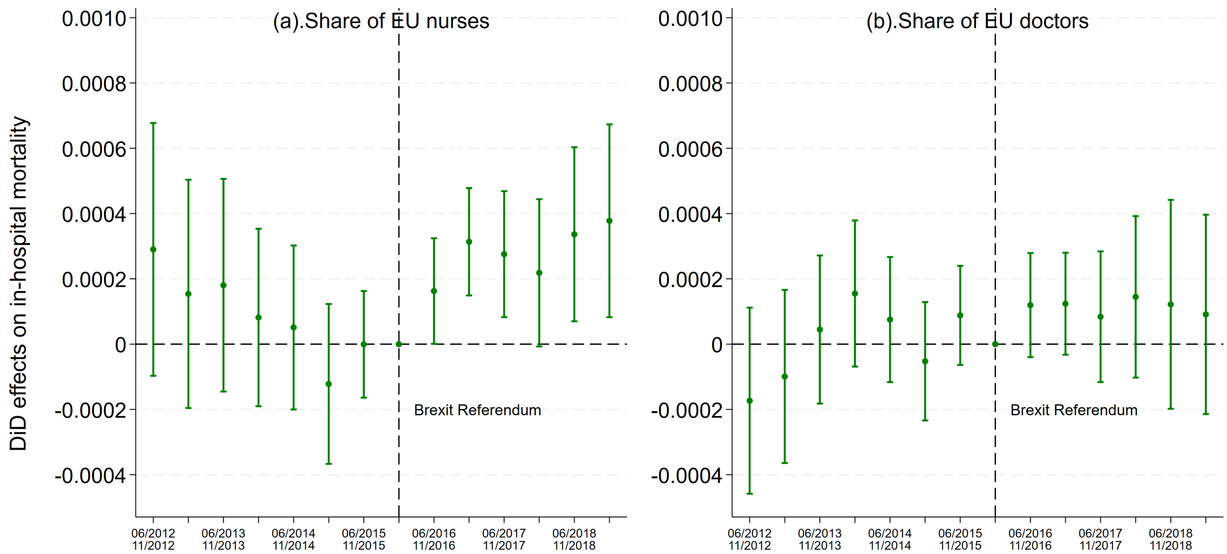
Notes. N = 32,445,509 hospital emergency admissions. $N_{clusters}$: 131 hospital organizations. This figure gives the dynamic treatment effects of the Brexit referendum on patient-level health outcomes by diagnosis by estimating Equation 3 with the continuous exposure. However, the continuous exposure is calculated based on the pre-policy year only in this figure. Robust standard errors clustered at hospital organization level; bands: 95% confidence intervals.

Figure A.14. DiD effects on in-hospital mortality (emergency patients), by pre-referendum exposure variable measured by EU nurse nationality subgroups



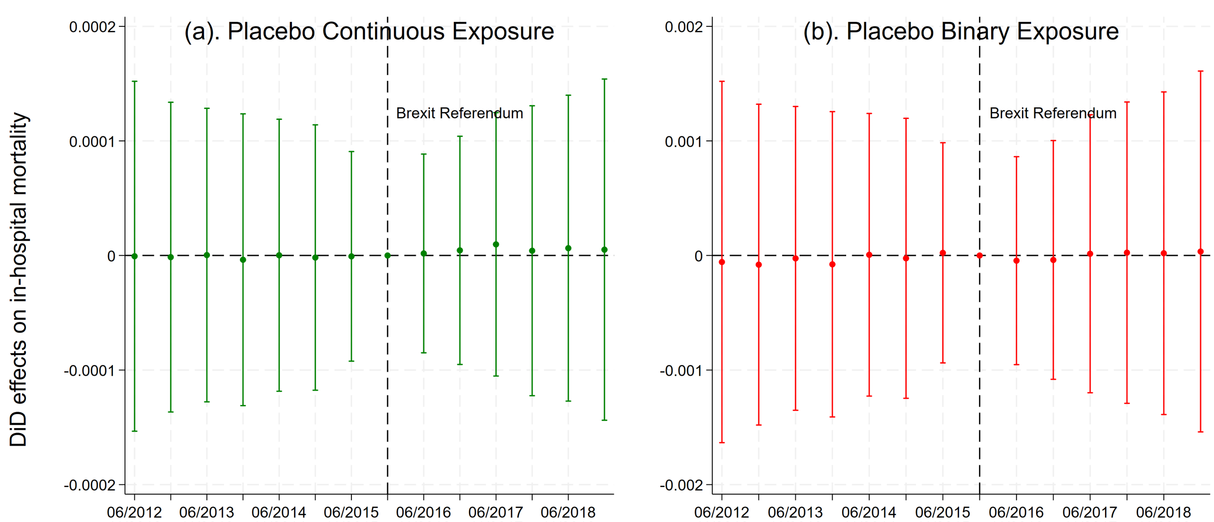
Notes. N = 32,445,509 hospital emergency admissions. $N_{clusters}$: 131 hospital organizations. This figure gives the dynamic treatment effects of the Brexit referendum on patient-level health outcomes by diagnosis by estimating Equation 3 with the continuous exposure. However, each panel refers to a different model where the continuous treatment exposure is calculated for the EU nationality subgroup specified in the panel header. Robust standard errors clustered at hospital organization level; bands: 95% confidence intervals.

Figure A.15. DiD effects on in-hospital mortality (emergency patients), controlling for the share of EU senior doctors



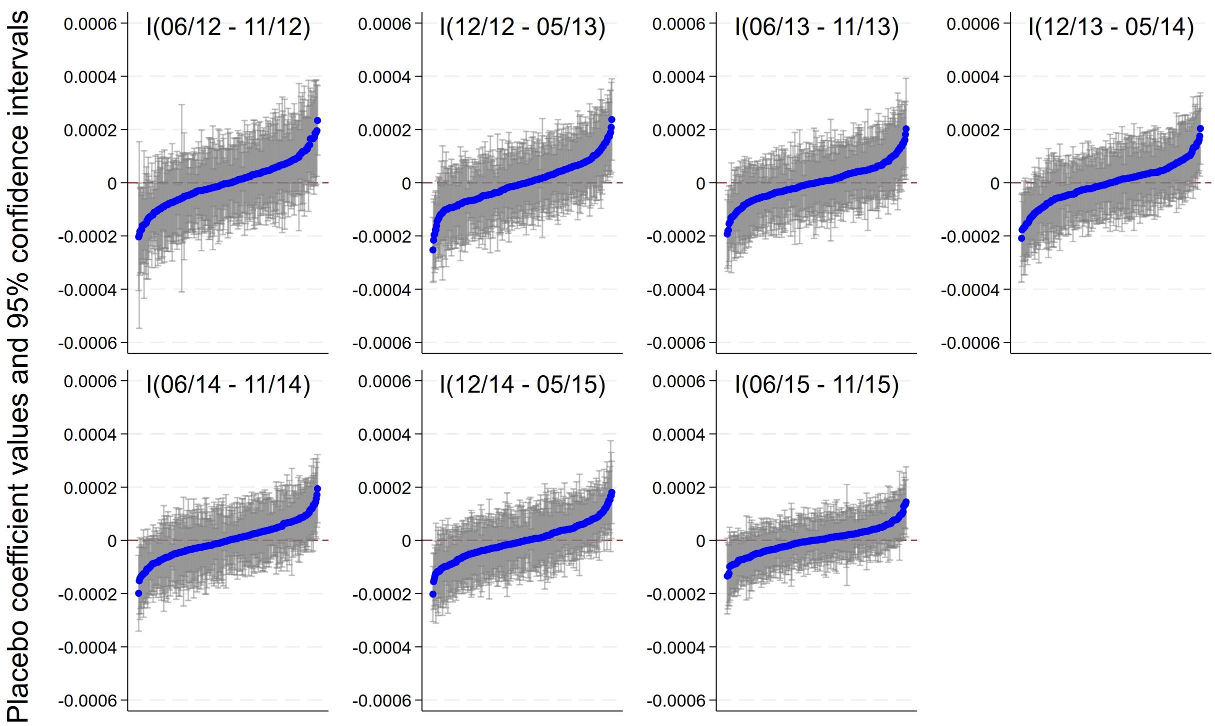
Notes. N = 32,445,509 hospital emergency admissions. $N_{clusters}$: 131 hospital organizations. This figure gives the dynamic treatment effects of the Brexit referendum on patient-level health outcomes by diagnosis by estimating Equation 3 with the continuous exposure. However, the continuous exposure is once calculated for nurses and once for doctors and both interactions are jointly estimated in the same regressions. Robust standard errors clustered at hospital organization level; bands: 95% confidence intervals.

Figure A.16. DiD effects on in-hospital mortality (emergency patients), falsification tests based on randomized inference



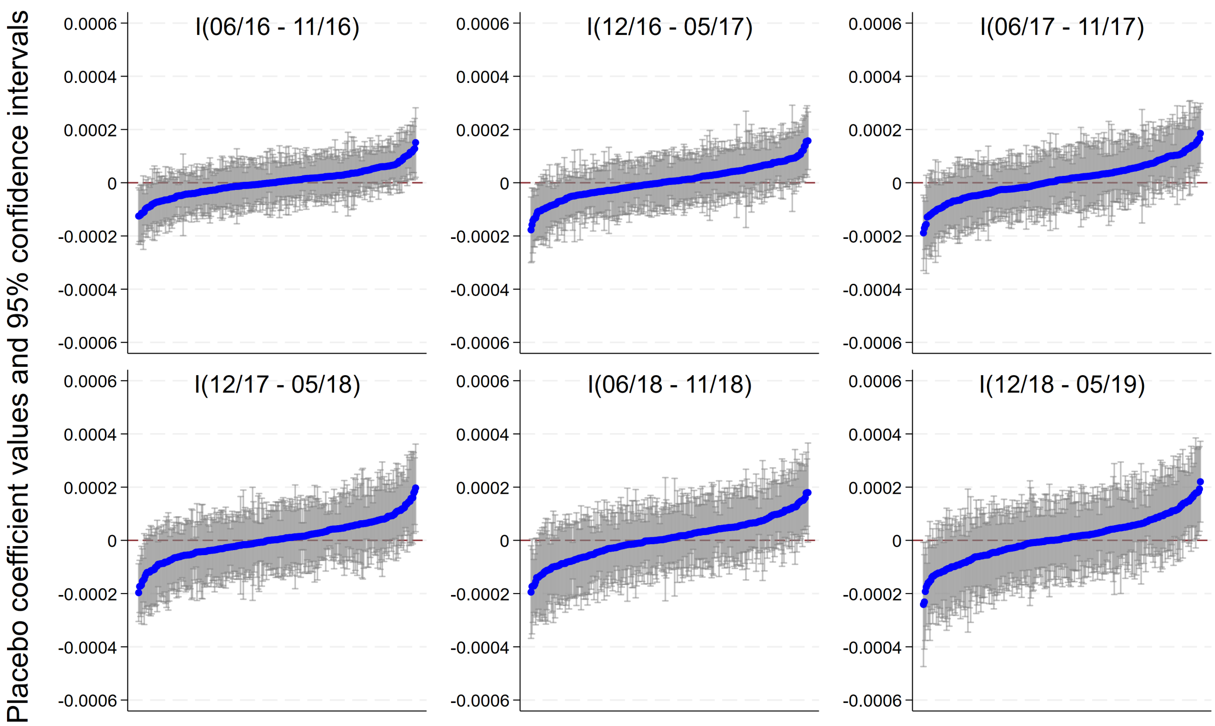
Notes. This figure gives the dynamic treatment effects of the Brexit referendum on patient-level health outcomes by estimating Equation 3 with a continuous log-normally distributed placebo exposure (*panel a*) or a binary placebo exposure allocating hospital organisations into the top quartile of the exposure distribution at random (*panel b*).

Figure A.17. Pre-treatment DiD effects on in-hospital mortality (emergency patients), falsification tests based on randomized inference



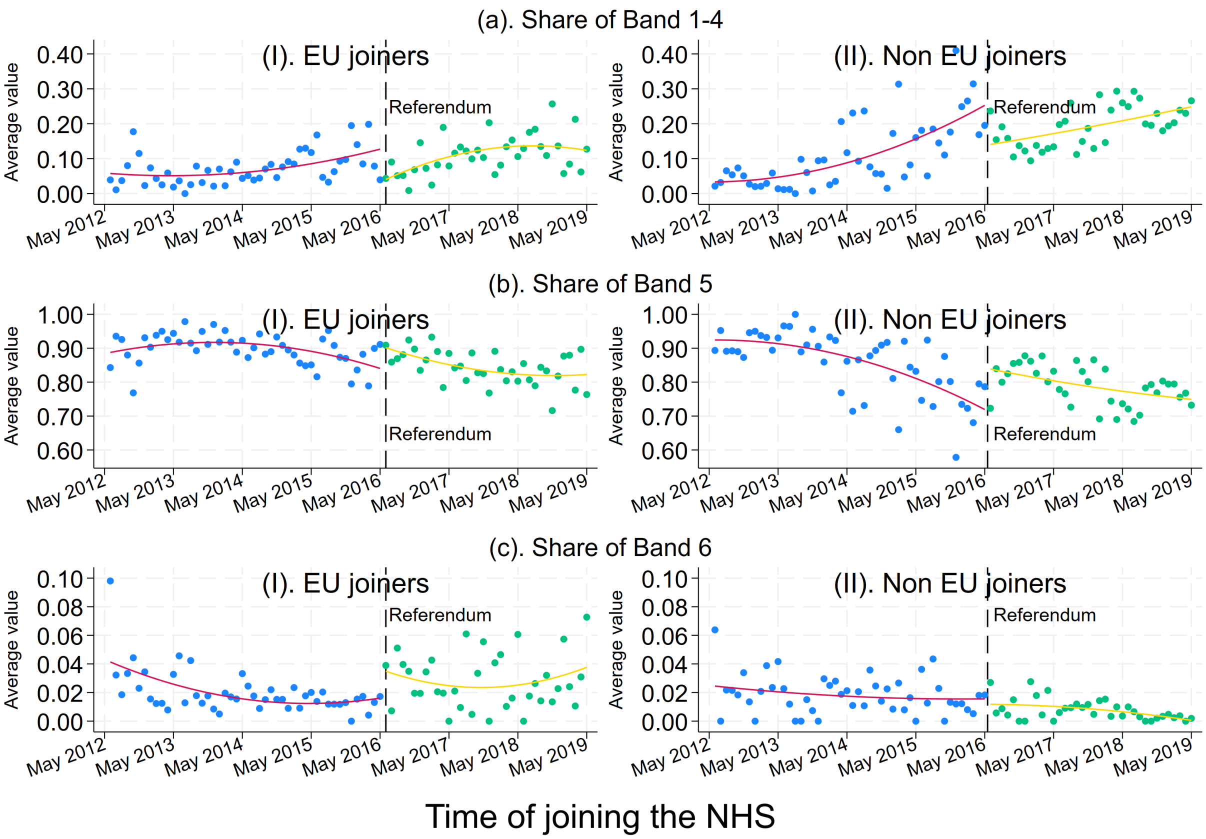
Notes. This figure gives the dynamic pre-referendum effects of the Brexit referendum on emergency patients' in-hospital mortality by estimating Equation 3 with a continuous log-normally distributed placebo exposure variable (pre-referendum share of EU nurses employed at each hospital organization in the sample).

Figure A.18. Post-treatment DiD effects on in-hospital mortality (emergency patients), falsification tests based on randomized inference



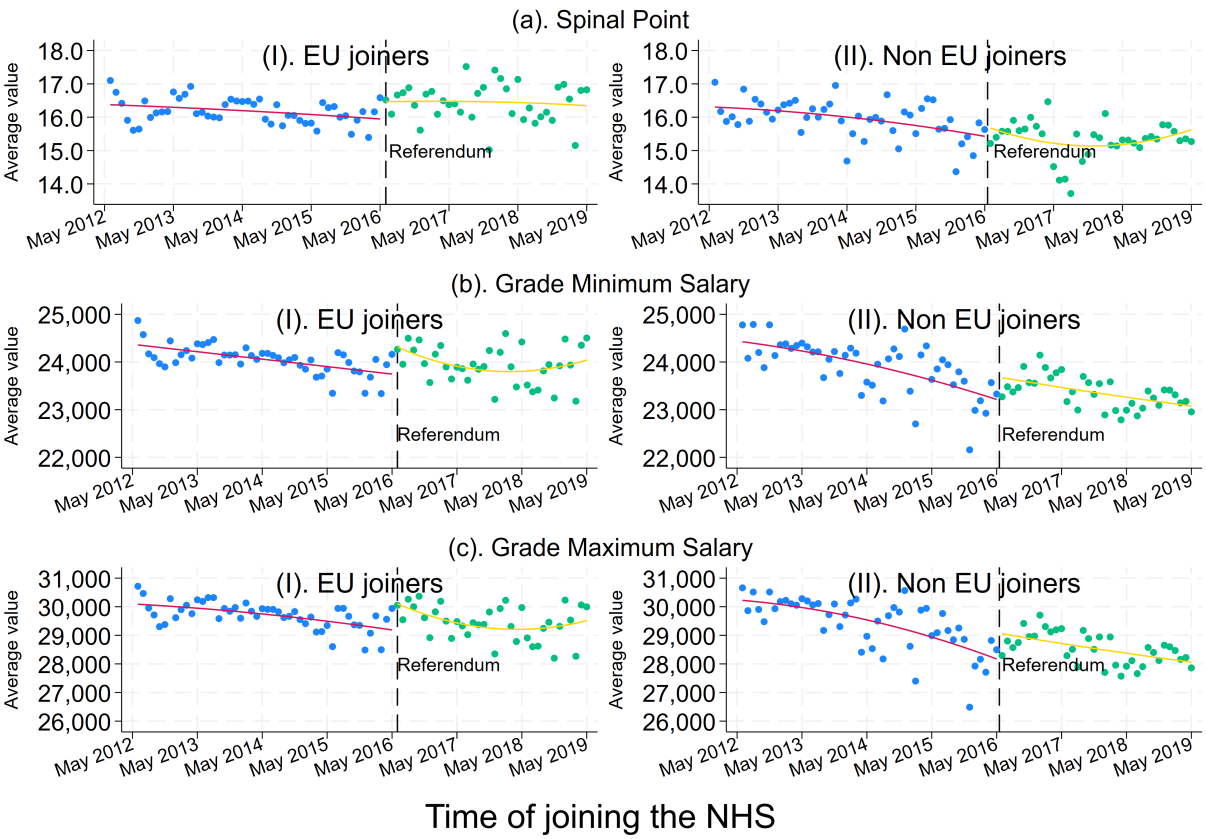
Notes. This figure gives the dynamic post-referendum effects of the Brexit referendum on emergency patients' in-hospital mortality by estimating Equation 3 with a continuous log-normally distributed placebo exposure variable (pre-referendum share of EU nurses employed at each hospital organization in the sample).

Figure A.19. Share of new NHS joiners by nationality subgroup and pay banding



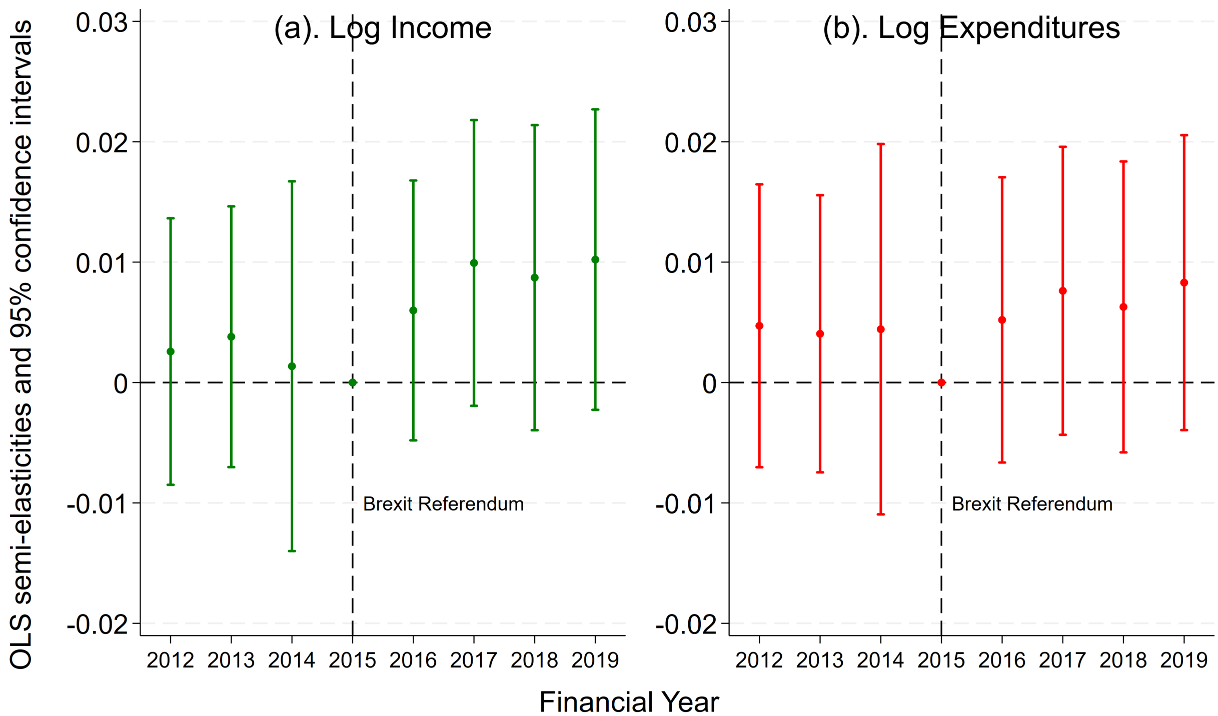
Notes. This figure gives the share of new NHS joining nurses by nationality group (EU and non-EU nurses) and by wage band over time.

Figure A.20. Share of new NHS joiners by nationality subgroup and salary grade



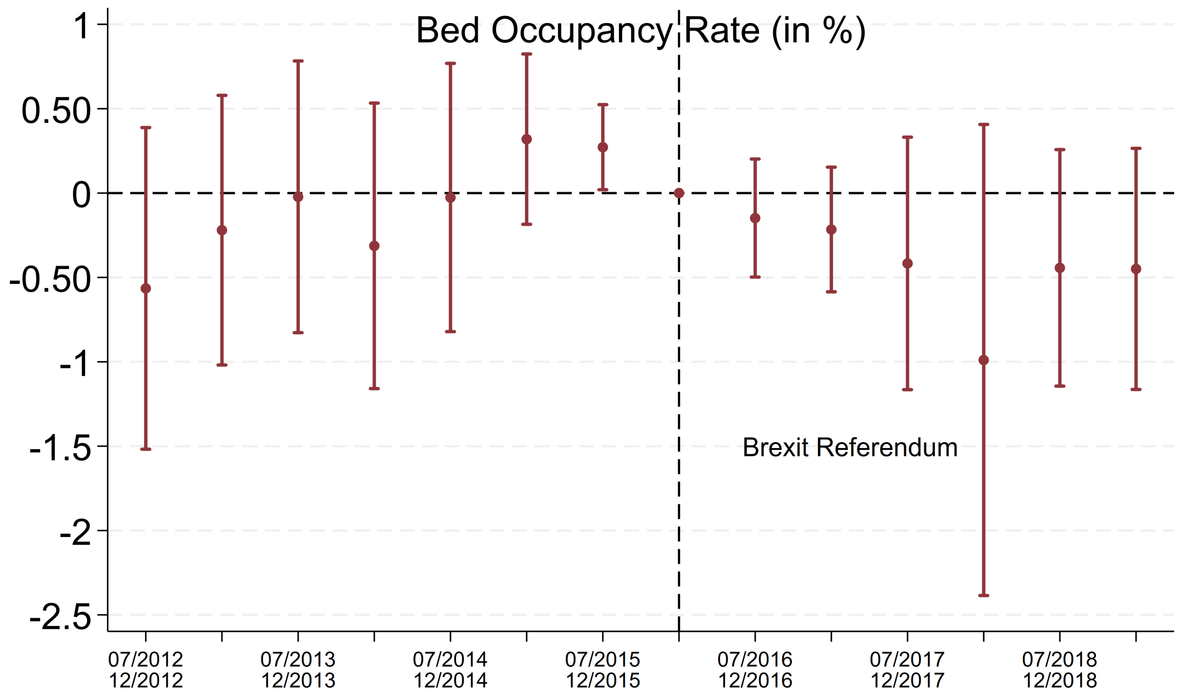
Notes. This figure gives the share of new NHS joining nurses by nationality group (EU and non-EU nurses) and by salary grade over time.

Figure A.21. Dynamic DiD effects on hospital financial positions



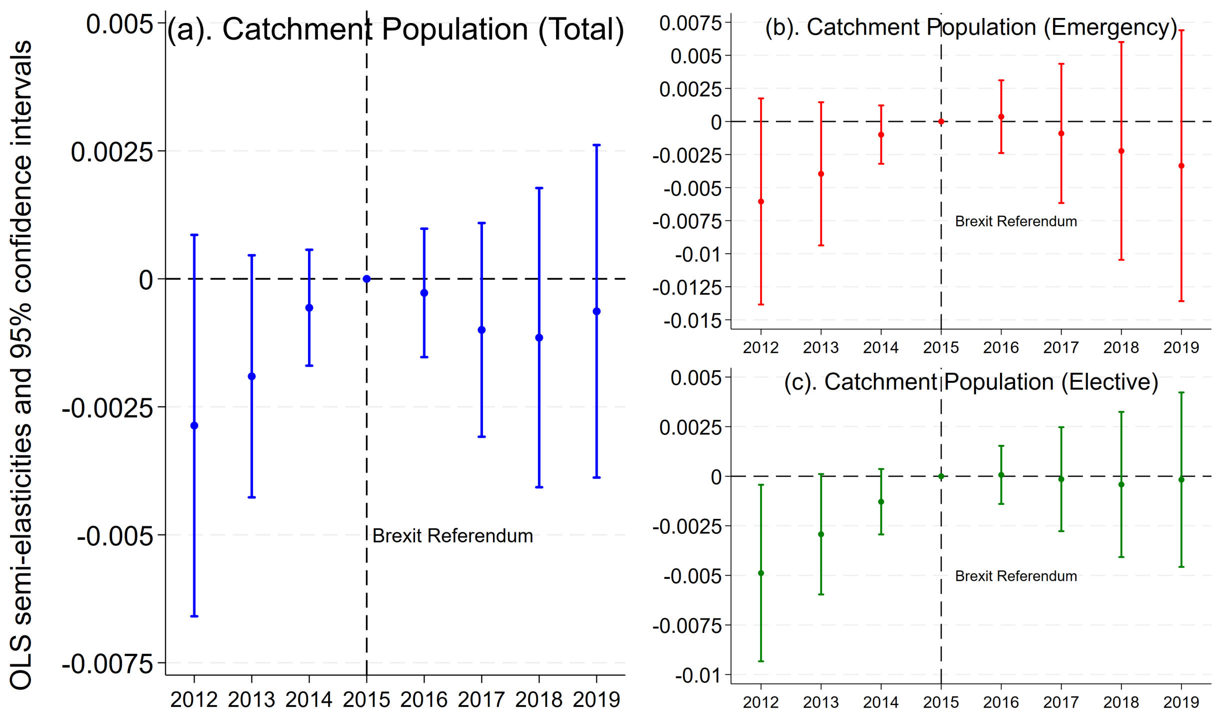
Notes. $N = 803$ observations. $N_{clusters}$: 131 hospital organizations. This figure gives the dynamic treatment effects of the Brexit referendum on provider-level financials by estimating Equation 3 with the continuous exposure at the hospital provider level. Robust standard errors clustered at hospital organization level; bands: 95% confidence intervals.

Figure A.22. Dynamic DiD effects on hospital bed occupancy rates



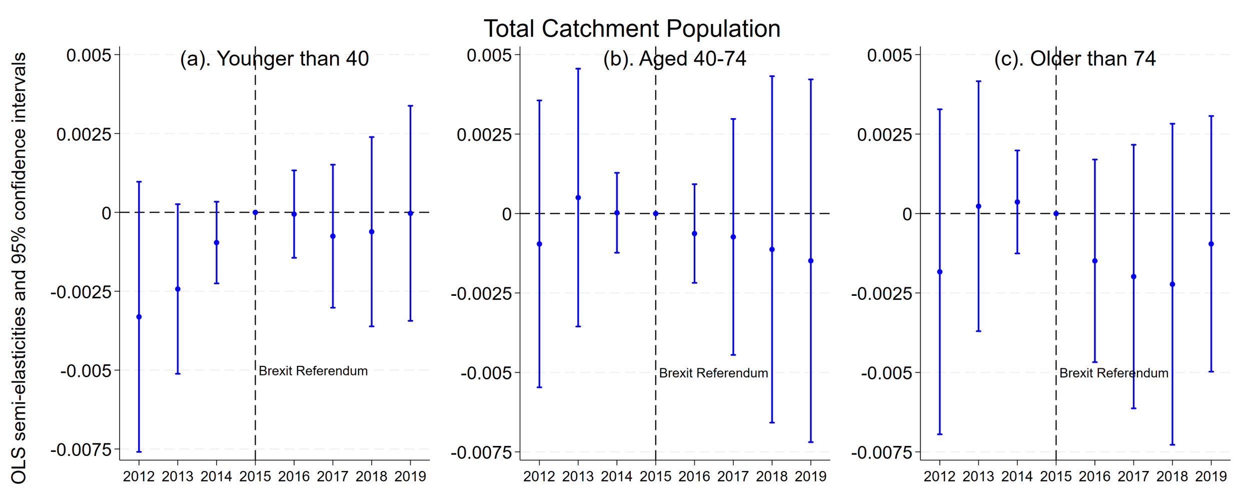
Notes. This figure gives the dynamic treatment effects of the Brexit referendum on provider-level occupancy rates by estimating Equation 3 with the continuous exposure at the hospital provider level. Sample size: 3,569 hospital organization × quarter-year observations. $N_{clusters}$: 130 hospital organizations. Robust standard errors clustered at hospital organization level; bands: 95% confidence intervals. Joint Wald test $H_0 : \beta_{t_{-1}} = \beta_{t_{-2}} = ... = \beta_{t_{-k}} = 0$, $\{t_{-1}, t_{-2}, ..., t_{-k}\}$ < June 2016 (pre-referendum effects = 0): 2.71 (F-stat); 0.012 (p-value). Joint Wald test $H_0 : \beta_{t_1} = \beta_{t_2} = ... = \beta_{t_k} = 0$, $\{t_1, t_2, ..., t_k\} \geqslant$ June 2016 (post-referendum effects = 0): 1.21 (F-stat); 0.306 (p-value).

Figure A.23. Dynamic DiD effects on patients' catchment population



Notes. N = 1,000 observations. $N_{clusters}$ = 125 hospital organizations. This figure gives the dynamic treatment effects of the Brexit referendum on the provider-level catchment area (total, emergency, and elective) by estimating Equation 3 with the continuous exposure at the hospital provider level. Robust standard errors clustered at hospital organization level; bands: 95% confidence intervals.

Figure A.24. Dynamic DiD effects on patients' catchment population by age group



Notes. This figure gives the dynamic treatment effects of the Brexit referendum on the provider-level catchment area (by age group) by estimating Equation 3 with the continuous exposure at the hospital provider level. Robust standard errors clustered at hospital organization level; bands: 95% confidence intervals.

Table A.1. Summary Statistics

	Pre-Brexit Referendum period		Post-Brexit Referendum period	
	Mean	Standard Deviation	Mean	Standard Deviation
Panel A: Patient health outcomes and covariates				
30-day in-hospital deaths per 100 admissions	3.26	(17.75)	3.04	(17.16)
30-day in- & out-of-hospital deaths per 100 admissions	4.23	(20.13)	4.05	(19.72)
30-day unplanned emergency readmissions per 100 admissions	15.20	(35.90)	16.08	(36.73)
Share of Female patients	0.52	(0.50)	0.53	(0.50)
Share of Income Deprivation Q1 (least deprived)	0.16	(0.36)	0.16	(0.37)
Share of Income Deprivation Q2	0.18	(0.39)	0.18	(0.39)
Share of Income Deprivation Q3	0.20	(0.40)	0.20	(0.40)
Share of Income Deprivation Q4	0.22	(0.41)	0.22	(0.41)
Share of Income Deprivation Q5 (most deprived)	0.24	(0.43)	0.24	(0.42)
Charlson comorbidities index (weighted)	5.07	(8.19)	5.76	(8.93)
Share of patients aged 0-18	0.15	(0.36)	0.15	(0.35)
Share of patients aged 18-29	0.10	(0.30)	0.09	(0.29)
Share of patients aged 30-39	0.08	(0.27)	0.08	(0.27)
Share of patients aged 40-49	0.09	(0.28)	0.08	(0.27)
Share of patients aged 50-59	0.10	(0.30)	0.10	(0.30)
Share of patients aged 60-69	0.12	(0.32)	0.11	(0.32)
Share of patients aged 70-79	0.15	(0.35)	0.15	(0.36)
Share of patients aged over 80	0.22	(0.42)	0.23	(0.42)
Share of Region: North West	0.15	(0.36)	0.15	(0.36)
Share of Region: North East	0.19	(0.39)	0.18	(0.39)
Share of Region: Midlands	0.16	(0.37)	0.16	(0.37)
Share of Region: East of England	0.10	(0.30)	0.10	(0.30)
Share of Region: South West	0.11	(0.31)	0.11	(0.32)
Share of Region: South East	0.16	(0.36)	0.17	(0.37)
Share of Region: London	0.13	(0.33)	0.13	(0.33)
Emergency Patients	9,471,534		8,287,621	
Emergency Admissions	17,610,090		14,835,419	
Panel B: Composition of hospital organization clinical workforce (monthly figures)				
Number of Employed Nurses	1,660.81	(939.77)	1,751.45	(1010.70)
Number of EU Employed Nurses	98.02	(116.58)	146.54	(166.17)
Number of Non-EU Employed Nurses	221.09	(248.54)	246.36	(278.90)
Number of Joiner Nurses	10.23	(11.91)	8.88	(11.51)
Number of EU Joiner Nurses	2.95	(6.04)	1.26	(2.36)
Number of non-EU Joiner Nurses	1.16	(2.74)	2.47	(4.80)
Number of Employed Senior Doctors	316.20	(186.86)	358.71	(211.21)
Number of EU Employed Senior Doctors	27.04	(19.34)	35.76	(27.25)
Number of non-EU Employed Senior Doctors	70.39	(46.82)	87.52	(54.26)
Number of Joiner Senior Doctors	1.72	(5.43)	1.50	(3.93)
Number of EU Joiner Senior Doctors	0.79	(1.17)	0.51	(1.06)
Number of non-EU Joiner Senior Doctors	0.73	(1.16)	1.13	(1.35)
Hospital-months records	6,288		6,288	
Number of hospital organizations	131		131	

Notes. Panel A reports the descriptive statistics on patient-level health outcomes and covariates for all emergency patients admitted to the 131 NHS hospital organizations in the sample. *Panel B* reports monthly workforce composition figures at hospital organization level. Pre-Brexit referendum period: June 2012 to May 2016; post-Brexit referendum period: June 2016 to May 2019.

Table A.2. Summary Statistics (all patients)

	Pre-Brexit Referendum period		Post-Brexit Referendum period	
	Mean	Standard Deviation	Mean	Standard Deviation
30-day in-hospital deaths per 100 admissions	1.21	(10.91)	1.15	(10.68)
30-day in- & out-of-hospital deaths per 100 admissions	1.62	(12.63)	1.59	(12.51)
30-day unplanned emergency readmissions per 100 admissions	7.80	(26.82)	8.38	(27.71)
Share of Female patients	0.55	(0.50)	0.55	(0.50)
Income Deprivation Q1 (least deprived)	0.18	(0.38)	0.18	(0.39)
Share of Income Deprivation Q2	0.19	(0.40)	0.20	(0.40)
Share of Income Deprivation Q3	0.20	(0.40)	0.20	(0.40)
Share of Income Deprivation Q4	0.21	(0.41)	0.21	(0.40)
Share of Income Deprivation Q5 (most deprived)	0.22	(0.41)	0.21	(0.41)
Charlson comorbidities Index (weighted)	3.26	(6.42)	3.88	(7.13)
Share of patients aged 0-18	0.10	(0.30)	0.10	(0.30)
Share of patients aged 18-29	0.10	(0.30)	0.09	(0.29)
Share of patients aged 30-39	0.10	(0.30)	0.10	(0.30)
Share of patients aged 40-49	0.10	(0.30)	0.09	(0.29)
Share of patients aged 50-59	0.13	(0.33)	0.13	(0.34)
Share of patients aged 60-69	0.16	(0.37)	0.15	(0.36)
Share of patients aged 70-79	0.17	(0.37)	0.18	(0.38)
Share of patients aged over 80	0.15	(0.35)	0.15	(0.36)
Share of Region: North West	0.15	(0.35)	0.14	(0.35)
Share of Region: North East	0.18	(0.38)	0.17	(0.38)
Share of Region: Midlands	0.15	(0.36)	0.15	(0.36)
Share of Region: East of England	0.10	(0.30)	0.10	(0.30)
Share of Region: South West	0.12	(0.32)	0.12	(0.32)
Share of Region: South East	0.15	(0.36)	0.16	(0.36)
Share of Region: London	0.15	(0.36)	0.15	(0.36)
Emergency and Non-Emergency Patients	18,124,652		15,723,616	
Emergency and Non-Emergency Admissions	49,352,148		40,376,204	

Notes. Descriptive statistics on patient-level health outcomes and covariates for all emergency and elective patients admitted to the 131 NHS hospital organizations in the sample. Pre-Brexit referendum period: June 2012 to May 2016; post-Brexit referendum period: June 2016 to May 2019.

Table A.3. Exposure to Brexit referendum shock and hospital patients' composition

	Emergency Patients				All Patients			
	Male	Age	Charlson Index	Income Depr. Index	Male	Age	Charlson Index	Income Depr. Index
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: Continuous Exposure								
I(06/2016 - 05/2019) * Pre-BR share of EU nurses	-0.00004	-0.00461	-0.04224**	0.00009	0.00025	-0.01583	-0.03576***	0.00008
	(0.00030)	(0.05813)	(0.02038)	(0.00006)	(0.00034)	(0.03227)	(0.01291)	(0.00006)
Panel B: Binary Exposure								
I(06/2016 - 05/2019) * Pre-BR share of EU nurses	-0.00008	0.33757	-0.11230	0.00046	0.00171	0.08976	-0.16989	0.00065
	(0.00201)	(0.37725)	(0.17151)	(0.00086)	(0.00229)	(0.24016)	(0.11114)	(0.00074)
Observations (Hospital Admissions)	33,115,230	33,115,230	33,115,230	32,665,571	97,291,055	97,291,055	97,291,055	95,335,630

Notes. This table presents the results of the difference-in-differences effects following Equation 3 with the continuous and binary exposure on different patient characteristics such as gender, age, severity, and deprivation for emergency only and all patients. Robust standard errors clustered at hospital organization level. $N_{clusters}$: 131 acute care NHS hospital organizations. Significance levels: *p<0.1; **p<0.05; ***p<0.01.

Table A.4. Exposure to Brexit referendum shock and changes in hospital staff employment

	Δ Total Employment		Δ Total Joiners		Δ Total Leavers	
	(1)	(2)	(3)	(4)	(5)	(6)
Pre-BR share of EU nurses	0.0102	0.0007	0.0459	-0.8384	0.3582	1.0889
	(0.1758)	(0.3101)	(0.3347)	(0.6484)	(0.3938)	(0.8430)
Observations (Hospital Organizations)			131			
NHS region FE	No	Yes	No	Yes	No	Yes

Notes. This table presents the results of the correlation of provider-level changes in total employment, total joiners, and total leavers with the continuous exposure share. The change in the total number of employees is computed between May 2019 and May 2016. The changes in the total number of joiners and leavers are computed as the changes in the cumulative number of joiners and leavers over the pre- and post-referendum periods. Robust standard errors are reported in parenthesis. Significance levels: *p<0.1; **p<0.05; ***p<0.01.

Table A.5. Exposure to Brexit referendum shock and changes in foreign nurses' employment shares

	Δ South-EU		Δ East EU		Δ North EU		Δ Irish	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: EU nurses								
Pre-BR share of EU nurses	-0.1646***	-0.2842***	0.0000	-0.0284	0.0033	-0.0022	-0.0515***	-0.0537*
	(0.0503)	(0.1061)	(0.0093)	(0.0211)	(0.0066)	(0.0128)	(0.0133)	(0.0274)
	Δ African		Δ Asian		Δ Other Non EU			
Panel B: Non-EU nurses								
Pre-BR share of EU nurses	-0.0144	0.0203	0.3428***	0.3338**	0.0096	0.0132		
	(0.0188)	(0.0356)	(0.0752)	(0.1348)	(0.0074)	(0.0162)		
Observations (Hospital Organizations)				131				
NHS region FE	No	Yes	No	Yes	No	Yes	No	Yes

Notes. This table presents the results of the correlation of provider-level changes in nurse employment by nationality group with the continuous exposure share. The changes in employment shares are computed between May 2019 and May 2016, namely the two endpoints of our post- and pre-BR analysis periods. Robust standard errors are reported in parenthesis. Significance levels: *p<0.1; **p<0.05; ***p<0.01.

Table A.6. Exposure to Brexit referendum shock and changes in foreign *joiner* nurses' employment shares

	Δ South-EU		Δ East EU		Δ North EU		Δ Irish	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: EU joining nurses								
Pre-BR share of EU nurses	-0.9977***	-1.6640***	0.0725	0.0460	0.0138	0.0224	-0.1474***	-0.2429**
	(0.2270)	(0.4634)	(0.0610)	(0.1502)	(0.0225)	(0.0458)	(0.0547)	(0.1159)
	Δ African		Δ Asian		Δ Other Non EU			
Panel B: Non-EU joining nurses								
Pre-BR share of EU nurses	0.0528	0.1546	1.0770***	0.9298*	0.0941**	0.1233		
	(0.0589)	(0.1288)	(0.2528)	(0.5002)	(0.0393)	(0.0890)		
Observations (Hospital Organizations)				131				
NHS region FE	No	Yes	No	Yes	No	Yes	No	Yes

Notes. This table presents the results of the correlation of provider-level changes in joining nurses by EU nationality group with the continuous exposure share. The changes in the number of joiners by nationality group are computed as the changes in the cumulative number of joiners by nationality over the pre- and post-referendum periods. Robust standard errors are reported in parenthesis. Significance levels: *p<0.1; **p<0.05; ***p<0.01.

Table A.7. Dynamic DiD estimates of the effects of nurse workforce exposure to Brexit on hospital care quality, emergency patients only

	Continuous Treatment			Binary Treatment		
	In-hospital death	In-and out-of-hospital death	Emergency Readmission	In-hospital death	In-and out-of-hospital death	Emergency Readmission
	(1)	(2)	(3)	(4)	(5)	(6)
I(06/2012 - 11/2012) * Pre-BR share of EU nurses	0.00027	0.00033	0.00006	0.00075	0.00157	0.00302
	(0.00020)	(0.00024)	(0.00054)	(0.00144)	(0.00173)	(0.00365)
I(12/2012 - 05/2013) * Pre-BR share of EU nurses	0.00014	0.00013	0.00005	-0.00032	-0.00006	0.00356
	(0.00018)	(0.00020)	(0.00054)	(0.00127)	(0.00146)	(0.00382)
I(06/2013 - 11/2013) * Pre-BR share of EU nurses	0.00019	0.00014	-0.00002	0.00072	0.00061	0.00226
	(0.00016)	(0.00020)	(0.00056)	(0.00122)	(0.00142)	(0.00387)
I(12/2013 - 05/2014) * Pre-BR share of EU nurses	0.00010	0.00014	0.00050	-0.00010	0.00032	0.00216
	(0.00014)	(0.00016)	(0.00046)	(0.00103)	(0.00115)	(0.00278)
I(06/2014 - 11/2014) * Pre-BR share of EU nurses	0.00006	0.00010	0.00003	0.00037	0.00078	0.00114
	(0.00013)	(0.00014)	(0.00045)	(0.00093)	(0.00101)	(0.00306)
I(12/2014 - 05/2015) * Pre-BR share of EU nurses	-0.00013	-0.00009	-0.00029	-0.00061	-0.00033	0.00003
	(0.00013)	(0.00015)	(0.00033)	(0.00094)	(0.00110)	(0.00234)
I(06/2015 - 11/2015) * Pre-BR share of EU nurses	0.00001	0.00011	-0.00040	-0.00028	0.00036	-0.00212
	(0.00008)	(0.00008)	(0.00027)	(0.00062)	(0.00066)	(0.00195)
I(06/2016 - 11/2016) * Pre-BR share of EU nurses	0.00018**	0.00014	-0.00002	0.00057	0.00074	0.00159
	(0.00008)	(0.00009)	(0.00030)	(0.00062)	(0.00067)	(0.00205)
I(12/2016 - 05/2017) * Pre-BR share of EU nurses	0.00033***	0.00023**	0.00064**	0.00121*	0.00101	0.00584***
	(0.00009)	(0.00009)	(0.00029)	(0.00066)	(0.00068)	(0.00215)
I(06/2017 - 11/2017) * Pre-BR share of EU nurses	0.00029***	0.00023**	0.00074*	0.00122	0.00163*	0.00332
	(0.00010)	(0.00011)	(0.00044)	(0.00075)	(0.00085)	(0.00379)
I(12/2017 - 05/2018) * Pre-BR share of EU nurses	0.00024**	0.00021	0.00076	0.00151*	0.00174*	0.00275
	(0.00011)	(0.00013)	(0.00050)	(0.00083)	(0.00102)	(0.00387)
I(06/2018 - 11/2018) * Pre-BR share of EU nurses	0.00035***	0.00035**	0.00060	0.00187*	0.00224**	0.00178
	(0.00013)	(0.00014)	(0.00046)	(0.00103)	(0.00113)	(0.00394)
I(12/2018 - 05/2019) * Pre-BR share of EU nurses	0.00039***	0.00035**	0.00084*	0.00246**	0.00263**	0.00217
	(0.00015)	(0.00016)	(0.00044)	(0.00111)	(0.00121)	(0.00421)
H_0: Pre-referendum coefficients = 0						
F-stat	1.123	1.350	1.991	0.88402	0.99710	1.08546
P-value	0.353	0.232	0.061	0.52113	0.43639	0.37633
H_0: Post-referendum coefficients = 0						
F-stat	2.823	2.002	2.659	0.980	0.979	3.020
P-value	0.013	0.070	0.018	0.441	0.442	0.008
Observations (emergency hospital admissions)	32,445,509					

Notes. This table gives the pooled and dynamic regression results of Equation 3 for all interactions with the continuous exposure variable. Robust standard errors clustered at hospital organization level. $N_{clusters}$: 131 acute care NHS hospital organizations. Significance levels: *p<0.1; **p<0.05; ***p<0.01.

Table A.8. Dynamic DiD estimates of the effects of nurse workforce exposure to Brexit on hospital care quality, all patients

	Continuous Treatment			Binary Treatment		
	In-hospital death	In- and out-of-hospital death	Emergency Readmission	In-hospital death	In- and out-of-hospital death	Emergency Readmission
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Event-study						
I(06/2012 - 11/2012) * Pre-BR share of EU nurses	0.00013*	0.00017**	-0.00004	0.00054	0.00096	0.00069
	(0.00007)	(0.00008)	(0.00025)	(0.00053)	(0.00064)	(0.00181)
I(12/2012 - 05/2013) * Pre-BR share of EU nurses	0.00004	0.00004	-0.00005	-0.00000	0.00012	0.00161
	(0.00006)	(0.00007)	(0.00023)	(0.00046)	(0.00054)	(0.00168)
I(06/2013 - 11/2013) * Pre-BR share of EU nurses	0.00007	0.00006	-0.00003	0.00047	0.00047	0.00122
	(0.00006)	(0.00007)	(0.00023)	(0.00043)	(0.00049)	(0.00178)
I(12/2013 - 05/2014) * Pre-BR share of EU nurses	0.00001	0.00001	0.00013	-0.00020	0.00002	0.00145
	(0.00005)	(0.00006)	(0.00021)	(0.00037)	(0.00041)	(0.00150)
I(06/2014 - 11/2014) * Pre-BR share of EU nurses	0.00003	0.00004	-0.00002	0.00019	0.00023	0.00051
	(0.00005)	(0.00006)	(0.00017)	(0.00040)	(0.00043)	(0.00130)
I(12/2014 - 05/2015) * Pre-BR share of EU nurses	-0.00004	-0.00004	-0.00013	-0.00023	-0.00020	-0.00002
	(0.00004)	(0.00005)	(0.00012)	(0.00034)	(0.00041)	(0.00097)
I(06/2015 - 11/2015) * Pre-BR share of EU nurses	0.00002	0.00006**	-0.00014	-0.00000	0.00024	-0.00037
	(0.00003)	(0.00003)	(0.00012)	(0.00023)	(0.00023)	(0.00088)
I(06/2016 - 11/2016) * Pre-BR share of EU nurses	0.00008***	0.00006*	0.00005	0.00032	0.00035	0.00054
	(0.00003)	(0.00003)	(0.00013)	(0.00024)	(0.00028)	(0.00096)
I(12/2016 - 05/2017) * Pre-BR share of EU nurses	0.00012***	0.00010***	0.00028*	0.00067***	0.00071***	0.00214*
	(0.00003)	(0.00003)	(0.00014)	(0.00023)	(0.00026)	(0.00118)
I(06/2017 - 11/2017) * Pre-BR share of EU nurses	0.00015***	0.00016***	0.00033*	0.00089***	0.00123***	0.00158
	(0.00004)	(0.00005)	(0.00020)	(0.00033)	(0.00039)	(0.00167)
I(12/2017 - 05/2018) * Pre-BR share of EU nurses	0.00012**	0.00013**	0.00036*	0.00085**	0.00105**	0.00218
	(0.00005)	(0.00006)	(0.00021)	(0.00037)	(0.00046)	(0.00180)
I(06/2018 - 11/2018) * Pre-BR share of EU nurses	0.00018***	0.00021***	0.00032	0.00097**	0.00128**	0.00179
	(0.00006)	(0.00007)	(0.00023)	(0.00045)	(0.00052)	(0.00196)
I(12/2018 - 05/2019) * Pre-BR share of EU nurses	0.00020***	0.00022***	0.00038	0.00116**	0.00140**	0.00150
	(0.00007)	(0.00007)	(0.00025)	(0.00054)	(0.00063)	(0.00227)
H_0: Pre-referendum coefficients = 0						
F-stat	2.546	3.026	0.926	0.939	1.437	0.603
p-value	0.017	0.006	0.489	0.479	0.196	0.753
H_0: Post-referendum coefficients = 0						
F-stat	3.433	2.632	1.028	2.043	2.643	2.002
p-value	0.004	0.019	0.410	0.064	0.019	0.070
Observations (emergency & non-emergency hospital admissions)	89,728,352					

Notes. This table gives the pooled and dynamic regression results of Equation 3 for all interactions with the continuous exposure variable - for all patients. Robust standard errors clustered at hospital organization level. $N_{clusters}$: 131 acute care NHS hospital organizations. Significance levels: *p<0.1; **p<0.05; ***p<0.01.

Table A.9. Heterogeneous DiD effects by diagnosis group (emergency patients)

	Continuous Treatment					
	In-hospital death		In- and out-of-hospital death		Emergency Readmission	
	Coefficient	SE	Coefficient	SE	Coefficient	SE
ICD chapter:						
Infectious/Parasitic Diseases	0.00000	(0.00033)	-0.00010	(0.00034)	0.00089*	(0.00047)
Neoplasms	0.00222***	(0.00077)	0.00189**	(0.00079)	0.00137	(0.00106)
Blood Diseases and Immune System Disorders	0.00017	(0.00021)	0.00048*	(0.00027)	-0.00021	(0.00186)
Metabolic Diseases	0.00021	(0.00023)	0.00004	(0.00024)	0.00214**	(0.00099)
Mental Disorders	0.00038	(0.00025)	0.00025	(0.00034)	0.00069	(0.00086)
Diseases of the nervous system	-0.00020	(0.00023)	-0.00023	(0.00027)	0.00072	(0.00067)
Diseases of the eye	-0.00026**	(0.00010)	-0.00029*	(0.00015)	-0.00073	(0.00097)
Diseases of the ear	0.00002	(0.00007)	0.00006	(0.00010)	0.00137	(0.00100)
Diseases of the circulatory system	0.00031	(0.00029)	0.00022	(0.00030)	0.00058	(0.00057)
Diseases of the respiratory system	0.00060**	(0.00030)	0.00045	(0.00032)	0.00066	(0.00051)
Diseases of the digestive system	0.00004	(0.00014)	0.00006	(0.00015)	0.00129**	(0.00058)
Diseases of the skin	-0.00005	(0.00014)	-0.00004	(0.00014)	-0.00031	(0.00134)
Diseases of the musculoskeletal system	-0.00003	(0.00010)	-0.00003	(0.00011)	-0.00031	(0.00076)
Diseases of the genitourinary system	0.00037*	(0.00020)	0.00015	(0.00022)	0.00104**	(0.00051)
Pregnancy/Childbirth	0.00000	(0.00001)	0.00001	(0.00001)	-0.00124	(0.00215)
Perinatal period conditions	-0.00001	(0.00006)	-0.00000	(0.00007)	0.00103	(0.00120)
Congenital malformations	-0.00007	(0.00036)	-0.00008	(0.00040)	0.00178	(0.00214)
Other symptoms	0.00017	(0.00014)	0.00015	(0.00016)	0.00038	(0.00060)
Injury/Poisoning	0.00015	(0.00012)	0.00011	(0.00012)	0.00083	(0.00052)

Notes. This table gives the pooled regression results of Equation 3 for the continuous exposure for emergency patients only by diagnosis. Robust standard errors clustered at hospital organization level. $N_{clusters}$: 131 acute care NHS hospital organizations. Significance levels: *p<0.1; **p<0.05; ***p<0.01.

Table A.10. Effects of nurse workforce exposure to Brexit on hospital care quality, excluding London hospitals from the sample

	Continuous Treatment			Binary Treatment		
	In-hospital death	In- and out-of-hospital death	Emergency Readmission	In-hospital death	In- and out-of-hospital death	Emergency Readmission
	(1)	(2)	(3)	(4)	(5)	(6)
I(06/2012 - 11/2012) * Pre-BR share of EU nurses	0.00033	0.00039	-0.00010	0.00160	0.00256	0.00236
	(0.00022)	(0.00026)	(0.00058)	(0.00149)	(0.00183)	(0.00402)
I(12/2012 - 05/2013) * Pre-BR share of EU nurses	0.00019	0.00018	-0.00015	0.00024	0.00060	0.00263
	(0.00019)	(0.00022)	(0.00057)	(0.00138)	(0.00160)	(0.00422)
I(06/2013 - 11/2013) * Pre-BR share of EU nurses	0.00023	0.00018	-0.00028	0.00122	0.00129	0.00122
	(0.00018)	(0.00022)	(0.00059)	(0.00133)	(0.00152)	(0.00417)
I(12/2013 - 05/2014) * Pre-BR share of EU nurses	0.00019	0.00021	0.00033	0.00049	0.00086	0.00161
	(0.00014)	(0.00017)	(0.00048)	(0.00108)	(0.00123)	(0.00307)
I(06/2014 - 11/2014) * Pre-BR share of EU nurses	0.00012	0.00017	-0.00013	0.00081	0.00128	-0.00001
	(0.00013)	(0.00015)	(0.00045)	(0.00101)	(0.00109)	(0.00328)
I(12/2014 - 05/2015) * Pre-BR share of EU nurses	-0.00014	-0.00009	-0.00047	-0.00045	-0.00012	-0.00172
	(0.00014)	(0.00017)	(0.00032)	(0.00105)	(0.00124)	(0.00234)
I(06/2015 - 11/2015) * Pre-BR share of EU nurses	-0.00002	0.00009	-0.00050*	-0.00018	0.00068	-0.00366*
	(0.00009)	(0.00009)	(0.00028)	(0.00069)	(0.00071)	(0.00195)
I(06/2016 - 11/2016) * Pre-BR share of EU nurses	0.00020**	0.00016*	-0.00008	0.00093	0.00113	0.00079
	(0.00009)	(0.00009)	(0.00033)	(0.00066)	(0.00071)	(0.00231)
I(12/2016 - 05/2017) * Pre-BR share of EU nurses	0.00038***	0.00028***	0.00060*	0.00182***	0.00174***	0.00516**
	(0.00009)	(0.00009)	(0.00032)	(0.00063)	(0.00058)	(0.00242)
I(06/2017 - 11/2017) * Pre-BR share of EU nurses	0.00030***	0.00025**	0.00066	0.00160*	0.00203**	0.00216
	(0.00010)	(0.00012)	(0.00049)	(0.00081)	(0.00094)	(0.00428)
I(12/2017 - 05/2018) * Pre-BR share of EU nurses	0.00028**	0.00025*	0.00074	0.00181*	0.00205*	0.00212
	(0.00012)	(0.00014)	(0.00056)	(0.00092)	(0.00114)	(0.00436)
I(06/2018 - 11/2018) * Pre-BR share of EU nurses	0.00040***	0.00038***	0.00063	0.00253**	0.00277**	0.00111
	(0.00014)	(0.00014)	(0.00052)	(0.00108)	(0.00124)	(0.00448)
I(12/2018 - 05/2019) * Pre-BR share of EU nurses	0.00044***	0.00040**	0.00083*	0.00304**	0.00317**	0.00113
	(0.00015)	(0.00016)	(0.00049)	(0.00118)	(0.00131)	(0.00477)
Observations (emergency hospital admissions)			28,357,810			

Notes. This table gives the pooled and dynamic regression results of Equation 3 for all interactions with the continuous exposure variable - excluding patients and hospitals from London. Robust standard errors clustered at hospital organization level. $N_{clusters}$: 131 acute care NHS hospital organizations. Significance levels: *p<0.1; **p<0.05; ***p<0.01.

Table A.11. Effects of nurse workforce exposure to Brexit on hospital care quality, using a Brexit shock exposure computed over 06/2015-05/2016

	Continuous Treatment			Binary Treatment		
	In-hospital death	In- and out-of-hospital death	Emergency Readmission	In-hospital death	In- and out-of-hospital death	Emergency Readmission
	(1)	(2)	(3)	(4)	(5)	(6)
I(06/2012 - 11/2012) * Pre-BR share of EU nurses	0.00023*	0.00028*	-0.00002	0.00122	0.00197	0.00546*
	(0.00012)	(0.00015)	(0.00032)	(0.00120)	(0.00137)	(0.00288)
I(12/2012 - 05/2013) * Pre-BR share of EU nurses	0.00013	0.00013	-0.00017	-0.00012	-0.00012	0.00234
	(0.00012)	(0.00014)	(0.00035)	(0.00106)	(0.00119)	(0.00329)
I(06/2013 - 11/2013) * Pre-BR share of EU nurses	0.00016	0.00015	-0.00017	0.00084	0.00098	0.00397
	(0.00011)	(0.00013)	(0.00037)	(0.00102)	(0.00111)	(0.00356)
I(12/2013 - 05/2014) * Pre-BR share of EU nurses	0.00012	0.00016	0.00024	-0.00002	0.00027	0.00332
	(0.00010)	(0.00011)	(0.00029)	(0.00113)	(0.00131)	(0.00267)
I(06/2014 - 11/2014) * Pre-BR share of EU nurses	0.00005	0.00009	-0.00012	0.00110	0.00143	0.00307
	(0.00009)	(0.00010)	(0.00032)	(0.00100)	(0.00107)	(0.00278)
I(12/2014 - 05/2015) * Pre-BR share of EU nurses	-0.00005	-0.00003	-0.00041*	-0.00002	0.00020	-0.00115
	(0.00009)	(0.00011)	(0.00025)	(0.00095)	(0.00107)	(0.00218)
I(06/2015 - 11/2015) * Pre-BR share of EU nurses	0.00000	0.00005	-0.00042**	-0.00051	-0.00021	-0.00229
	(0.00006)	(0.00007)	(0.00019)	(0.00087)	(0.00097)	(0.00179)
I(06/2016 - 11/2016) * Pre-BR share of EU nurses	0.00014**	0.00011*	-0.00002	0.00026	0.00042	0.00090
	(0.00006)	(0.00006)	(0.00021)	(0.00061)	(0.00062)	(0.00187)
I(12/2016 - 05/2017) * Pre-BR share of EU nurses	0.00027***	0.00022***	0.00045**	0.00159***	0.00126**	0.00534**
	(0.00007)	(0.00007)	(0.00022)	(0.00058)	(0.00061)	(0.00214)
I(06/2017 - 11/2017) * Pre-BR share of EU nurses	0.00022***	0.00018**	0.00043	0.00127	0.00154*	0.00403
	(0.00007)	(0.00008)	(0.00030)	(0.00082)	(0.00089)	(0.00365)
I(12/2017 - 05/2018) * Pre-BR share of EU nurses	0.00017*	0.00011	0.00037	0.00128	0.00115	0.00116
	(0.00009)	(0.00010)	(0.00036)	(0.00090)	(0.00104)	(0.00483)
I(06/2018 - 11/2018) * Pre-BR share of EU nurses	0.00028***	0.00027***	0.00030	0.00213*	0.00260**	0.00010
	(0.00009)	(0.00010)	(0.00032)	(0.00112)	(0.00122)	(0.00414)
I(12/2018 - 05/2019) * Pre-BR share of EU nurses	0.00024**	0.00017	0.00042	0.00214**	0.00228**	0.00023
	(0.00011)	(0.00012)	(0.00033)	(0.00105)	(0.00112)	(0.00430)
Observations (emergency hospital admissions)			32,445,509			

Notes. This table gives the pooled and dynamic regression results of Equation 3 for all interactions with the continuous exposure variable and the binary exposure variable where both variables are calculated based on the last pre-policy year only. Robust standard errors clustered at hospital organization level. $N_{clusters}$: 131 acute care NHS hospital organizations. Significance levels: *p<0.1; **p<0.05; ***p<0.01.

Table A.12. Effects of nurse workforce exposure to Brexit on hospital care quality, including the pre Brexit referendum share of non-EU nurses as control

	Continuous Treatment		
	In-hospital death	In- and out-of-hospital death	Emergency Readmission
	(1)	(2)	(3)
I(06/2012 - 11/2012) * Pre-BR share of EU nurses	0.00026	0.00030	0.00008
	(0.00019)	(0.00023)	(0.00054)
I(12/2012 - 05/2013) * Pre-BR share of EU nurses	0.00014	0.00010	0.00009
	(0.00017)	(0.00019)	(0.00054)
I(06/2013 - 11/2013) * Pre-BR share of EU nurses	0.00020	0.00014	0.00001
	(0.00016)	(0.00019)	(0.00055)
I(12/2013 - 05/2014) * Pre-BR share of EU nurses	0.00011	0.00013	0.00050
	(0.00013)	(0.00015)	(0.00045)
I(06/2014 - 11/2014) * Pre-BR share of EU nurses	0.00007	0.00008	0.00004
	(0.00013)	(0.00014)	(0.00045)
I(12/2014 - 05/2015) * Pre-BR share of EU nurses	-0.00011	-0.00009	-0.00029
	(0.00013)	(0.00015)	(0.00033)
I(06/2015 - 11/2015) * Pre-BR share of EU nurses	-0.00000	0.00009	-0.00042
	(0.00008)	(0.00008)	(0.00026)
I(06/2016 - 11/2016) * Pre-BR share of EU nurses	0.00016*	0.00013	-0.00011
	(0.00008)	(0.00010)	(0.00030)
I(12/2016 - 05/2017) * Pre-BR share of EU nurses	0.00033***	0.00023**	0.00057*
	(0.00009)	(0.00009)	(0.00029)
I(06/2017 - 11/2017) * Pre-BR share of EU nurses	0.00025***	0.00019*	0.00068
	(0.00009)	(0.00011)	(0.00044)
I(12/2017 - 05/2018) * Pre-BR share of EU nurses	0.00022*	0.00018	0.00067
	(0.00012)	(0.00014)	(0.00050)
I(06/2018 - 11/2018) * Pre-BR share of EU nurses	0.00029**	0.00029**	0.00054
	(0.00013)	(0.00014)	(0.00047)
I(12/2018 - 05/2019) * Pre-BR share of EU nurses	0.00034**	0.00030*	0.00087*
	(0.00015)	(0.00016)	(0.00045)
I(06/2012 - 11/2012) * Pre-BR share of Non-EU nurses	0.00001	0.00008	-0.00004
	(0.00010)	(0.00011)	(0.00021)
I(12/2012 - 05/2013) * Pre-BR share of Non-EU nurses	-0.00001	0.00008	-0.00012
	(0.00008)	(0.00010)	(0.00022)
I(06/2013 - 11/2013) * Pre-BR share of Non-EU nurses	-0.00004	0.00002	-0.00008
	(0.00006)	(0.00008)	(0.00024)
I(12/2013 - 05/2014) * Pre-BR share of Non-EU nurses	-0.00003	0.00001	0.00001
	(0.00007)	(0.00008)	(0.00020)
I(06/2014 - 11/2014) * Pre-BR share of Non-EU nurses	-0.00001	0.00005	-0.00002
	(0.00007)	(0.00007)	(0.00020)
I(12/2014 - 05/2015) * Pre-BR share of Non-EU nurses	-0.00006	0.00001	0.00000
	(0.00006)	(0.00007)	(0.00018)
I(06/2015 - 11/2015) * Pre-BR share of Non-EU nurses	0.00004	0.00006	0.00007
	(0.00004)	(0.00005)	(0.00013)
I(06/2016 - 11/2016) * Pre-BR share of Non-EU nurses	0.00004	0.00004	0.00023**
	(0.00005)	(0.00005)	(0.00010)
I(12/2016 - 05/2017) * Pre-BR share of Non-EU nurses	-0.00001	0.00001	0.00018
	(0.00005)	(0.00005)	(0.00013)
I(06/2017 - 11/2017) * Pre-BR share of Non-EU nurses	0.00010*	0.00012*	0.00016
	(0.00005)	(0.00006)	(0.00021)
I(12/2017 - 05/2018) * Pre-BR share of Non-EU nurses	0.00005	0.00007	0.00024
	(0.00006)	(0.00007)	(0.00029)
I(06/2018 - 11/2018) * Pre-BR share of Non-EU nurses	0.00018***	0.00019**	0.00016
	(0.00007)	(0.00008)	(0.00025)
I(12/2018 - 05/2019) * Pre-BR share of Non-EU nurses	0.00014*	0.00014	-0.00009
	(0.00008)	(0.00009)	(0.00025)
Observations (emergency hospital admissions)		32,445,509	

Notes. This table gives the pooled and dynamic regression results of Equation 3 for all interactions with the continuous exposure variable for in-hospitals deaths, in- and out-of-hospital deaths, and emergency readmissions. Robust standard errors clustered at hospital organization level. $N_{clusters}$: 131 acute care NHS hospital organizations. Significance levels: *p<0.1; **p<0.05; ***p<0.01.

Table A.13. Effects of nurse workforce exposure to Brexit on hospital care quality, including the pre Brexit referendum share of EU doctors as control

	Continuous Treatment					
	In-hospital death	In- and out-of-hospital death	Emergency Readmission	In-hospital death	In- and out-of-hospital death	Emergency Readmission
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Event study						
I(06/2012 - 11/2012) * Pre-BR share of EU nurses	0.00028	0.00034	0.00007			
	(0.00019)	(0.00024)	(0.00054)			
I(12/2012 - 05/2013) * Pre-BR share of EU nurses	0.00015	0.00015	0.00000			
	(0.00017)	(0.00020)	(0.00054)			
I(06/2013 - 11/2013) * Pre-BR share of EU nurses	0.00018	0.00015	-0.00003			
	(0.00016)	(0.00019)	(0.00054)			
I(12/2013 - 05/2014) * Pre-BR share of EU nurses	0.00007	0.00010	0.00048			
	(0.00013)	(0.00015)	(0.00045)			
I(06/2014 - 11/2014) * Pre-BR share of EU nurses	0.00005	0.00009	0.00003			
	(0.00012)	(0.00014)	(0.00043)			
I(12/2014 - 05/2015) * Pre-BR share of EU nurses	-0.00011	-0.00008	-0.00033			
	(0.00012)	(0.00015)	(0.00031)			
I(06/2015 - 11/2015) * Pre-BR share of EU nurses	-0.00000	0.00009	-0.00040			
	(0.00008)	(0.00008)	(0.00026)			
I(06/2016 - 11/2016) * Pre-BR share of EU nurses	0.00016**	0.00013	0.00003			
	(0.00008)	(0.00009)	(0.00027)			
I(12/2016 - 05/2017) * Pre-BR share of EU nurses	0.00030***	0.00021**	0.00068**			
	(0.00008)	(0.00008)	(0.00027)			
I(06/2017 - 11/2017) * Pre-BR share of EU nurses	0.00027***	0.00022**	0.00080*			
	(0.00009)	(0.00011)	(0.00042)			
I(12/2017 - 05/2018) * Pre-BR share of EU nurses	0.00022**	0.00018	0.00079			
	(0.00011)	(0.00013)	(0.00049)			
I(06/2018 - 11/2018) * Pre-BR share of EU nurses	0.00033**	0.00033**	0.00069			
	(0.00013)	(0.00014)	(0.00045)			
I(12/2018 - 05/2019) * Pre-BR share of EU nurses	0.00038***	0.00035**	0.00089**			
	(0.00014)	(0.00015)	(0.00042)			
I(06/2012 - 11/2012) * Pre-BR share of EU doctors	-0.00017	-0.00019	-0.00041	-0.00014	-0.00015	-0.00041
	(0.00014)	(0.00019)	(0.00040)	(0.00014)	(0.00018)	(0.00040)
I(12/2012 - 05/2013) * Pre-BR share of EU doctors	-0.00010	-0.00014	-0.00004	-0.00008	-0.00012	-0.00004
	(0.00013)	(0.00018)	(0.00040)	(0.00013)	(0.00017)	(0.00039)
I(06/2013 - 11/2013) * Pre-BR share of EU doctors	0.00005	-0.00002	-0.00022	0.00006	-0.00001	-0.00023
	(0.00011)	(0.00016)	(0.00036)	(0.00012)	(0.00016)	(0.00037)
I(12/2013 - 05/2014) * Pre-BR share of EU doctors	0.00016	0.00020	-0.00009	0.00016	0.00021	-0.00004
	(0.00011)	(0.00014)	(0.00033)	(0.00011)	(0.00014)	(0.00032)
I(06/2014 - 11/2014) * Pre-BR share of EU doctors	0.00008	0.00006	-0.00041	0.00008	0.00006	-0.00041
	(0.00010)	(0.00012)	(0.00034)	(0.00010)	(0.00012)	(0.00033)
I(12/2014 - 05/2015) * Pre-BR share of EU doctors	-0.00005	0.00000	0.00001	-0.00007	-0.00001	-0.00003
	(0.00009)	(0.00011)	(0.00027)	(0.00010)	(0.00011)	(0.00027)
I(06/2015 - 11/2015) * Pre-BR share of EU doctors	0.00009	0.00010	-0.00006	0.00009	0.00011	-0.00010
	(0.00008)	(0.00009)	(0.00021)	(0.00008)	(0.00009)	(0.00021)
I(06/2016 - 11/2016) * Pre-BR share of EU doctors	0.00012	0.00009	-0.00051*	0.00014*	0.00010	-0.00050*
	(0.00008)	(0.00010)	(0.00027)	(0.00008)	(0.00009)	(0.00027)
I(12/2016 - 05/2017) * Pre-BR share of EU doctors	0.00013	0.00013	-0.00044	0.00016*	0.00015	-0.00037
	(0.00008)	(0.00011)	(0.00031)	(0.00008)	(0.00011)	(0.00033)
I(06/2017 - 11/2017) * Pre-BR share of EU doctors	0.00009	0.00010	-0.00065	0.00011	0.00013	-0.00056
	(0.00010)	(0.00013)	(0.00051)	(0.00010)	(0.00012)	(0.00053)
I(12/2017 - 05/2018) * Pre-BR share of EU doctors	0.00015	0.00031**	-0.00019	0.00017	0.00032**	-0.00011
	(0.00013)	(0.00014)	(0.00054)	(0.00012)	(0.00013)	(0.00056)
I(06/2018 - 11/2018) * Pre-BR share of EU doctors	0.00012	0.00022	-0.00062	0.00016	0.00025*	-0.00054
	(0.00016)	(0.00015)	(0.00050)	(0.00016)	(0.00015)	(0.00053)
I(12/2018 - 05/2019) * Pre-BR share of EU doctors	0.00009	0.00016	-0.00046	0.00013	0.00020	-0.00038
	(0.00015)	(0.00016)	(0.00045)	(0.00015)	(0.00016)	(0.00049)
Observations (emergency hospital admissions)		32,445,509			32,445,509	

Notes. This table gives the dynamic regression results of Equation 3 for all interactions with the continuous exposure variable for nurses and doctors separately. Robust standard errors clustered at hospital organization level. $N_{clusters}$: 131 acute care NHS hospital organizations. Significance levels: *p<0.1; **p<0.05; ***p<0.01.

Table A.14. Effects of nurse workforce exposure to Brexit on (log) hospital admissions

	Continuous Treatment			Binary Treatment		
	log(Total) (1)	log(Emergency) (2)	log(Non-Emergency) (3)	log(Total) (4)	log(Emergency) (5)	log(Non-Emergency) (6)
I(06/2012 - 11/2012) * Pre-BR share of EU nurses	-0.00373	-0.00238	-0.00456	-0.05270	-0.04814	-0.05592
	(0.00382)	(0.00689)	(0.00424)	(0.03513)	(0.04723)	(0.03725)
I(12/2012 - 05/2013) * Pre-BR share of EU nurses	-0.00334	-0.00012	-0.00413	-0.04806	-0.02855	-0.05691*
	(0.00361)	(0.00670)	(0.00410)	(0.03216)	(0.04732)	(0.03369)
I(06/2013 - 11/2013) * Pre-BR share of EU nurses	-0.00137	0.00081	-0.00343	-0.02903	-0.00231	-0.04449
	(0.00302)	(0.00585)	(0.00314)	(0.03396)	(0.05096)	(0.03197)
I(12/2013 - 05/2014) * Pre-BR share of EU nurses	-0.00106	0.00191	-0.00311	-0.01650	-0.00054	-0.02959
	(0.00256)	(0.00473)	(0.00271)	(0.03292)	(0.04522)	(0.02986)
I(06/2014 - 11/2014) * Pre-BR share of EU nurses	-0.00064	0.00189	-0.00238	-0.01792	-0.00450	-0.03142
	(0.00214)	(0.00455)	(0.00207)	(0.03195)	(0.04271)	(0.02878)
I(12/2014 - 05/2015) * Pre-BR share of EU nurses	-0.00147	-0.00034	-0.00187	-0.00847	0.00553	-0.01593
	(0.00167)	(0.00282)	(0.00168)	(0.02091)	(0.02836)	(0.01904)
I(06/2015 - 11/2015) * Pre-BR share of EU nurses	0.00085	0.00076	0.00056	0.00944	0.01698	0.00435
	(0.00122)	(0.00198)	(0.00140)	(0.00938)	(0.01586)	(0.01002)
I(06/2016 - 11/2016) * Pre-BR share of EU nurses	-0.00092	-0.00354	-0.00124	0.00533	-0.00903	0.00866
	(0.00139)	(0.00308)	(0.00162)	(0.00952)	(0.01643)	(0.01069)
I(12/2016 - 05/2017) * Pre-BR share of EU nurses	-0.00158	-0.00038	-0.00195	-0.00624	0.00114	-0.00662
	(0.00128)	(0.00327)	(0.00160)	(0.00967)	(0.01524)	(0.01196)
I(06/2017 - 11/2017) * Pre-BR share of EU nurses	-0.00314*	-0.00577	-0.00370	-0.02036	-0.02932	-0.02270
	(0.00189)	(0.00493)	(0.00261)	(0.01303)	(0.02788)	(0.01658)
I(12/2017 - 05/2018) * Pre-BR share of EU nurses	-0.00315	-0.00355	-0.00326	-0.03140**	-0.05502*	-0.02233
	(0.00224)	(0.00440)	(0.00318)	(0.01530)	(0.02940)	(0.02087)
I(06/2018 - 11/2018) * Pre-BR share of EU nurses	-0.00120	-0.00228	-0.00256	-0.02291	-0.03381	-0.02461
	(0.00275)	(0.00458)	(0.00347)	(0.01923)	(0.03254)	(0.02342)
I(12/2018 - 05/2019) * Pre-BR share of EU nurses	-0.00278	-0.00335	-0.00404	-0.04087*	-0.03903	-0.04058
	(0.00321)	(0.00566)	(0.00383)	(0.02266)	(0.03561)	(0.02572)
Observations (hospital organisations x months)		11,004			11,004	

Notes. This table gives the pooled regression results of Equation 3 for the continuous and binary exposure variable. The outcome is the natural logarithm of the number of total, emergency, or non-emergency patients. Robust standard errors clustered at hospital organization level. $N_{clusters}$: 131 acute care NHS hospital organizations. Significance levels: *p<0.1; **p<0.05; ***p<0.01.

Table A.15. Pay grades of foreign joiner nurses, before and after the Brexit referendum

	Pre-BR period		Post-BR period	
	Mean	St.Dev.	Mean	St.Dev.
Share of Band 1-4	0.081	0.054	0.166	0.059
Share of Band 5	0.887	0.052	0.808	0.052
Share of Band 6	0.019	0.012	0.014	0.010
Spinal Point	16.119	0.350	15.702	0.423
Grade Minimum Salary	24,012.54	322.218	23,542.52	340.501
Grade Maximum Salary	29,625.81	524.921	28,829.16	565.240

Notes. Descriptive statistics of the EU and non-EU joiner nurse pay grade variables, split by the two sub-periods (June 2012 - May 2016; June 2016 - May 2019) in our sample, based on NHS hospitals ESR records.