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ABSTRACT

Foreign Nurses and Hospital Quality: Evidence from Brexit*

We exploit the 2016 Brexit referendum as a migration shock to evaluate the impact of reduced labour supply on the provision of hospital care. After the referendum, a sharp drop in the number of early-career new joiners from Europe resulted in a considerable decrease in the share of EU nurses in the English NHS. Using an enclave instrumental variable empirical strategy, we find that emergency readmission rates increased, and more so in hospital organizations more exposed to the missing inflow of new joiners. A theoretical model shows that this is consistent with a decrease in the quality of new hires.

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

Keywords: labour supply, workers' mobility, immigration, patient care, hospital quality, Brexit

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1 Introduction

The June 2016 Brexit referendum is one of the main international political events of the last decade, given its impact on several dimensions of the society (see Sampson (2017) for an early review). The unexpected referendum outcome has affected a disparate number of economic areas, from fast reacting markets such as stocks and currencies (Sathyanarayana and Gargesha, 2016; Davies and Studnicka, 2018; Breinlich et al., 2018; Alvarez-Diez et al., 2019) to economic outputs with stickier adjustments, such as inflation (Breinlich et al., 2022), trade (Dhingra et al., 2017; Graziano et al., 2021; Douch and Edwards, 2022), UK outward investments in the remaining European Union (EU) 27 members (Breinlich et al., 2020) and foreign direct investments in the UK (Dhingra et al., 2016; McGrattan and Waddle, 2020).

Besides the aforementioned short-term consequences of the referendum, many of which were unintended, since the beginning the enforcement of more restrictive immigration policies and ending the EU freedom of movement of workers had been one of the central nodes of the Brexit debate, and had been repeatedly advocated by Brexit supporters as a worthy motivation for exiting the EU and its Common Market. However, immigration and workers' mobility policies are of strategic importance for the growth of an economy in several dimensions (Cortes and Tessada, 2011; Peri, 2012; Dustmann and Frattini, 2014; Bosetti et al., 2015; Foged and Peri, 2016), because they can affect the labour supply chain and the stock of human capital available to produce goods and services; hence, the relevance of investigating the Brexit effects on UK, EU and non-EU labour markets and organizations' productivity as a key economic research question.

As the transitory period following the UK withdrawal from the EU was effectively over only in January 2021, the labour market effects of the enforcement of the official Brexit agreement between the UK and the EU are still understudied. Instead, there is already evidence about the impacts of the Brexit referendum on UK labour markets. Wadsworth (2018) finds that, at least in the short run after the referendum, there was no effect on the wages of UK-born workers. Javorcik et al. (2020) shows that labour demand proxied by online job postings fell in regions more exposed to barriers to the export of professional services, with higher impacts for high-skilled jobs. Vieira Marques Da Costa et al. (2022) report that employees in sectors most exposed to the sterling depreciation saw their real wages falling permanently by 2.6 percent per annum compared to a counterfactual scenario without Brexit. Moreover, the uncertainty triggered by the Brexit referendum and the visa barriers subsequently imposed by the UK government on EU citizens led to a sharp reduction in net migration from Europe: Di Iasio and Wahba (2023) document that the post-referendum decrease in net EU migration to the UK was due both to a sharp decline in migration inflows

from Europe and an increase in EU emigration from the UK.

With this work, we contribute to the labour, health and political economics literatures by being among the first to study the effects of the Brexit referendum on migration inflows of skilled workers (in our case, hospital nurses and doctors) and the way it affected hospital quality for emergency and planned inpatients treated at English National Health Service (NHS) hospitals. Understanding whether the Brexit referendum had any impact on NHS hospitals' quality of care is topical for at least two reasons: the NHS has been suffering from a long-standing workforce crisis that started years before the Brexit referendum; furthermore, NHS hospitals are highly exposed to systemic migration shocks like the one triggered by the Brexit referendum, as they rely considerably on the periodic inflows of foreign clinical workers (i.e., nurses and doctors).

Our analysis is based on rich administrative payroll data and patients' admission records from the universe of English NHS acute care hospitals, covering the period from 2011 to 2019. We provide three main contributions to the literature. First, we describe the effects of the Brexit Referendum (BR) on the composition of the bulk of the English NHS clinical workforce (nurses and fully qualified doctors). We show that - starting from July 2016 - the number of EU nurses in the English NHS has declined considerably. The peculiarity is that, since immigration rules from EU countries did not change until December 2020, the fall in EU nurse staff numbers we document was driven exclusively by a change in prospective migrant workers' expectations with respect to moving to Britain after the BR outcome. We find that the fall in EU nurse staff numbers was almost entirely due to a sharp reduction in the number of early-career new joiners from Europe, i.e. those who revised their migration to UK opportunity costs, rather than a sharp increase of leavers from the pre-existing EU nurses employed by NHS hospitals. Moreover, we show that the drop in EU nurses was compensated by an increase in new NHS joiners from non-EU countries, also thanks to the 2018 relaxation of the cap on healthcare workers' visas for non-EU migrants (Portes, 2022). Instead, the BR did not significantly impact the English NHS doctors' workforce, whose staff composition remained virtually unaffected.

Second, we estimate the effect of the nurses' migration shock induced by the BR on hospital quality. We construct hospital standardized quality measures, 30-day mortality and emergency readmission rates, for both emergency and planned patients. Then, we evaluate whether a change in EU nurse joiners has any effect on changes in NHS hospital quality (between the post- and pre-BR period) by estimating a two-stage least square (2SLS) regression in differences. To instrument the post-Brexit change in the number of NHS hospital nurse joiners from Europe, we draw from the migration literature and construct an enclave

instrumental variable (IV) (Card, 2001) based on the past joining rate of EU nurses at each hospital organization. Such instrument is a predetermined measure of exposure to the post-BR migration shock, therefore it represents a plausibly exogeneous source of variation associated with the magnitude of the migration shock of interest, i.e. the change in NHS nurse joiners from the EU (Altonji and Card, 1991; Lee et al., 2022). A notable difference, compared to the previous use of similar identification strategies, is that our approach is based not only on the cross-sectional variation due to the historical EU enclave but also and crucially on the unexpected Brexit shock, therefore limiting the risks of a violation of the exclusion restriction raised by recent literature.

Third, to better understand the connection between the BR and hospital quality, we develop a simple but flexible theoretical framework. Our model predictions are consistent with the empirical patterns we document and provide a skill selection mechanism linking the BR's result to changes in hospital quality.

Our main results show that, after the BR, NHS hospitals historically employing a higher number of EU nurses experienced the most pronounced drop in new EU nurse joiners rate, and that, while there is no significant effect on hospital mortality rates, hospital quality for patients undergoing planned care (henceforth, *planned patients*) decreased. In particular, an additional 100 joining nurses from Europe per 1,000 staff members reduce the emergency readmission rate by about 2.2 percentage points among English NHS patients that were initially admitted for an elective treatment. This finding has also negative implications for the already tight NHS finances, as unplanned readmissions cause additional monetary costs for the hospitals where patients are readmitted, and monetary penalties for the hospital that is responsible for the index planned hospitalization. Our estimates suggest that the costs implied by the increased emergency readmissions in the whole NHS acute hospital sector were of the order of £61.9 millions, which could have been used instead to fund the hiring of about 2,000 more senior nurses and reduce hospital staff shortages.

We investigate several possible mechanisms underlying such findings. For instance, we show that the BR did not result in significant nurse shortages across NHS hospitals and that the negative change in hospital care quality for planned patients is not associated with EU nurse leaving rates. Rather, the significant effect on care quality appears to arise from the change in the composition of the NHS hospital nursing workforce. Hospitals that relied more on the inflow of EU workers experienced larger decreases in the share of EU nurses and more severe increases in planned patients' readmission risk.

As we do not observe direct data on workers' skills and professional qualifications, we rely on a simple theory model to link changes in the workforce composition to hospital quality

outcomes. Our theoretical framework shows that the decrease in hospital quality following the reduction in the EU nurse joining rate is consistent with a decline in the quality of new hires. In a market where wages are fixed exogenously, a negative labour supply shock — such as the reduced inflow of EU nurses induced by the Brexit referendum — forces hospitals to decrease their hiring skill cutoff to satisfy their labour demand. The drop in the hiring cutoff then translates itself into a fall in the quality of care. Moreover, in our model, hospital organizations that rely more heavily on EU workers face larger decreases in their labour supply post-referendum and, consequently, larger decreases in their hiring skill cutoff and quality of care.

It is important to highlight that our results do not imply nor assume that non-EU are less skilled than EU workers. The decrease in new joiners' quality occurs across all workers' origins and is present regardless of the skill distributions of British, EU, and non-EU workers (nurses); thus, even when the average ex-ante quality of professional training is assumed to be the same across distinct countries of origin. In addition, the hiring skill cutoff in our model is homogeneous across EU and non-EU workers both pre and post-referendum. Therefore, in our framework, no differential inference about a worker's skill can be made based on their country of origin. The main insight is that the reduced labour supply deteriorates hiring standards used for all workers across all origins and more so at hospitals more exposed to the shock, such as the ones that historically receive a larger inflow of EU workers.

This study is related to several previous contributions in social sciences. We build on the economics and demography literatures that show how changes in immigration policy regulations shape the migration in- and out-flows to/from host countries, and how immigrant enclaves attract new migrants settlers (Bartel, 1989; Czaika and Parsons, 2017; Lee et al., 2022). In particular, our empirical strategy is similar to Lee et al. (2022), who employ instrumental variables based on migrant enclaves to evaluate the labour market effects of repatriations of Mexican border from the US in the 1930s.

We also add to the studies that investigate the relationship between immigration and labour supply in the healthcare sector. In this area, two recent studies report a positive causal effect of immigration on both staff levels and quality of care in US nursing homes (Furtado and Ortega, 2023; Grabowski et al., 2023). Our work is focused on the impact of immigration on labour supply in the hospital care sector, not the long-term care sector, and relies on the combination of an exogenous shock (the Brexit referendum outcome) with an enclave IV to tease out the effect on quality of hospital care, instead of using shift-shares instruments.

Most importantly, we contribute to the economic literature examining the relationship

between labour supply in the healthcare sector and patient outcomes, which represents the endgame of our investigation in terms of economic outcomes of interest. Propper and Van Reenen (2010) report evidence of a longitudinal association between higher outside wages for nurses and heart-attack mortality of English NHS hospital patients, suggesting that one possible mechanism could be lower quality agency nurses employed in hospitals facing larger nurse shortages. With respect to their contribution, which shares our same English NHS institutional setting but a different period of analysis, we innovate mainly by providing causal evidence based on an exogenous shock (the Brexit referendum) and a different empirical strategy. Lin (2014) and Akosa Antwi and Bowblis (2018) show causal evidence that the increased supply of registered nurses enhances quality in nursing homes, using instrumental variable (IV) strategies. Our work differs from Lin (2014) and Akosa Antwi and Bowblis (2018) in the empirical IV strategy, the healthcare sector analyzed (hospital instead of nursing homes) and the fact that in our institutional setting, the English NHS hospital market, the presence of nationally-regulated salaries for healthcare workers prevents bias from selective wage bargaining arising instead in healthcare systems like the U.S. one. Finally, Friedrich and Hackmann (2021) show causal evidence of negative effects of healthcare workers' shortages on patient care quality, based on a maternity leave policy which led to a shortage of nurse labour supply in Danish hospitals and nursing homes. We measure health outcomes through the same indicators used in their study, mortality and unplanned emergency readmission rates, but the methods, institutional setting and the use of an immigration-based exogenous shock are peculiar of our investigation.

The empirical and theoretical results of our work are informative for policy-makers, and provide two main take-away messages. 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 data sources used in this study and the effects of the Brexit referendum on the composition of the English NHS workforce. Section 3 presents the econometric models. Section 4 reports the main results of this paper. Section 5 tests their robustness as well as investigating their underlying mechanisms. Section 6 provides a theoretical framework which rationalizes our 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 final BR turnout was 72.21%, with 17,410,742 people (corresponding to 51.9% of the actual voters) voting in favour of leaving the EU. This outcome triggered the resignation of the incumbent Prime Minister and leader of the Conservative Party, David Cameron, who explicitly campaigned for the UK to remain in the European Union. He was succeeded as Prime Minister by the English Home Secretary, Theresa May, who in March 2017 signed a formal notice to the EU about the intent of the UK to leave the Union. Theresa May's government began the Brexit negotiations with the EU and drafted the first versions of a Withdrawal Agreement, which the British parliament rejected multiple times. As a result, also Theresa May resigned as Prime Minister (July 2019) and she was succeeded by her former Foreign Secretary, Boris Johnson, who in 23 January 2020 secured the Parliament approval of a final version of the EU Withdrawal Agreement.

The official exit from the EU is dated 31 January 2020, 11:00PM (UK time). However, 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 departure 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. The principles of the freedom of movement policy, still valid within EU country members, are established by the 1992 Treaty of Maastricht. They allow any EU national to freely move and seek a job in another member state of the European Single Market (European Parliament, 2023). Hence, 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 need to be granted 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 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. The length of such medical training generally varies from 7 to 10 years, depending on the chosen medical specialty. 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).[1]

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 by seating either the International English Language Testing System (IELTS) or the Occupational English Test (OET). 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 registering with the relevant regulatory body and for joining the English NHS.

[1] 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.

Starting from January 2021, the accreditation process described above applies to all international doctors and nurses, regardless of which foreign country they obtained their professional qualification from. 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.

The wages of nurses and doctors employed in NHS hospitals are nationally regulated and based on pay bands that are updated nationally each year by independent commissions for nurses (NHS Pay Review Body) and doctors (Doctors' and Dentists' Remuneration Review Body). Remarkably, the pay levels of these two groups of skilled hospital workers are sensibly different: in 2016, the average basic pay of a Band 5 registered nurse was £25,298, whereas the basic salary of a first year senior doctor (consultant) was almost three times such amount and equal to £76,001.[2]

2.3 Data sources

We create a unique dataset from multiple data sources. We use Electronic Staff Records (ESR) data, an administrative monthly payroll database, whose records on the universe of NHS hospital nurses and doctors include rich information of clinical workers' demographics (e.g. age, nationality, gender) and employment-related variables, such as hours worked, earnings, staff grade and role, date of joining the NHS, and hospital organization (NHS Trust) of employment. We use the ESR data to compute inflows and outflows of NHS nurses and senior doctors (i.e. fully qualified doctors, also referred to as "consultants" or "specialty and specialist (SAS)" in the NHS) in our sample, for three different nationality groups, British, EU, and non-EU, as well as our main enclave IV. Because 9% of the ESR nurses' and doctors' records presents a missing nationality, we exploit the panel nature of the ESR data to recover the nationality of approximately half of these workers from their first ESR entry with a non-missing nationality information.[3]

We use Hospital Episodes Statistics (HES) data to compute a range of hospital quality

[2]See `https://www.nhsemployers.org/system/files/2021-06/Pay-Circular-AFC-1-2016.pdf` and `https://www.nhsemployers.org/system/files/2021-06/Pay-and-Conditions-Circular-MD-12016.pdf`.

[3]We use the first non-missing record, since nationality is time-varying, especially for foreign workers who acquire the British citizenship some years after having settled in the UK and joined the English NHS.

measures. HES is an administrative database containing the universe of patient admissions in the English NHS. It has rich information on patients' demographics, medical conditions, calendar month and method of admission to hospital, which we exploit to derive risk-adjusted hospital quality metrics. We link patient-level HES records with the Office for National Statistics (ONS) Civil Registration Deaths dataset, which has information on the exact date of death of patients treated by NHS healthcare providers, to compute hospital-level mortality and emergency readmission rates within 30 days from admission to hospital, separately for patients with emergency and elective conditions. The risk-adjustment procedure follows a standard statistical approach, adopted and described also by NHS Digital (NHS Digital, 2022, 2023*b*), the official statistical agency of the NHS: first, patient mortality (unplanned readmission) binary indicators are regressed using a logit model on observed patient characteristics (i.e. age categories, gender, Charlson comorbidities); then, predicted cumulative death (readmission) rates at the hospital organization level are obtained (denominator) and compared with the number of observed deaths (numerator).

Finally, we exploit UK 2001 and 2011 Census data from the ONS to retrieve the historical shares of EU residents in the Lower Super Output Areas (LSOA) that fall in a 90- kilometre radius around each hospital organization headquarter, which we then use as alternative enclave IVs.[4]

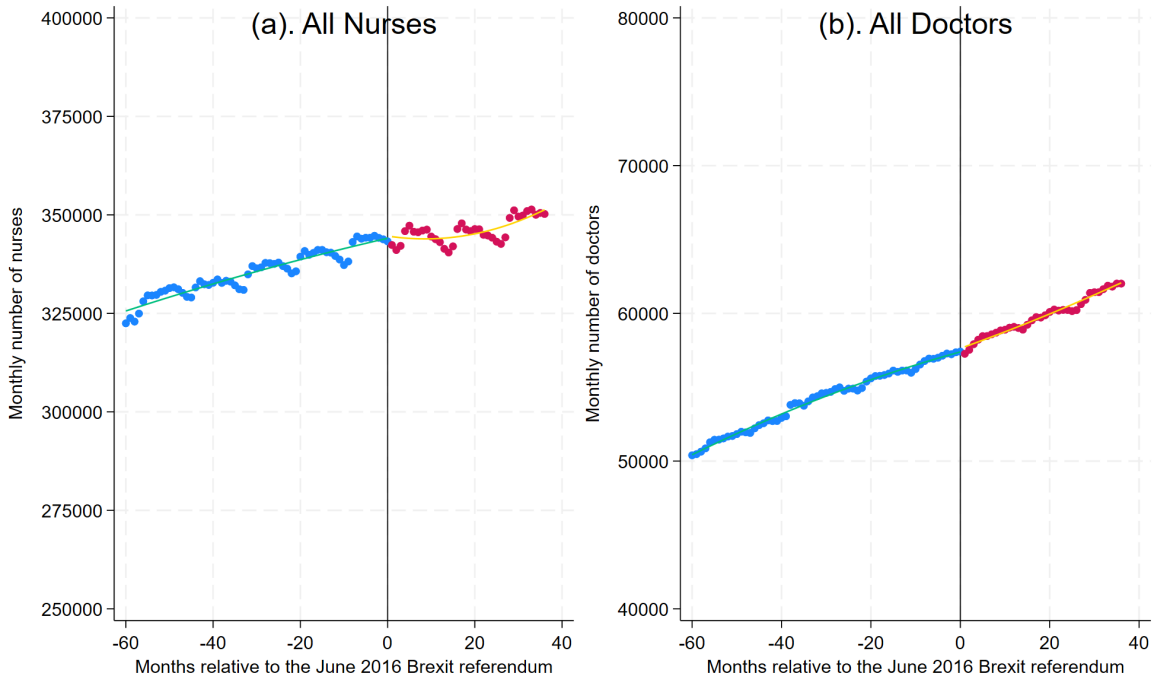
2.4 Descriptive evidence

Figure 1 plots the total number of nurses and senior doctors in the English NHS over time. It shows that the outcome of the Brexit referendum did not have a significant impact at the aggregate level on neither the nursing nor the medical workforce. Around June 2016, the overall staff levels associated with both workers' groups remained on the same positive trends, without displaying any clear discontinuity with respect to the pre-referendum period.

However, the more granular breakdown by nationality group provided in Figure 2 depicts a different picture. 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). If anything, only the number of non-EU doctors increased faster in the post-referendum period, although at a much slower rate if compared to the nursing group.

[4]LSOAs are small geographical areas defined by the ONS. They comprise between 400 and 1,200 households and usually have a resident population between 1,000 and 3,000 persons. There are 33,755 LSOAs in England.

Figure 1. Clinical staff levels around the Brexit referendum date

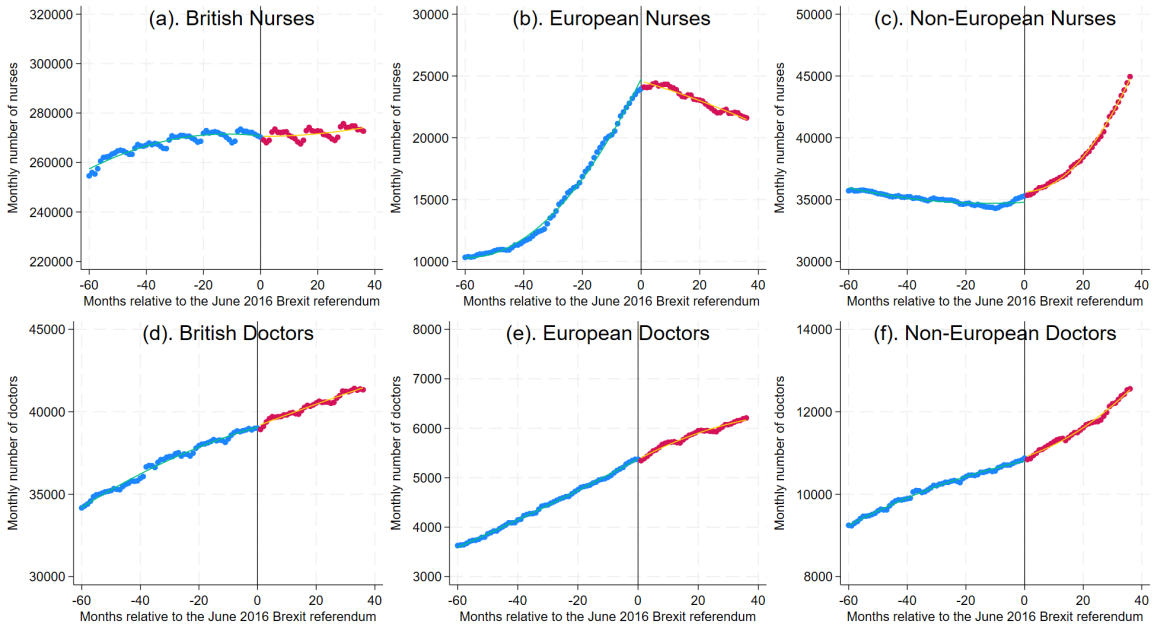


Notes: Total number of nurses and senior doctors in the English NHS around the Brexit referendum date (June 2016).

Figure 3 investigates what drove the decrease (increase) in the overall number of European (non-European) NHS nurses emerging from Figure 2. More specifically, it explores whether the rates at which these two groups of foreign nurses join or leave the English NHS present any discontinuity around the referendum date. Panel a shows that the number of European nurses joining the English NHS reduced by almost 50% immediately following the referendum date. This fall in the number of European joining nurses was only later compensated by a higher joining rate among non-European nurses (panel c).

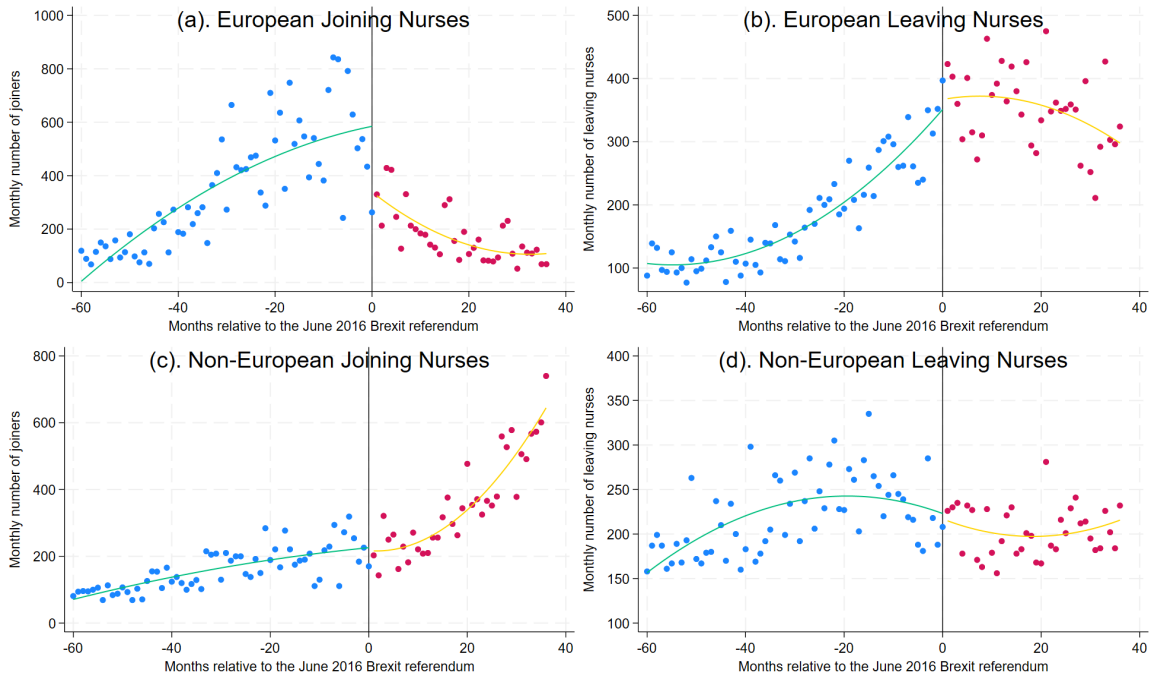
The same pattern does not emerge from the leaving rate of neither EU nationals nor non-EU foreign nurses. The EU national workers already employed and settled in the UK prior to the BR have made personal and professional investments, such as fostering their career within NHS hospitals, marrying, forming a household, having children. For these workers, abruptly relocating outside the UK would imply substantial divestment costs. Therefore, EU migrants employed in the UK before the BR were likely less sensitive to the BR outcome than prospective EU movers to the UK. These patterns are consistent with our Section 6 conceptual framework. In line with Di Iasio and Wahba (2023), EU nationals nurses present a growing leaving rate in the pre-referendum period (panel b), which has eventually slowed down since June 2016. To summarise, the outcome of the Brexit referendum led to

Figure 2. Clinical staff levels by nationality group



Notes: Nurses' and Senior doctors' staff levels around the Brexit referendum date (June 2016) by nationality group. 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 3. Nurses joining and leaving the English NHS by nationality group

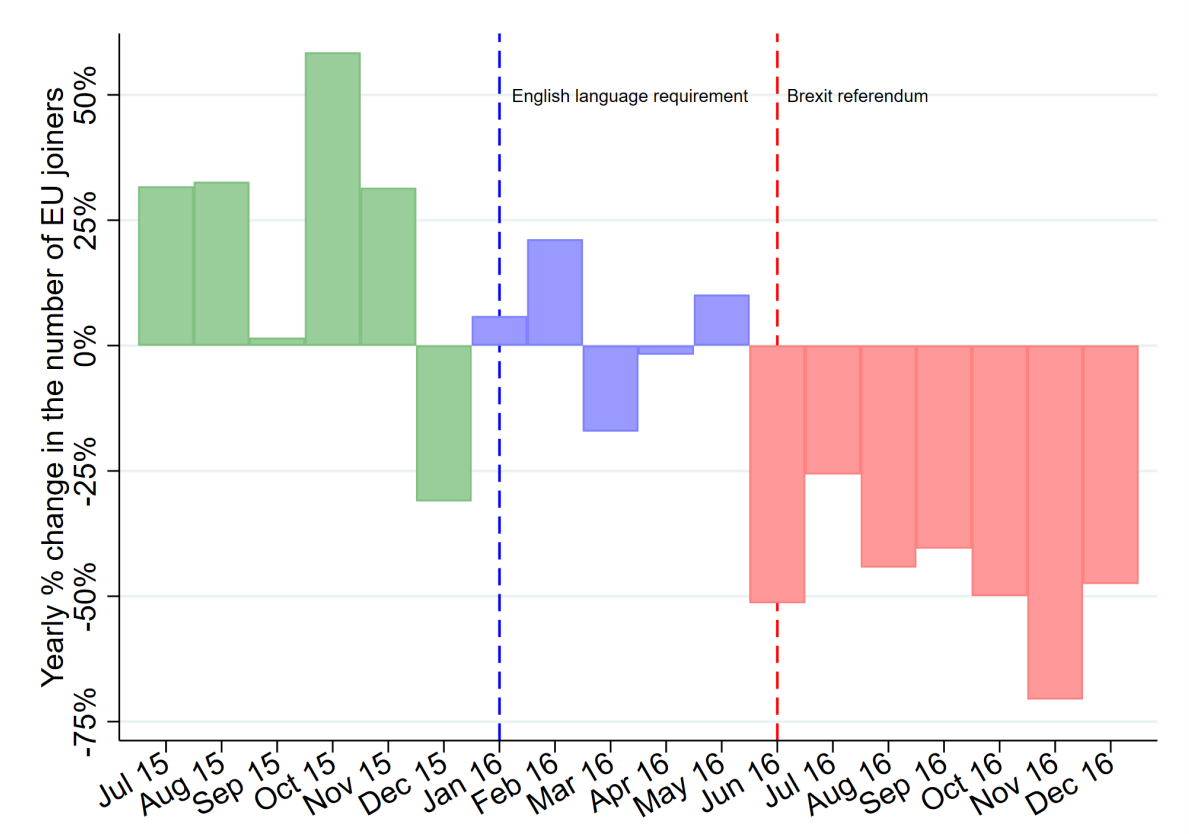


Notes: NHS joining and leaving monthly figures around the Brexit referendum date (June 2016) among nurses of different nationalities.

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.[5]

Figure A.3 further explores which subgroups of new joining nurses from Europe explain the discontinuity displayed by panel a of Figure 3. The BR mostly affected the joining rates of non-registered nurses (pay bands 1-4, panel a) and newly qualified nurses (pay band 5, panel b). Instead, the European senior nurses' joining rate (pay bands 6-9, panel c) presents a smooth change around the referendum date. This finding is in line with most migration reports on Brexit, which had a disproportionate impact on lower-skilled and essential migrant workers (e.g. Sumption and Fernandez Reino 2018, Fernández-Reino and Kierans 2020). In light of the above, the rest of the paper will primarily focus on the subgroup of EU nurses covered by up to the pay band 5 section, whose joining rate experienced the most serious shock due to Brexit.

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



Notes: Percentage-point change in the total monthly number of NHS nurse joiners from Europe compared to the same month of the year before.

[5]Figure A.1 reports the corresponding graphs for English NHS doctors. Consistently with Figure 2, around the Brexit referendum date there was no considerable change in the joining and leaving rates of both European and non-European doctors.

So far, we have assumed that the drop in EU nurses joining rates was entirely due to the uncertainty triggered by the BR outcome, although a concomitant driver of such drop could be, at least partially, the new English language requirement imposed in January 2016 on prospective nurses from the EU (see Section 2.2). To assess which of these two shocks was mostly responsible for the aforementioned drop, in Figure 4 we plot the yearly percentage-point change in the monthly number of EU joiner nurses around the January and June 2016 dates. Figure 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. The relative irrelevance of the English language requirement is similar to the case occurred for EU hospital doctors, whose NHS joining rate did not change when a similar English language requirement was introduced in June 2014 (see panel a of Figure A.1).

3 Empirical strategy

We test the relationship between hospital quality and the drop in EU joining nurses following the June 2016 referendum outcome using a linear specification in differences:

$$\Delta Q_h = \beta_0 + \beta_1 \Delta EUJOIN_h + u_h, \tag{1}$$

where Δ is an operator taking the difference between a given variable in a 12-month post-referendum period and the same variable in the 12 months preceding the Brexit referendum (i.e. from July 2015 to June 2016). Q_h is hospital h quality, measured as the average of risk-adjusted standardized mortality or unplanned readmission rates over a 12 months period. Similarly, $EUJOIN_h$ is the average joining rate of EU nurses up to pay band 5 in hospital h over a 12-month period; as such, $EUJOIN_h$ is computed as the number of new joiners in during a 12-month period divided by the average of total nurse staff employed at hospital organization h in the baseline year from July 2015 to June 2016. Our baseline model uses the EU nurse joiner rate as the variable of interest since the BR primarily impacted this hospital labour supply dimension, as shown in section 2; in section 5, we demonstrate that our results are qualitatively equivalent if we use the share of EU nurses as the variable of interest, which also decreased after the BR (see Figure 2).[6]

The parameter β_1 measures how the post-referendum change in the number of EU joining

[6]Our preferred specification has the EU joiner rate in the RHS of Equation 1 because compositional changes in the share of EU nurses may result from two different types of labour market shocks: (i) a decrease in the EU nurse joining rates, which effectively occurred; (ii) and an increase in the EU nurse leaving rate, which instead did not result sharply from the BR outcome (see Figure 3).

nurses affects changes in the quality of care of English NHS hospitals. By focusing on changes in hospital quality indicators before/after the BR, rather than levels, we difference out all the time-invariant determinants of hospital quality. By focusing on changes in the EU joining rate before/after the BR, we are instead able to exploit the unexpected variation in the EU nurse joining rate induced by the BR. Therefore, we can rule out concerns of reverse causality as time-invariant hospital quality and EU nurse joining rate components are both differenced out.[7]

As the consequences of the BR on the hospital nursing workforce accumulated over time (see Figure 2), we investigate this relationship separately over three different post-referendum periods: (i) from July 2016 to June 2017 (i.e. 2016/17); (ii) (i) from July 2017 to June 2018 (i.e. 2017/18); and (i) from July 2018 to June 2019 (i.e. 2018/19). We also estimate Equation 1 by pooling all these yearly records together, in order to increase the power of our estimates if compared to a simple yearly cross-sectional regression. In this case, we augment the right-hand side of Equation 1 with dummies for each time subperiod t, which control for quality shocks to patient care that hit all hospitals during each of the three different 12-months periods pooled together, and we cluster standard errors at hospital organization level.

The OLS estimates of β_1 do not identify the effect of EU nurse joining rate on hospital quality, unless the EU nurses' joining rate is exogenous. Given the unexpected outcome of the Brexit referendum and the uncertainty for workers and businesses that it caused until a Brexit deal was agreed with the European Union (only in late 2020), the change in the EU nurse joining rate could be thought as plausibly exogenous and unrelated to unobserved hospital quality characteristics. Still, some concerns of endogeneity remain. For instance, there may be bias due to simultaneity, i.e. if changes in EU nurse joining rate is both a driver and a function of changes in hospital quality, or to time-varying latent factors that correlate with both hospital quality and EU nurse joining rate.

For this reason, our main empirical strategy relies on an instrumental variable specification estimated through two-stage least squares (2SLS), in which we instrument the variable of interest, $\Delta EUJOIN_h$, with the historical EU nurse joining rate of the same hospital organization measured in the five years prior to the Brexit referendum, i.e. from June 2011 to July 12:

$$\Delta EUJOIN_h = \alpha_0 + \alpha_1 EUJOIN_{-5,h} + \eta_h. \tag{2}$$

In Section 4 we show that the historical EU nurse joining rate of the hospital is a strong predictor of the post-referendum change in EU joining nurses; it is reasonably more exoge-

[7]Reverse causality bias might occur if historically better-quality (worse-quality) hospital organizations attracted more (less) EU nurse joiners than the national average.

neous than the contemporaneous EU nurses' joining rate, because it is measured around five years prior to the Brexit referendum shock, thus reducing concerns related to simultaneity or time-varying unobserved confounding. Furthermore, as recently shown by Angrist and Kolesár (2023), the finite sample statistical behaviour of just-identified IV strategies like ours is simple and transparent, allows the use of standard t, F and Anderson-Rubin tests, and guarantees a high confidence interval coverage "unless endogeneity is extraordinarily high".

We also provide 2SLS estimates employing alternative instruments, i.e. we instrument $\Delta EUJOIN_h$ with the 2001 share of EU national residents in the 90-km radius of each hospital headquarter from the UK census ONS data. This census enclave approach has two main advantages: it allows us to validate our main findings by using an IV that comes from a different dataset than the ESR; the census enclave IV is measured in 2001, therefore it is more predetermined to the Brexit referendum than our past EU nurse joining rate. Even in this case, we show that the share of local residents from Europe is a significant predictor of the change in EU nurses' joining rate following the 2016 Brexit referendum. Migrant workers tend to geographically sort into sub-community enclaves in the hosting country. Thus, hospitals located in areas with a historically larger share of EU migrants likely experienced a larger drop in the inflow of EU joiner nurses.

Both IVs – the one based on the past share of EU joiner nurses and the one based on the past share EU national residents – are strongly and negatively correlated with the post-BR change in EU joiner nurses, due to the aggregative nature of migrants' enclaves. Foreign workers of any skillset level may prefer settling in areas with larger enclaves of foreigners for both cultural and informal safety-net reasons. As such, hospitals in areas with larger historical EU immigration attract more EU job applicants and rely more heavily on their inflow to fill open vacancies. If prospective migrant workers from the EU believe immigration restrictions following the BR will negatively affect their career and life prospects in the UK, they will stop considering moving to the UK. In this case, it is likely — and consistent with the empirical patterns we observe — that hospital organizations in locations with larger EU enclaves receive a stronger negative shock on their labour supply and are more affected by the BR results.

4 Results

4.1 Summary statistics

Our final analysis sample includes up to 144 hospitals for which we can compute mortality and emergency readmission indicators over the period from July 2015 to June 2019. Table 1 provides some summary statistics. Over the 12 months prior to the Brexit referendum (columns 1 and 2), the average mortality risk for an emergency patient was 6.1%. It was only 0.62% for a patient admitted with an elective condition. Instead, the probability of an emergency readmission was 14.45% (6.36%) for an emergency (elective) patient.

Table 1. Summary Statistics

	Pre-Brexit		Post-Brexit change	
	Mean	SD	Mean	SD
30-day Mortality (Emergency patients)	6.10	7.26	-0.36	3.27
30-day Mortality (Elective patients)	0.62	0.44	0.02	0.23
30-day Readmission Rate (Emergency patients)	14.45	2.34	0.47	2.13
30-day Readmission Rate (Elective patients)	6.36	1.13	0.41	1.11
EU Nurses' Joining Rate	21.69	27.55	-14.06	23.48
Non-EU Nurses' Joining Rate	4.84	7.22	2.32	14.76
Percentage of British Nurses	70.18	17.26	-0.32	4.04
Percentage of EU Nurses	12.41	9.61	-1.89	4.26
Percentage of Non-EU Nurses	14.28	9.06	2.70	5.42
Total Nurses	861.68	502.80	-19.04	116.50
Number of hospitals (N)	144			

Notes: The pre-Brexit period corresponds to the 12 months prior to the Brexit referendum, i.e. from July 2015 to June 2016. The post-Brexit values are computed as the grand average of the yearly average values in the first three years following the Brexit referendum, i.e. July 2016-June 2017, July 2017-June 2018 and July 2018-June 2019.

Almost 22 EU nurses per 1,000 staff and hospital joined the English NHS in the 12 months leading to the referendum. This amount is considerably larger than that associated with non-EU joiners, as already shown by Figure 3. However, the share of non-EU nurses (0.143) is generally higher than that of EU nurses (0.124). On average, a English NHS hospital in our sample has approximately 862 nurses.

In the three years following the Brexit referendum, the mortality risk of emergency patients decreased by 0.36 percentage points, whereas that of elective patients remained largely constant. The emergency readmission risk increased by more than 0.40 percentage points, for both emergency and elective patients. The EU nurse joining rate decreased by almost

66% in the post-Brexit period. On the contrary, the non-EU nurse joining rate increased by around 50%. As a result, the average share of EU (non-EU) nurses in the English NHS decreased by 1.89 (increased by 2.70) percentage points. Finally, the average number of hospital nurses reduced by 19 units.

4.2 Main results

Columns 1-4 of Table 2 report the OLS estimates of β_1. We estimate Equation 1 based on four different sub-samples; the first three, reported in panels A, B and C, respectively use the differences in hospital quality and EU nurse joining rates in years 2016/17, 2017/18 and 2018/19 versus the baseline pre-BR year 2015/16; the last one, reported in panel D, is the stacked regression of the differences above.

The change in the EU nurses' joining rate has a negative association with all hospital quality measures except the elective patients' mortality rate. Since most of the sample variation in the EU nurses' joining rate results from the unexpected and sudden consequences of the Brexit referendum, this finding suggests that an increase in the number of EU nurses (up to pay band 5) joining the English NHS has the potential to improve patient care quality. However, the only statistically significant association arises when the quality indicator is the emergency readmission risk for elective patients (Column 4), where the coefficient of interest, β_1, is negative and statistically significant at 5% level in three out four regression panels of Table 2 (Panels A, C and D).

The OLS estimate of β_1 using the stacked regression, our preferred model specification, indicates that an additional 100 joining nurses from Europe per 1,000 staff members reduce 30-day unplanned emergency readmission rate by 0.9 percentage points. Columns 5-9 of Table 2 report the 2SLS estimates of (1), where the change (with respect to the 12 months prior to the Brexit referendum) in the EU nurse joining rate is instrumented with the historical 2011/12 EU nurse joining rate of the same hospital organization. The first-stage coefficients (reported in Column 5) show that the IV strongly predicts the post-Brexit drop in the EU nurses' joining rate: the IV coefficient is negative and significant at 1% level, so hospitals with higher past EU nurse joining rates experienced the most pronounced decrease in the EU joining rate after the outcome of the June 2016 referendum. Despite the small sample size, the corresponding first-stage F-statistics values range from 20.60 (Panel A) to 25.63 (Panel D), thus considerably above the minimum threshold of 10 that has been frequently used in the weak instrument literature (Stock et al. 2002, Hahn and Hausman 2003).

Moreover, even if our first-stage F-statistic is above the 10-20 value critical range, for each specification we report the Anderson and Rubin (1949) test statistic (henceforth, AR49)

Table 2. The effect of EU nurse joining rate on hospital quality (*OLS and 2SLS estimates*)

	OLS				2SLS				
					1st stage	2nd stage			
	Δ Mortality		Δ Em. Readmission			Δ Mortality		Δ Em. Readmission	
	Emergency	Elective	Emergency	Elective	Δ EU Joining Rate	Emergency	Elective	Emergency	Elective
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A: 2016/17 vs 2015/16									
Δ EU Joining Rate	-0.022	0.001	-0.009*	-0.007**		0.043	-0.004	-0.018	-0.020*
	(0.020)	(0.001)	(0.005)	(0.003)		(0.052)	(0.002)	(0.012)	(0.010)
EU Joining Rate (2011/12)					-0.801***				
					(0.177)				
F-stat					20.60				
Anderson-Rubin test (p-value)						0.79 (0.38)	3.65 (0.06)	2.27 (0.13)	4.83 (0.03)
Kleibergen-Paap test (p-value)						6.81 (0.01)	7.12 (0.01)	7.12 (0.01)	7.12 (0.01)
Panel B: 2017/18 vs 2015/16									
Δ EU Joining Rate	-0.009	0.000	-0.003	-0.008*		0.039	-0.004*	-0.013	-0.015
	(0.008)	(0.001)	(0.004)	(0.004)		(0.043)	(0.002)	(0.014)	(0.010)
EU Joining Rate (2011/12)					-0.888***				
					(0.194)				
F-stat					21.00				
Anderson-Rubin test (p-value)						0.85 (0.36)	3.49 (0.06)	0.84 (0.36)	2.86 (0.09)
Kleibergen-Paap test (p-value)						12.06 (0.00)	12.63 (0.00)	12.06 (0.00)	12.63 (0.00)
Panel C: 2018/9 vs 2015/6									
Δ EU Joining Rate	-0.005	0.000	-0.002	-0.011**		0.054	0.000	-0.025	-0.030***
	(0.004)	(0.001)	(0.006)	(0.005)		(0.057)	(0.002)	(0.020)	(0.010)
EU Joining Rate (2011/12)					-0.986***				
					(0.200)				
F-stat					24.40				
Anderson-Rubin test (p-value)						0.91 (0.34)	0.02 (0.88)	1.47 (0.23)	10.66 (0.00)
Kleibergen-Paap test (p-value)						11.64 (0.00)	12.04 (0.00)	12.04 (0.00)	12.04 (0.00)
Panel D: Stacked vs 2015/16									
Δ EU Joining Rate	-0.011	0.001	-0.004	-0.009**		0.046	-0.002	-0.019	-0.022***
	(0.009)	(0.001)	(0.004)	(0.004)		(0.051)	(0.002)	(0.012)	(0.009)
EU Joining Rate (2011/12)					-0.891***				
					(0.176)				
F-stat					25.63				
Anderson-Rubin test (p-value)						0.86 (0.35)	2.01 (0.16)	2.28 (0.13)	8.79 (0.00)
Kleibergen-Paap test (p-value)						10.34 (0.00)	10.78 (0.00)	10.78 (0.00)	10.78 (0.00)

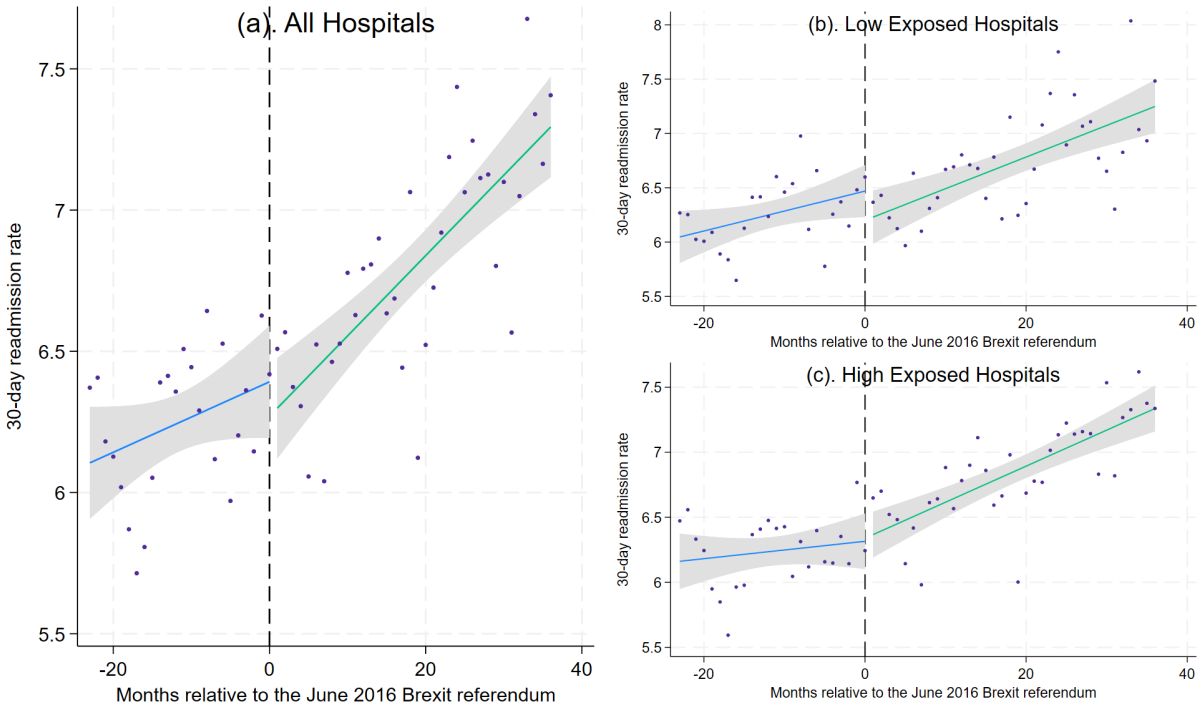
Notes. Columns (1) to (4) report the OLS estimates of β_1. Column (5) reports the OLS estimates of the first stage regression coefficient α_1. Columns (6) to (9) report the 2SLS estimates of β_1. Huber-White heteroschedasticity-robust standard errors in Panels A, B and C; heteroschedasticity-robust standard errors clustered at hospital organization level in Panel D. Significance levels: *p<0.1; **p<0.05; ***p<0.01.

– which is robust to the "power asymmetry" problem rending the first stage t-test unreliable according to Keane and Neal (2023) even when instruments are quite strong – along with its p-value. As we show, the AR49 statistic for the emergency readmissions of elective patients is significant at 1% level in specifications reported in Panel C and D, and at 5% in Panel A, but generally never significant at 5% level in any other hospital quality outcome. The Kleibergen and Paap (2006) rank Wald statistic is significant at 1% level or below for any specification, casting away major doubts regarding the underidentification of the 2SLS estimates.

The second-stage coefficients are in line with the OLS results. There is no statistically meaningful relationship between the number of nursing joiners from Europe and the first three hospital quality indicators, whereas a change in the EU nurse joining rate has a negative effect on the change in the emergency readmission risk of elective patients. Compared to OLS, the 2SLS estimates are about more than twice as large. According to the stacked specification reported in Panel D, an additional 100 joining nurses from Europe per 1,000 staff members reduce the emergency readmission rate by about 2.2 percentage points.

These results find also a graphical confirmation in Figure 5. We split the hospital sample

Figure 5. Emergency readmission trends by hospital exposure to EU migration



Notes. 30-day emergency readmission rates among elective patients over time. The split between low- and high-exposure hospitals is based on the hospital joining rate of EU nurses (up to pay band 5) in 2011. Hospitals with a historically higher joining rate among EU nurses were more exposed to the migration consequences of the June 2016 Brexit referendum, which has led to a sharp drop in the number of EU nurses joining the English NHS (see Figure 3).

based on whether, during financial year 2011/12, hospitals recorded a EU pay band 1-5 nurse joining rate falling below (low-exposure) or above (high-exposure) the median of the overall sample distribution, and plot 30-day elective patients' readmissions rates levels over the months around the Brexit referendum. The scatterplot shows not only that the emergency readmission rates of elective patients increased after the Brexit referendum, but also that such increase was driven by the high-exposure hospitals.

Overall, these findings suggest that the immigration shock to the English NHS hospital sector labour market caused by the Brexit referendum decreased hospital quality, at least when measured by the elective patients' emergency readmission rate.

5 Robustness checks and mechanisms

In this section, we provide additional checks testing the robustness of our findings to several methodological or institutional factors, as well possible mechanisms at play behind the main results. All estimates reported in Table 3 are from our preferred stacked specification, whereas the corresponding yearly cross-sectional estimates are reported in Tables A.2, A.3 and A.4.

5.1 2SLS estimates based on a residents' census IV

Table 3, Panel A reports the 2SLS estimates of β_1 when the change in EU nurse joining rates is instrumented with the share of EU residents within 90km from each hospital headquarter, which we computed from the UK 2001 census. The first stage coefficient is significant (with F-stat=23.14), suggesting that also the 2001 local share of EU residents is a strong predictor of the post-referendum drop in EU nursing joiners: hospitals located in areas with more EU-born residents experienced the most pronounced reduction in the EU nurse joining rate.

The second-stage estimate of the effect of the EU nurse joining rate on unplanned elective patients' emergency readmissions is negative, significant at 5% level and of similar magnitude to the baseline estimate reported in Panel D of Table 2. Again, the effects on 30-day mortality and unplanned emergency patients' emergency readmissions are not significantly different from zero.

The same conclusions can be drawn from Table 3, Panel B, which uses the 2011 share of EU census residents as IV. The first stage coefficient is negative and significant at 1% level (with a F-stat=22.04), whereas the second-stage effects on hospital quality are broadly similar to those displayed in Panel A.

5.2 2SLS estimates excluding Irish nurses

So far, our analysis has grouped together English NHS nurses from all EU countries into one single group. However, Figure A.2 shows that the drop in EU joiners following the Brexit referendum has primarily interested nurses from Southern and Eastern EU countries. This fact may represent a concern for our results, as a large share of EU nurses joining the English NHS come from the Republic of Ireland, a country with historical and geographical stronger links with the UK than the rest of Europe. Most importantly, the outcome of the Brexit referendum likely had a limited effect on the Irish nurses' intention to move to the UK and join the English NHS, because the freedom of movement between the Republic of Ireland

Table 3. Robustness checks (*stacked panel specification*)

	1st stage	2nd stage			
		Δ Mortality		Δ Em. Readmission	
		Emergency	Elective	Emergency	Elective
	(1)	(2)	(3)	(4)	(5)
Panel A: 2001 Census	Δ EU Joining Rate				
Share of EU residents within 90km (2001 Census)	-8.822*** (1.834)				
Δ EU Joining Rate		0.038 (0.039)	0.000 (0.002)	-0.019 (0.014)	-0.018** (0.007)
F-stat	23.14				
Anderson-Rubin test (p-value)		1.06 (0.30)	0.03 (0.87)	2.05 (0.15)	6.31 (0.01)
Kleibergen-Paap test (p-value)		18.24 (0.00)	19.28 (0.00)	19.28 (0.00)	19.28 (0.00)
Panel B: 2011 Census	Δ EU Joining Rate				
Share of EU residents within 90km (2011 Census)	-4.635*** (0.987)				
Δ EU Joining Rate		0.036 (0.039)	0.000 (0.002)	-0.017 (0.014)	-0.017** (0.008)
F-stat	22.04				
Anderson-Rubin test (p-value)		0.98 (0.32)	0.05 (0.82)	1.44 (0.23)	5.50 (0.02)
Kleibergen-Paap test (p-value)		17.67 (0.00)	18.73 (0.00)	18.73 (0.00)	18.73 (0.00)
Panel C: without Irish Nurses	Δ EU Joining Rate				
EU Joining Rate (2011/12)	-1.351*** (0.198)				
Δ EU Joining Rate		-0.009 (0.015)	-0.002 (0.002)	-0.024* (0.014)	-0.018** (0.009)
F-stat	46.55				
Anderson-Rubin test (p-value)		0.39 (0.53)	0.03 (0.87)	2.06 (0.15)	5.77 (0.02)
Kleibergen-Paap test (p-value)		8.56 (0.00)	8.88 (0.00)	8.88 (0.00)	8.88 (0.00)
Panel D: excluding London	Δ EU Joining Rate				
EU Joining Rate (2011/12)	-1.674*** (0.384)				
Δ EU Joining Rate		-0.004 (0.006)	-0.001 (0.002)	-0.023* (0.012)	-0.021** (0.009)
F-stat	18.97				
Anderson-Rubin test (p-value)		0.38 (0.54)	0.48 (0.49)	4.64 (0.03)	5.22 (0.02)
Kleibergen-Paap test (p-value)		9.23 (0.00)	9.33 (0.00)	9.33 (0.00)	9.33 (0.00)

Notes. Column (1): OLS estimates of the first stage regression coefficient α_1. Columns (2) to (5): 2SLS estimates of β_1. Standard errors are heteroschedasticity-robust and clustered at hospital organization level. Significance levels: *p<0.1; **p<0.05; ***p<0.01.

and the UK was guaranteed by the Common Travel Area (CTA), and therefore beyond an eventual departure of the UK from the EU.

In this section, we replicate our baseline analysis after excluding the Republic of Ireland from our EU group. First, Figure A.4 plots the nurses' joining rate from the Republic of Ireland (Panel a) and the rest of Europe (Panel b). The two figures confirm what mentioned above, namely that the drop in EU nurses joining the English NHS did not regard Irish nurses, but rather only nurses from EU countries. Second, Table 3, Panel C, reports the 2SLS β_1 estimate once Irish nurses have been removed from the computation of both the historical 2011/12 EU nurse joining rate of the hospital and the change in EU joiners in each of the three post-referendum years.

The results are consistent with those provided in the rest of the paper. The first-stage F-statistics are greater than those reported in the main results and the census-based IVs (Table 3, Panels A and B), suggesting the validity of excluding Irish nurses from the EU group.[8] The second stage 2SLS estimate of the pooled model is negative, significant at 5% level and with a magnitude very similar to the previous results, confirming once again that a drop in EU nurse joiners leads to a significantly higher emergency readmission risk for

[8]This exercise cannot be replicated with UK Census data, as there is no breakdown by country of origin.

elective patients.

5.3 2SLS estimates excluding London hospitals

Another concern related to our baseline findings is the inclusion in the analysis sample of the group of hospitals located in the London metropolitan area, which may represent outliers in terms of the EU nurse joining rate given the large European community that has historically settled in the English capital. For this reason, we explore the sensitivity of our results by providing 2SLS estimates after excluding the subgroup of London hospitals from the analysis sample.

Results for this exercise are provided in Panel D of Table 3 and they are consistent with the baseline analysis. If anything, excluding London hospitals seems to make our effect of interest on elective patients' readmission risk even slightly larger in magnitude. We conclude that the findings of this study are not driven by the subgroup of hospitals located in the London area.

5.4 Mechanisms: leavers, staff shortages and composition

There are several mechanisms that might help explaining the findings of our work. First, we replicate the baseline analysis but replacing the number of EU nursing joiners with that of EU nursing leavers. Although Figure 3 shows that the drop in the share of nurses from Europe following the Brexit referendum was almost entirely due to a drop in the number of joiners, hospitals more exposed to EU migration might have experienced even an increase in the number of leavers, which itself has the potential of affect hospital quality. The OLS estimates are provided in Table A.1, whereas Panel A of Table 4 reports the 2SLS estimates: the first stage coefficient is weak (F-stat=0.07) and indicates that there was no significant increase in the number of EU nursing leavers in those hospitals with an historical high EU leaving rate. The effect on elective patients' emergency readmissions (column 5) is negative but not statistically significant.

Panel B of Table 4 provides 2SLS β_1 estimates in which we replace the change in the EU nurses' joining rate with the change in the total number of nurses at the hospital level, which we still instrument with the historical EU nurses' joining rate. The first-stage coefficient is not statistically significant, suggesting that hospitals particularly exposed to EU migration did not experience any significant drop in total staff levels, despite recording a considerable drop in the number of joining nurses from Europe. We conclude that the nursing staff shortages are unlikely to explain our main findings.

Third, we investigate the confounding from the joining rate of non-EU nurses. Figure 3

shows that the drop in the EU nurse joining rate was followed by a lagged increase in the number of nurses joining the English NHS from outside Europe. Therefore, we estimate our baseline specification by replacing the EU nurse joining rate with that of non-EU nurses. The OLS estimate is provided in Panel D of Table A.1. The coefficients indicate that the number of non-EU joiners is at most associated with a lower emergency readmission risk among patients that were originally admitted for an emergency condition, and we do not find any significant correlation with mortality indicators. We also provide two sets of 2SLS estimates. In the first one, reported in Panel C of Table 4, we instrument the number of non-EU joining nurses with the 2011/12 EU nurse joining rate, to test whether hospitals suffering the larger drops in EU joiner nurses also experienced a compensating increase in the number of joiners from overseas. The first-stage coefficients are all positive but not statistically significant: we do not find any evidence of an increase in the number of non-EU joiners in hospitals experiencing the larger post-Brexit referendum decrease in EU joiners. Very similar findings emerge from Panel D, where the change in the number of non-EU joiners has been instrumented with the historical 2011/12 hospital-level non-EU nurse joining rate.

Table 4. Mechanisms (Stacked panel specification)

	1st stage	2nd stage			
		Δ Mortality		Δ Em. Readmission	
		Emergency	Elective	Emergency	Elective
	(1)	(2)	(3)	(4)	(5)
Panel A: EU leavers	Δ EU Leaving Rate				
EU Leaving Rate (2011/12)	-0.035 (0.128)				
Δ EU Leaving Rate		0.255 (1.664)	-0.042 (0.149)	-0.328 (1.180)	-0.298 (1.089)
F-stat	0.07				
Anderson-Rubin test (p-value)		0.34 (0.56)	3.80 (0.05)	2.04 (0.15)	5.77 (0.02)
Kleibergen-Paap test (p-value)		0.02 (0.88)	0.08 (0.78)	0.08 (0.78)	0.08 (0.78)
Panel B: Staff levels	Δ Total Nurses' Levels				
EU Joining Rate (2011/12)	0.166 (0.640)				
Δ Total Nurses' Levels		-214.605 (760.505)	11.594 (46.336)	101.504 (419.562)	118.474 (452.697)
F-stat	0.07				
Anderson-Rubin test (p-value)		0.86 (0.35)	2.01 (0.16)	2.28 (0.13)	8.79 (0.00)
Kleibergen-Paap test (p-value)		0.08 (0.78)	0.06 (0.80)	0.06 (0.80)	0.06 (0.80)
Panel C: non-EU joiners (EU enclave as IV)	Δ Non-EU Joining Rate				
EU Joining Rate (2011/12)	0.177 (0.133)				
Δ Non-EU Joining Rate		-0.222 (0.265)	0.011 (0.011)	0.095 (0.093)	0.111 (0.090)
F-stat	1.77				
Anderson-Rubin test (p-value)		0.86 (0.35)	2.01 (0.16)	2.28 (0.13)	8.79 (0.00)
Kleibergen-Paap test (p-value)		2.16 (0.14)	2.08 (0.15)	2.08 (0.15)	2.08 (0.15)
Panel D: non-EU joiners (non-EU enclave as IV)	Δ Non-EU Joining Rate				
Non-EU Joining Rate (2011/12)	0.667 (0.548)				
Δ Non-EU Joining Rate		0.000 (0.020)	-0.006 (0.006)	0.032 (0.042)	0.031 (0.043)
F-stat	1.48				
Anderson-Rubin test (p-value)		0.00 (1.00)	2.00 (0.16)	0.91 (0.34)	1.68 (0.19)
Kleibergen-Paap test (p-value)		1.15 (0.28)	1.14 (0.28)	1.14 (0.28)	1.14 (0.28)
Panel E: EU nurses' share	Δ EU Nurses' Share				
EU Joining Rate (2011/12)	-0.173*** (0.032)				
Δ EU Workers' Share		0.230 (0.252)	-0.011 (0.007)	-0.097 (0.069)	-0.113*** (0.042)
F-stat	29.13				
Anderson-Rubin test (p-value)		0.86 (0.35)	2.01 (0.16)	2.28 (0.13)	8.79 (0.00)
Kleibergen-Paap test (p-value)		4.94 (0.03)	4.90 (0.03)	4.90 (0.03)	4.90 (0.03)

Notes. Column (1): OLS estimates of the first stage regression coefficient α_1. Columns (2) to (5): 2SLS estimates of β_1. Standard errors are heteroschedasticity-robust and clustered at hospital organization level. Significance levels: *p<0.1; **p<0.05; ***p<0.01.

Fourth, to test whether our results are rather due to a change in the staff composition,

we replace the change in the EU nurse joining rate with the change in the share of EU nurses, which has substantially decreased following the Brexit referendum (see Figure 2). Because the hospital share of EU workers is a stock variable that takes time to adjust, we measure it over the second quarter (i.e. from April to June) of each of the four years around the BR date, rather than over an entire yearly period. The results of this exercise are displayed in Panel E of Table 4. The first-stage coefficients are negative and significant at the 1% level, with a F-stat of 29.13. Thus, hospitals with an historically higher joining rate of EU nurses experienced a more significant drop in their EU workforce. The second-stage coefficients are in line with those reported in Table 2. A higher share of EU nurses is associated with a lower readmission risk among elective patients. Instead, there is no statistically meaningful relationship with the other hospital quality measures. Hence, the findings of this paper appear driven by the change in the hospital staff composition induced by the Brexit referendum.

To conclude, in the specifications reported in Table 4, the values of the AR49 and Kleibergen-Paap statistics are in line with the baseline analysis shown in Table 2.

6 Conceptual Framework

The administrative data that we have access to for this study does not include any variable capturing either the quality of NHS workers, their educational degree grades or their English language proficiency. Therefore, we develop a simple conceptual framework to guide the interpretation of our empirical results about the impacts of the Brexit referendum on workforce composition and hospital quality. This model also allows us to formalize and study the BR's heterogeneous effects 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

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

[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.

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 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

$$\max_{h:\mathbb{R}\to[0,1]} \int q(\theta)h(\theta)a(\theta)d\theta. \tag{3}$$

[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.

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

subject to

$$\int h(\theta)a(\theta)d\theta \leq M. \tag{4}$$

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 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 losses the Brexit enforcement regulation might cause to EU national workers based in the UK, such as increased costs for travels, visa, recognition of overseas-acquired qualifications and 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.*

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

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.

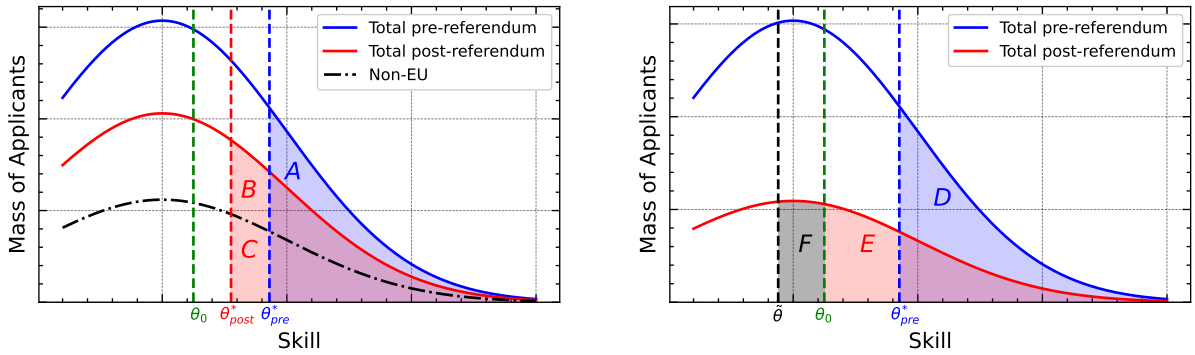
In our model, the resulting hiring skill cutoff θ^* is the same for EU and non-EU workers pre and post-referendum. The decrease in the quality of care stems from substituting higher-skill EU workers with lower-skill workers of any origin, i.e. Europeans, non-Europeans, and British. Figures 6 and 7 illustrate this substitution pattern when we observe worker shortages and when we do not, as well as across low and high-exposure hospitals.

Figure 6a 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 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 6b 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.

Figure 6. Model implied applicant pool and hiring cutoffs.



(a) No worker shortages

(b) Increased worker shortages

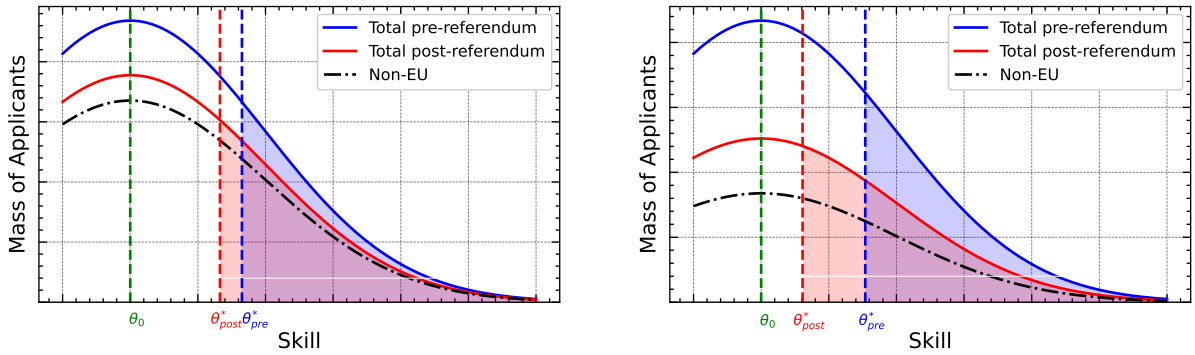
Our empirical results are consistent with the case depicted in Figure 6a. The immediate shortages of hospital nurses after the BR changed hospital staff composition by nationality and the hiring skill level. θ^*_{post} decreased, but not below the standard NHS hiring cutoff θ_0. Therefore, the quality of hospital care decreased but only slightly, significantly increasing the emergency readmissions of planned patients – who are less frail and risky patients than emergency patients – and without any significant impact on hospital mortality. Instead, in case serious nursing staff shortages had arisen after the BR, the corresponding scenario depicted in Figure 6b would have seen a likely significant deterioration of hospital quality indicators such as mortality and emergency readmissions of emergency patients.

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 (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 7a and 7b 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 7a than in 7b. 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 7. High versus Low Exposure.



(a) Low-exposure Hospitals

(b) High-exposure Hospitals

Finally, our model sheds light on why we might observe the referendum's effects for some occupations (junior nurses) but not others (doctors and senior nurses). We show that the effect of a decrease in γ_e on the set of hired workers vanishes as the 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 for high-paying jobs, such as the roles of NHS hospital doctors, the decrease in the non-wage benefits of moving to the UK is small compared to the monetary gains. As the referendum did not affect the NHS wages, it has little effect on the applicants' decisions when ω's are large. This explains why there was a drop of EU joiners for hospital nurses, who are relatively low-paid, and not for hospital doctors, whose yearly salary is much higher.

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

Proposition 3 is useful to explain several other patterns in our data. NHS senior hospital doctors – in our sample defined as both NHS *consultants* and *SAS* (specialty and associate specialty) contract physicians – earn monthly gross salaries that are 2-2.5 times higher than entry-level (Pay Band 1-5) NHS hospital nurses, therefore EU national senior hospital doctors are not largely deterred to migrate to the UK and work for NHS hospitals by the BR. Similarly, senior nurses (Pay Band 6-9) have higher pays than entry-level NHS hospital nurses, therefore EU nationals hired as senior nurses have lesser incentives not to join the NHS.

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 (and doctors) who are employed in the English NHS hospital 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 decrease of new EU nationals nurse joiners, but not to a significant increase of existing EU nationals nurse leavers. Prospective foreign workers decide whether to move to work in a given host country forming expectations based on the existing labour market conditions, and revising 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 are less responsive to the Brexit referendum outcome, either because they have already gained settlements rights, or because they wait to react to the final immigration regulatory framework that defines their rights (in our case, the 2020 European Union Withdrawal Agreement Act), or because the divestment process to move out of the UK is very costly if performed too quickly.

Moreover, and quite importantly, we find that sudden changes in the composition of skilled workers have the potential to disrupt, at least partially, the quality of services provided. In the case we studied, a missing intake of 100 hospital nurse joiners from Europe per 1,000 staff members increases the emergency readmission rate for elective patients by about 2.2 percentage points (95% confidence interval: [-3.96; -0.44]), which is equivalent to an increase of 29,480 elective patients' unplanned readmissions per year, based on the 2015/16 figures used to compute elective patients' readmission rates (1.34 million). With an estimated average £2,100 cost per 30 day readmission (Billings et al., 2012), this translates into additional £61,908,000 (95% confidence interval: [£12,269,040.00; £111,546,960]) costs per year for the NHS, or £429,916.67 (95% confidence interval: [£85,202; £774,632]) per year for each of the 144 NHS hospital Trusts in our analysis.[13] In terms of the 2016 regulated NHS nurse pay scales, by avoiding the estimated increase in unplanned hospital readmissions due to the Brexit referendum shock and its implied costs (£61.9MM), the NHS hospital sector would have been able to afford recruiting additional 2,447 (Band 5) staff nurses, or 2,039 (Band 6) senior nurses, or 1,707 (Band 7) nurse practitioners.

Instead, we find no significant effect on changes in hospital-related mortality and unplanned readmissions of emergency patients. Additional results suggest that the Brexit ref-

[13]The total cost at the mean is computed as 1,340,000*0.022*2,100.

erendum did not affect the quality of elective hospital care through shortages, but through changes in the composition of the workforce. Our conceptual framework reconciles all the results above, showing that compositional changes in the NHS hospital nursing workforce prevented the insurgence of long-lasting and severe nurse shortages, but likely at the cost of a decrease in the quality of new hires: 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. Therefore, a significant impact only on the least severe measure of hospital quality – readmissions of planned patients – and no significant impacts on the most severe quality indicators, such as patient mortality, is consistent with newly hired workers' quality falling, but the overall nursing staff quality still higher than a critical cutoff level.

The takeaway message of our study is that, in countries relying on skilled foreign labour force such as the US and the UK, political initiatives that are expected to have an impact on immigration patters should be carefully weighed against the potential disruptions to the labour supply chain in critical sectors of the economy, such as healthcare. The central message that making a country less attractive for immigration harms the supply of skilled workers applies to many scenarios, spanning from Brexit-like policies to several commonly proposed and implemented anti-immigration policies. Beyond the direct short-term effect on skilled workers' labour supply discussed here, these policies might have severe long-term impacts. For instance, creating immigration barriers can affect the size (or even the existence) of migrants' local enclaves, thus influencing the inflow of prospective workers of any skill type. Even in institutional contexts where policy-makers and voters strictly prefer to host primarily foreign skilled workers, the latter might prefer settling in countries with larger enclaves of foreigners. Banning low-skill workers' immigration might shrink the size of the local enclaves and potentially discourage foreign high-skill workers from moving to or remaining in the host country. Understanding both the short and long-term effects of immigration policies remains a crucial topic for future research.

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 the productivity of an economy, or, at the very least, of the sectors most exposed to immigration-related labour supply shocks.

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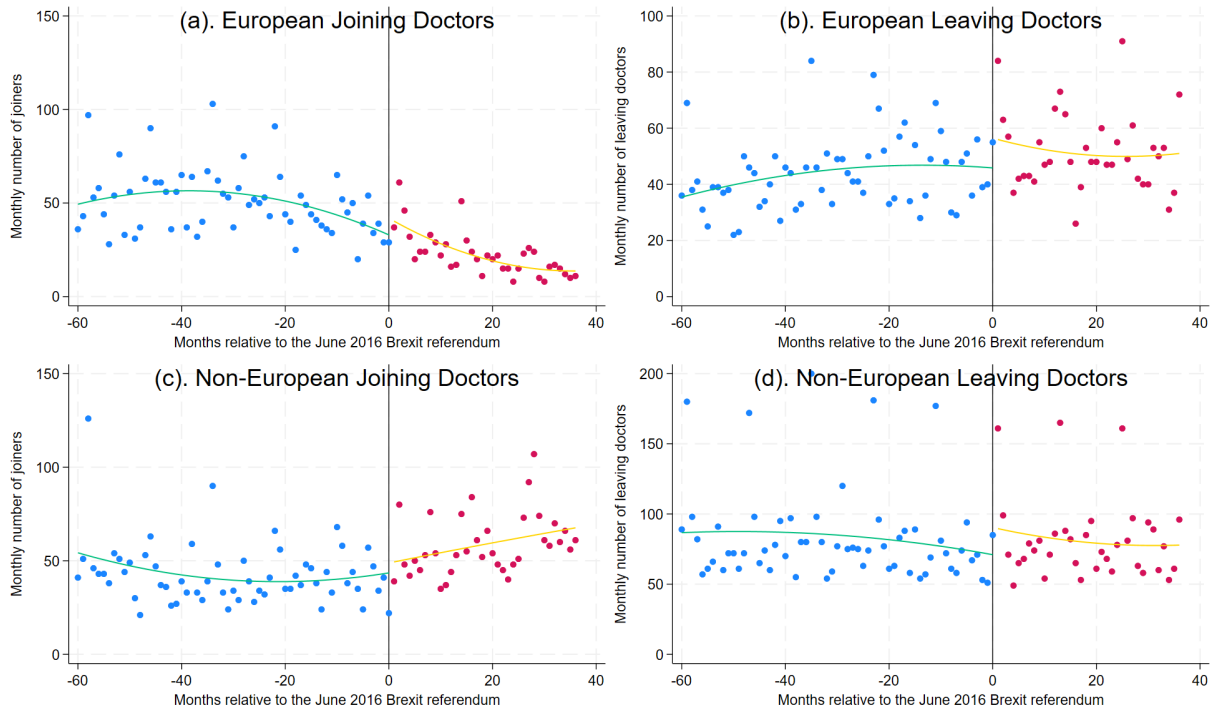
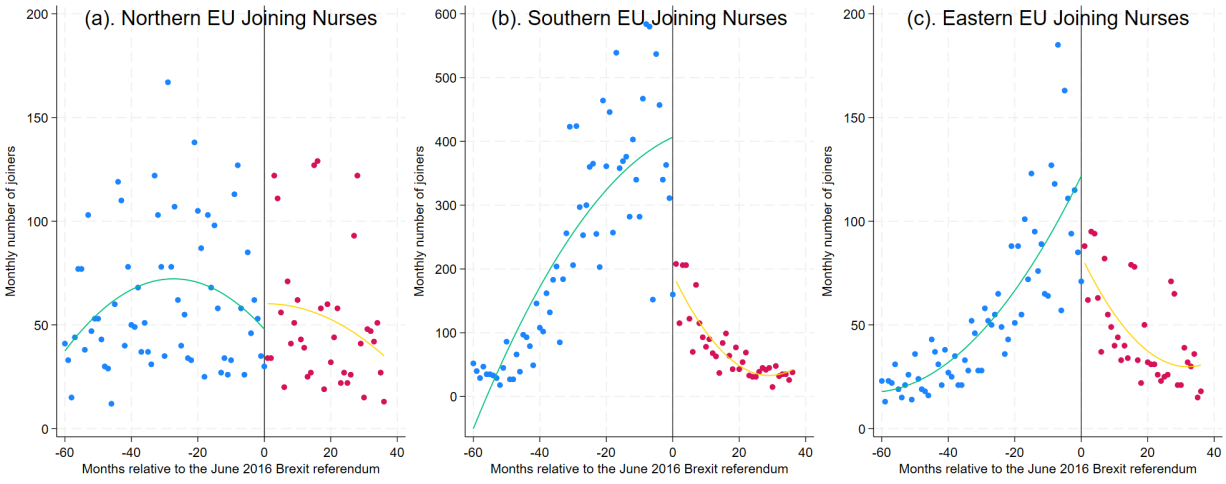
Appendix A: Figures and Tables

Figure A.1. Senior doctors joining and leaving the English NHS by nationality group



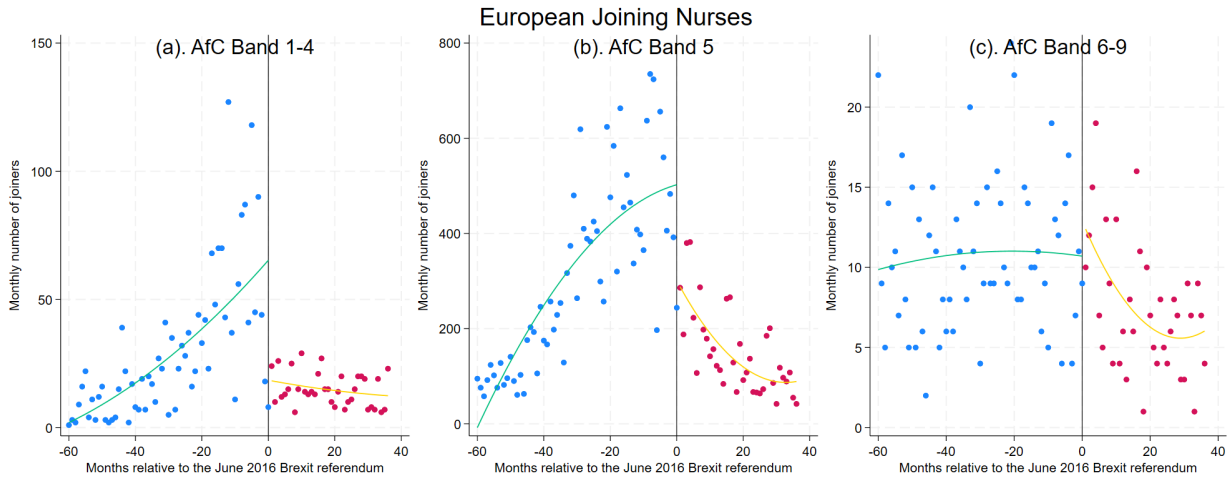
Notes. NHS joining and leaving monthly figures around the Brexit referendum date (June 2016) among senior doctors of different nationality groups.

Figure A.2. Nurses joining the English NHS by different European nationality subgroups



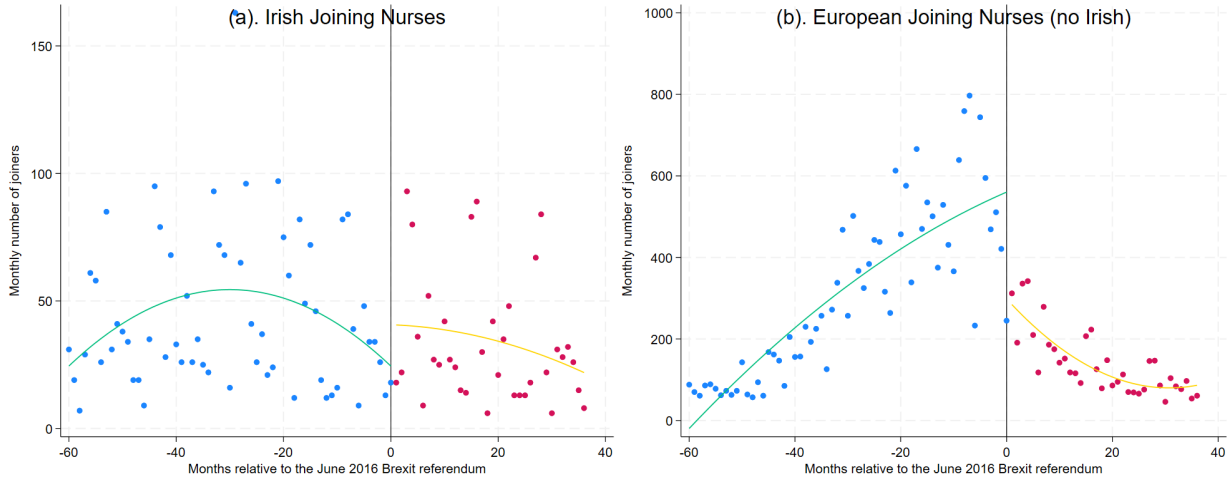
Notes. NHS joining monthly figures around the Brexit referendum date (June 2016) among European nurses from different European nationality subgroups.

Figure A.3. European nurses joining the English NHS by pay band section



Notes. NHS joining monthly figures around the Brexit referendum date (June 2016) among nurses of different pay band sections.

Figure A.4. Irish and other EU nurses joining the English NHS



Notes. NHS joining monthly figures around the Brexit referendum date (June 2016) among Irish nurses and nurses from other EU countries than Ireland.

Table A.1. Additional OLS estimates (Stacked vs baseline year 2015/16)

	Δ Mortality		Δ Em. Readmission	
	Emergency (1)	Elective (2)	Emergency (3)	Elective (4)
Panel A: without Irish nurses	-0.007	0.001	-0.003	-0.009**
Δ EU Joining Rate	(0.005)	(0.001)	(0.004)	(0.003)
Panel B: excluding London	-0.001	0.001	-0.004	-0.011**
Δ EU Joining Rate	(0.002)	(0.001)	(0.004)	(0.004)
Panel C: EU leavers	-0.001	-0.001***	0.002*	0.001
Δ EU Leaving Rate	(0.001)	(0.000)	(0.001)	(0.002)
Panel D: Staff levels	-0.002	-0.000	-0.001	-0.001***
Δ Total Nurses' Levels	(0.002)	(0.000)	(0.001)	(0.000)
Panel E: non-EU joiners	0.000	0.000	-0.009**	-0.002
Δ Non-EU Joining Rate	(0.003)	(0.001)	(0.004)	(0.003)
Panel F: EU Nurses' share	0.073	-0.004	0.022	-0.034*
Δ EU Workers' Share	(0.090)	(0.004)	(0.031)	(0.019)

Notes. Columns (1) to (4): OLS estimates of β_1. Standard errors are heteroschedasticity-robust and clustered at hospital organization level. Significance levels: *p<0.1; **p<0.05; ***p<0.01.

Table A.2. Additional 2SLS estimates (2016/17 vs baseline year 2015/16)

	1st stage	2nd stage			
		Δ Mortality		Δ Em. Readmission	
		Emergency	Elective	Emergency	Elective
	(1)	(2)	(3)	(4)	(5)
Panel A: 2001 Census	Δ EU Joining Rate				
Share of EU residents within 90km (2001 Census)	-6.810*** (1.625)				
Δ EU Joining Rate		0.040 (0.046)	-0.001 (0.002)	-0.037** (0.016)	-0.024** (0.011)
F-stat	17.57				
Anderson-Rubin test (p-value)		0.92 (0.34)	0.18 (0.67)	5.98 (0.01)	5.93 (0.01)
Kleibergen-Paap test (p-value)		14.21 (0.00)	15.22 (0.00)	15.22 (0.00)	15.22 (0.00)
Panel B: 2011 Census	Δ EU Joining Rate				
Share of EU residents within 90km (2011 Census)	-3.602*** (0.871)				
Δ EU Joining Rate		0.039 (0.045)	-0.001 (0.002)	-0.037** (0.017)	-0.024** (0.012)
F-stat	17.09				
Anderson-Rubin test (p-value)		0.87 (0.35)	0.11 (0.74)	5.84 (0.02)	5.32 (0.02)
Kleibergen-Paap test (p-value)		13.99 (0.00)	15.01 (0.00)	15.01 (0.00)	15.01 (0.00)
Panel C: without Irish Nurses	Δ EU Joining Rate				
EU Joining Rate (2011/12)	-1.276*** (0.180)				
Δ EU Joining Rate		-0.009 (0.014)	-0.003 (0.002)	-0.023 (0.015)	-0.015 (0.009)
F-stat	50.09				
Anderson-Rubin test (p-value)		0.43 (0.51)	2.06 (0.15)	2.71 (0.10)	2.87 (0.09)
Kleibergen-Paap test (p-value)		6.56 (0.01)	6.92 (0.01)	6.92 (0.01)	6.92 (0.01)
Panel D: excluding London	Δ EU Joining Rate				
EU Joining Rate (2011/12)	-1.274*** (0.320)				
Δ EU Joining Rate		-0.001 (0.006)	-0.001 (0.002)	-0.020** (0.009)	-0.019 (0.013)
F-stat	15.87				
Anderson-Rubin test (p-value)		0.05 (0.82)	0.21 (0.64)	5.13 (0.02)	2.31 (0.13)
Kleibergen-Paap test (p-value)		6.24 (0.01)	6.31 (0.01)	6.31 (0.01)	6.31 (0.01)
Panel E: EU leavers	Δ EU Leaving Rate				
EU Leaving Rate (2011/12)	0.229* (0.116)				
Δ EU Leaving Rate		-0.012 (0.032)	0.009 (0.007)	0.075 (0.071)	0.049* (0.030)
F-stat	3.88				
Anderson-Rubin test (p-value)		0.16 (0.69)	4.05 (0.04)	2.53 (0.11)	7.21 (0.01)
Kleibergen-Paap test (p-value)		3.32 (0.07)	2.55 (0.11)	2.55 (0.11)	2.55 (0.11)
Panel F: Staff levels	Δ Total Nurses' Levels				
EU Joining Rate (2011/12)	0.277 (0.376)				
Δ Total Nurses' Levels		-118.509 (208.533)	10.200 (12.866)	52.497 (92.316)	56.876 (83.213)
F-stat	0.54				
Anderson-Rubin test (p-value)		0.79 (0.38)	3.65 (0.06)	2.27 (0.13)	4.83 (0.03)
Kleibergen-Paap test (p-value)		0.43 (0.51)	0.41 (0.52)	0.41 (0.52)	0.41 (0.52)
Panel G: non-EU joiners (EU enclave as IV)	Δ Non-EU Joining Rate				
EU Joining Rate (2011/12)	0.057 (0.076)				
Δ Non-EU Joining Rate		-0.557 (0.850)	0.050 (0.070)	0.257 (0.370)	0.278 (0.386)
F-stat	0.56				
Anderson-Rubin test (p-value)		0.79 (0.38)	3.65 (0.06)	2.27 (0.13)	4.83 (0.03)
Kleibergen-Paap test (p-value)		0.67 (0.41)	0.59 (0.44)	0.59 (0.44)	0.59 (0.44)
Panel H: non-EU joiners (non-EU enclave as IV)	Δ Non-EU Joining Rate				
Non-EU Joining Rate (2011/12)	0.027 (0.312)				
Δ Non-EU Joining Rate		0.974 (44.012)	-0.096 (1.132)	1.352 (15.842)	1.013 (12.021)
F-stat	0.01				
Anderson-Rubin test (p-value)		0.33 (0.57)	0.59 (0.44)	4.51 (0.03)	3.40 (0.07)
Kleibergen-Paap test (p-value)		0.00 (0.98)	0.01 (0.93)	0.01 (0.93)	0.01 (0.93)
Panel I: EU nurses' share	Δ EU Nurses' Share				
EU Joining Rate (2011/12)	-0.047 (0.032)				
Δ EU Workers' Share		0.701 (1.001)	-0.060 (0.043)	-0.309 (0.361)	-0.335 (0.306)
F-stat	2.21				
Anderson-Rubin test (p-value)		0.79 (0.38)	3.65 (0.06)	2.27 (0.13)	4.83 (0.03)
Kleibergen-Paap test (p-value)		1.16 (0.28)	1.12 (0.29)	1.12 (0.29)	1.12 (0.29)

Notes. Column (1): OLS estimates of the first stage regression coefficient α_1. Columns (2) to (5): 2SLS estimates of β_1. Huber-White heteroschedasticity-robust standard errors. Significance levels: *p<0.1; **p<0.05; ***p<0.01.

Table A.3. Additional 2SLS estimates (2017/18 vs baseline year 2015/16)

	1st stage	2nd stage			
		Δ Mortality		Δ Em. Readmission	
	(1)	Emergency (2)	Elective (3)	Emergency (4)	Elective (5)
Panel A: 2001 Census	Δ EU Joining Rate				
Share of EU residents within 90km (2001 Census)	-9.160*** (2.023)				
Δ EU Joining Rate		0.033 (0.032)	-0.001 (0.002)	-0.016 (0.014)	-0.007 (0.007)
F-stat	20.51				
Anderson-Rubin test (p-value)		1.18 (0.28)	0.10 (0.75)	1.42 (0.23)	1.13 (0.29)
Kleibergen-Paap test (p-value)		16.51 (0.00)	17.52 (0.00)	17.52 (0.00)	17.52 (0.00)
Panel B: 2011 Census	Δ EU Joining Rate				
Share of EU residents within 90km (2011 Census)	-4.781*** (1.094)				
Δ EU Joining Rate		0.031 (0.033)	-0.000 (0.002)	-0.015 (0.015)	-0.006 (0.007)
F-stat	19.09				
Anderson-Rubin test (p-value)		1.02 (0.31)	0.04 (0.85)	1.03 (0.31)	0.71 (0.40)
Kleibergen-Paap test (p-value)		15.71 (0.00)	16.72 (0.00)	16.72 (0.00)	16.72 (0.00)
Panel C: without Irish Nurses	Δ EU Joining Rate				
EU Joining Rate (2011/12)	-1.351*** (0.223)				
Δ EU Joining Rate		-0.009 (0.014)	-0.004* (0.002)	-0.019 (0.015)	-0.012 (0.008)
F-stat	36.71				
Anderson-Rubin test (p-value)		0.40 (0.53)	3.69 (0.05)	1.55 (0.21)	1.84 (0.17)
Kleibergen-Paap test (p-value)		9.78 (0.00)	10.34 (0.00)	10.34 (0.00)	10.34 (0.00)
Panel D: excluding London	Δ EU Joining Rate				
EU Joining Rate (2011/12)	-1.830*** (0.421)				
Δ EU Joining Rate		-0.006 (0.008)	-0.003 (0.002)	-0.021* (0.012)	-0.013** (0.006)
F-stat	18.88				
Anderson-Rubin test (p-value)		0.64 (0.43)	2.10 (0.15)	3.47 (0.06)	4.29 (0.04)
Kleibergen-Paap test (p-value)		10.26 (0.00)	10.35 (0.00)	10.35 (0.00)	10.35 (0.00)
Panel E: EU leavers	Δ EU Leaving Rate				
EU Leaving Rate (2011/12)	0.015 (0.109)				
Δ EU Leaving Rate		-0.375 (2.484)	0.164 (1.226)	0.714 (5.575)	0.313 (2.406)
F-stat	0.02				
Anderson-Rubin test (p-value)		0.61 (0.43)	4.67 (0.03)	1.42 (0.23)	0.77 (0.38)
Kleibergen-Paap test (p-value)		0.02 (0.88)	0.02 (0.89)	0.02 (0.89)	0.02 (0.89)
Panel F: Staff levels	Δ Total Nurses' Levels				
EU Joining Rate (2011/12)	-0.247 (0.647)				
Δ Total Nurses' Levels		151.333 (477.401)	-12.851 (33.725)	-47.930 (121.220)	-53.677 (150.140)
F-stat	0.15				
Anderson-Rubin test (p-value)		0.85 (0.36)	3.49 (0.06)	0.84 (0.36)	2.86 (0.09)
Kleibergen-Paap test (p-value)		0.13 (0.72)	0.16 (0.69)	0.16 (0.69)	0.16 (0.69)
Panel G: non-EU joiners (EU enclave as IV)	Δ Non-EU Joining Rate				
EU Joining Rate (2011/12)	0.183 (0.167)				
Δ Non-EU Joining Rate		-0.181 (0.239)	0.017 (0.019)	0.065 (0.097)	0.072 (0.090)
F-stat	1.20				
Anderson-Rubin test (p-value)		0.85 (0.36)	3.49 (0.06)	0.84 (0.36)	2.86 (0.09)
Kleibergen-Paap test (p-value)		1.66 (0.20)	1.60 (0.21)	1.60 (0.21)	1.60 (0.21)
Panel H: non-EU joiners (non-EU enclave as IV)	Δ Non-EU Joining Rate				
Non-EU Joining Rate (2011/12)	0.812 (0.652)				
Δ Non-EU Joining Rate		-0.008 (0.021)	-0.005 (0.006)	0.021 (0.035)	0.011 (0.029)
F-stat	1.55				
Anderson-Rubin test (p-value)		0.19 (0.66)	0.97 (0.32)	0.47 (0.49)	0.23 (0.63)
Kleibergen-Paap test (p-value)		1.17 (0.28)	1.15 (0.28)	1.15 (0.28)	1.15 (0.28)
Panel I: EU nurses' share	Δ EU Nurses' Share				
EU Joining Rate (2011/12)	-0.184*** (0.034)				
Δ EU Workers' Share		0.183 (0.197)	-0.017** (0.009)	-0.064 (0.070)	-0.072* (0.040)
F-stat	29.80				
Anderson-Rubin test (p-value)		0.85 (0.36)	3.49 (0.06)	0.84 (0.36)	2.86 (0.09)
Kleibergen-Paap test (p-value)		5.14 (0.02)	5.10 (0.02)	5.10 (0.02)	5.10 (0.02)

Notes. Column (1): OLS estimates of the first stage regression coefficient α_1. Columns (2) to (5): 2SLS estimates of β_1. Huber-White heteroschedasticity-robust standard errors. Significance levels: *p<0.1; **p<0.05; ***p<0.01.

Table A.4. Additional 2SLS estimates (2018/19 vs baseline year 2015/16)

	1st stage	2nd stage			
		Δ Mortality		Δ Em. Readmission	
		Emergency	Elective	Emergency	Elective
	(1)	(2)	(3)	(4)	(5)
Panel A: 2001 Census	Δ EU Joining Rate				
Share of EU residents within 90km (2001 Census)	-10.573*** (2.071)				
Δ EU Joining Rate		0.040 (0.041)	0.002 (0.002)	-0.010 (0.019)	-0.023** (0.009)
F-stat	26.06				
Anderson-Rubin test (p-value)		1.07 (0.30)	1.27 (0.26)	0.26 (0.61)	7.59 (0.01)
Kleibergen-Paap test (p-value)		20.29 (0.00)	21.21 (0.00)	21.21 (0.00)	21.21 (0.00)
Panel B: 2011 Census	Δ EU Joining Rate				
Share of EU residents within 90km (2011 Census)	-5.565*** (1.115)				
Δ EU Joining Rate		0.039 (0.041)	0.002 (0.002)	-0.006 (0.021)	-0.023** (0.009)
F-stat	24.92				
Anderson-Rubin test (p-value)		1.01 (0.31)	1.11 (0.29)	0.07 (0.79)	6.80 (0.01)
Kleibergen-Paap test (p-value)		19.67 (0.00)	20.60 (0.00)	20.60 (0.00)	20.60 (0.00)
Panel C: without Irish Nurses	Δ EU Joining Rate				
EU Joining Rate (2011/12)	-1.426*** (0.229)				
Δ EU Joining Rate		-0.010 (0.017)	0.000 (0.002)	-0.029 (0.021)	-0.027** (0.011)
F-stat	38.86				
Anderson-Rubin test (p-value)		0.40 (0.53)	3.69 (0.05)	1.55 (0.21)	1.84 (0.17)
Kleibergen-Paap test (p-value)		9.78 (0.00)	10.34 (0.00)	10.34 (0.00)	10.34 (0.00)
Panel D: excluding London	Δ EU Joining Rate				
EU Joining Rate (2011/12)	-1.921*** (0.462)				
Δ EU Joining Rate		-0.002 (0.005)	0.000 (0.002)	-0.026 (0.020)	-0.031*** (0.012)
F-stat	17.29				
Anderson-Rubin test (p-value)		0.18 (0.67)	0.00 (0.96)	2.16 (0.14)	6.66 (0.01)
Kleibergen-Paap test (p-value)		10.41 (0.00)	10.54 (0.00)	10.54 (0.00)	10.54 (0.00)
Panel E: EU leavers	Δ EU Leaving Rate				
EU Leaving Rate (2011/12)	-0.353 (0.277)				
Δ EU Leaving Rate		0.016 (0.033)	0.000 (0.003)	-0.019 (0.039)	-0.044 (0.038)
F-stat	1.62				
Anderson-Rubin test (p-value)		0.27 (0.60)	0.01 (0.93)	0.30 (0.58)	6.23 (0.01)
Kleibergen-Paap test (p-value)		1.31 (0.25)	1.46 (0.23)	1.46 (0.23)	1.46 (0.23)
Panel F: Staff levels	Δ Total Nurses' Levels				
EU Joining Rate (2011/12)	0.469 (1.224)				
Δ Total Nurses' Levels		-104.925 (274.796)	-0.540 (3.365)	51.556 (149.933)	64.008 (167.131)
F-stat	0.15				
Anderson-Rubin test (p-value)		0.91 (0.34)	0.02 (0.88)	1.47 (0.23)	10.66 (0.00)
Kleibergen-Paap test (p-value)		0.16 (0.69)	0.14 (0.70)	0.14 (0.70)	0.14 (0.70)
Panel G: non-EU joiners (EU enclave as IV)	Δ Non-EU Joining Rate				
EU Joining Rate (2011/12)	0.292 (0.217)				
Δ Non-EU Joining Rate		-0.178 (0.211)	-0.001 (0.006)	0.083 (0.092)	0.103 (0.080)
F-stat	1.81				
Anderson-Rubin test (p-value)		0.91 (0.34)	0.02 (0.88)	1.47 (0.23)	10.66 (0.00)
Kleibergen-Paap test (p-value)		1.89 (0.17)	1.86 (0.17)	1.86 (0.17)	1.86 (0.17)
Panel H: non-EU joiners (non-EU enclave as IV)	Δ Non-EU Joining Rate				
Non-EU Joining Rate (2011/12)	1.171 (0.750)				
Δ Non-EU Joining Rate		0.000 (0.015)	-0.005 (0.004)	0.009 (0.035)	0.023 (0.026)
F-stat	2.44				
Anderson-Rubin test (p-value)		0.00 (1.00)	2.78 (0.10)	0.06 (0.80)	1.73 (0.19)
Kleibergen-Paap test (p-value)		1.77 (0.18)	1.73 (0.19)	1.73 (0.19)	1.73 (0.19)
Panel I: EU nurses' share	Δ EU Nurses' Share				
EU Joining Rate (2011/12)	-0.291*** (0.042)				
Δ EU Workers' Share		0.180 (0.189)	0.001 (0.006)	-0.083 (0.071)	-0.103*** (0.034)
F-stat	48.54				
Anderson-Rubin test (p-value)		0.91 (0.34)	0.02 (0.88)	1.47 (0.23)	10.66 (0.00)
Kleibergen-Paap test (p-value)		6.70 (0.01)	6.67 (0.01)	6.67 (0.01)	6.67 (0.01)

Notes. Column (1): OLS estimates of the first stage regression coefficient α_1. Columns (2) to (5): 2SLS estimates of β_1. Huber-White heteroschedasticity-robust standard errors. Significance levels: *p<0.1; **p<0.05; ***p<0.01.

Appendix B: 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 (4). 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 (4) 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 (4)

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, $\big[h^*_{pre}(\theta)a_{pre}(\theta) - h^*_{post}(\theta)a_{post}(\theta)\big]$ single-crosses zero from below and $\int \big[h^*_{pre}(\theta)a_{pre}(\theta) - h^*_{post}(\theta)a_{post}(\theta)\big] \geq 0$. 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, $\theta^* = \theta_0$. Note that θ^* as defined in Lemma 1 is a continuous and, by item 1, decreasing function of γ_e. Therefore, $\theta^*_{post} > \theta_0$, unless the decrease in γ_e is sufficiently large.□ □

Proof of Proposition 2. The mass of 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 7a and 7b). That is,

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

Hence,

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

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

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

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 $n \to +\infty$. □