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Research Paper

The effect of waiting times on health outcomes for coronary bypass and angioplasty

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ABSTRACT

Long waiting times are a major health policy issue across many OECD countries, and have been exacerbated by the COVID-19 pandemic. For urgent care, such as for cardiovascular conditions, a major concern for patients is that health may deteriorate while waiting and waiting times could affect health outcomes. This study investigates the effect of waiting times on health outcomes and resource use for two common procedures for patients with coronary heart disease: coronary artery bypass grafting (CABG) and percutaneous transluminal coronary angioplasty (PTCA). In addition to controlling for a range of patient characteristics and hospital characteristics (through hospital fixed effects), we pursue an instrumental variable approach. For each patient, we instrument the referral-to-treatment waiting time with a measure of provider congestion, which is calculated as the average waiting time of patients admitted to the same hospital and referred to the outpatient services in the 30 days preceding the referral of a given patient. We conduct separate analyses before (2015–2019) and after COVID-19 (up to 2021/22). Our IV results suggest that longer waiting times do not lead to higher mortality, readmission rates or longer hospital length of stay for either CABG or PTCA during the pre-pandemic period. Instead, we find that during the pandemic, when waiting times increased substantially, an increase in waiting time by two months for patients undergoing CABG leads to a 0.5 and 0.8 percentage points increase in 30-day and 1-year mortality respectively, and extends hospital length of stay by 0.2 days. These effects are particularly evident among older, more complex, and more deprived patients. There is no statistically significant relationship between waiting times and outcomes for the PTCA sample in the pandemic period.

1. Introduction

Long waiting times are a major health policy concern across many OECD countries where patients have to wait weeks or months to access non-emergency health care (OECD, 2023). Waiting times tend to arise in health systems that combine limited capacity with publicly funded insurance and limited co-payments (OECD, 2013). If the demand systematically exceeds the supply, a waiting list is formed and patients have to wait to access health care (Martin and Smith, 1999).

Waiting times generate health losses to patients while waiting because health benefits are postponed (Gravelle and Siciliani, 2008a). In addition, a major concern for urgent care is that the health may deteriorate while waiting and waiting times could affect

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health outcomes if the procedure becomes less effective (Koopmanschap et al., 2005; Moscelli et al., 2016). For example, patients with a long wait for planned cardiovascular procedures can experience worsening symptoms, deterioration in the patient's health condition, and less favourable clinical outcomes, including an increase in the probability of preoperative death and unplanned emergency admission (Sobolev and Fradet, 2008). From a policy perspective, investing in higher supply of health services to reduce waiting times will be more impactful and generate a higher return if shorter waiting times increase the capacity to benefit and prevent hospitalisations or higher healthcare use.

Although patients tend to wait less for relatively more urgent treatments, such as a coronary bypass surgery, than a less urgent one, such as a hip replacement surgery, waiting times still remain significant (OECD, 2013). For example, in England the mean waiting time in 2018 was 71 days for a coronary bypass, while for a hip replacement it was 118 days (OECD Health Statistics, 2024). Waiting lists have grown rapidly following the COVID-19 pandemic, when elective care was suspended for several months in 2020 (OECD, 2023). Between 2019 and 2020, the volume for coronary bypass fell by 18% across 30 OECD countries and by 36% in England. The reduction was smaller for coronary angioplasty: about 10% across 30 OECD countries and 12% in England (OECD, 2023). In England, the waiting list for non-emergency (elective) patients was over 7 million of patients in 2023. This reinforces patient concerns about the possible adverse effects of waiting for a long time for urgent care.

Whether waiting times affect health outcomes is *a priori* unclear. On one hand, waiting times could worsen health outcomes due to worsening of symptoms and deterioration in the patient's condition, as mentioned above. On the other hand, patients are prioritised on the waiting list, which can mitigate such effects. This study investigates the effect of waiting times on health outcomes for patients with a cardiovascular disease, which remains a leading cause of death.[1]

We focus on two common procedures for patients with coronary heart disease: coronary artery bypass grafting (CABG) and percutaneous transluminal coronary angioplasty (PTCA). Both procedures are carried out to reduce symptoms such as chest pain and shortness of breath. PTCA is often used for patients with less severe blockages, while CABG is more common for patients with more severe or multiple blockages. There were over 15,000 CABG surgeries performed in the UK in 2018 and over 80,000 PTCAs (OECD Health Statistics, 2024). PTCA is a much less invasive procedure relative to CABG. It is less costly for the provider and involves a quicker recovery for the patient. However, PTCA is not appropriate for more complex cases, for example, patients with severely blocked arteries, coronary heart failure or diabetes. By including both procedures in our analysis, we are able to assess whether the impact of waiting times on outcomes differs across clinical profiles and procedural pathwa. We expect that waiting times could have stronger effects on health outcomes for patients in need of CABG than those requiring PTCA. However, given that PTCA is performed much more frequently and the demand for it keeps rising, even a small effect of waiting times on health for these patients could generate significant health losses.

From a policy perspective, distinguishing between these two procedures allows us to identify whether efforts to reduce waiting times should be targeted more aggressively toward higher-risk CABG patients, or more broadly across the cardiac pathway, including PTCA. Furthermore, differences in the effects of waiting times may reveal whether substitution between procedures—e.g. prioritising PTCA in place of delayed CABG—is clinically and economically justified. This comparative approach also reflects planning challenges in cardiac care, where both surgical and interventional capacities must be managed concurrently.

In more detail, to test the effect of waiting times for CABG and PTCA on health outcomes, we measure health outcomes by 30-day and 1-year mortality, and the risk of an emergency readmission following 28 days from hospital discharge. For PTCA we also measure the probability of reintervention within six months. In addition to health outcomes, we also test if waiting times affect resources, which we proxy through patient length of stay (LOS). Our measure of waiting time is comprehensive. Waiting time for each patient is measured from the time of a referral (from GPs or other specialists) to surgery, therefore encompassing what is known as the outpatient (from referral to addition to the list during the specialist visit) and inpatient waiting time (from addition to the list to surgery). Our primary sample includes all patients who had a CABG or PTCA in the five years before the COVID-19 pandemic (2015–2019). We also compare the results with a sample following COVID-19 (up to financial year 2021/22).

One key concern in estimating the effect of waiting times on health outcomes is omitted variable bias due to more severe patients being prioritised and having shorter waiting times while having a higher risk of adverse events. We include in our regression models an extensive range of patient characteristics (number and type of diagnoses, age, income deprivation, ethnicity, month and day of admission). We also control for systematic differences across hospitals by including hospital fixed effects. For example, hospitals with higher quality could have both lower mortality rates and longer waiting times driven by higher demand. However, unobserved dimensions of patient severity may remain. To address this, we pursue an instrumental variable approach.

For each patient, we instrument the referral-to-treatment waiting time with a measure of provider congestion, which is calculated as the average referral-to-treatment waiting time of all the patients who were admitted to the same hospital for the same procedure, and had been referred to the outpatient services in the 30 days preceding the referral of a given patient (Godøy et al., 2024). We argue that this variable is as good as random. Patients are responsible for choosing their outpatient provider of care through a phone or online system (NHS England, 2025) following the referral by a GP (or another physician). Since it is unknown at the time of referral whether a patient will require surgery when they are referred to their outpatient appointment, it is unlikely that the initial choice of provider for the outpatient appointment is systematically based on future surgical outcomes, even if patients chose providers with better surgical outcomes. From the patient's perspective, the timing of the referral (whether at busy times or not) is random, and any congestion is not linked to surgical outcomes. Because a longer average waiting time for a provider extends the period patients must wait for an

[1] World Health Organization. Health topics: Cardiovascular diseases (last accessed 10/06/2024).

appointment or treatment, it is unlikely to influence health outcomes (except indirectly through waiting times).

Our instrumental-variable results suggest that longer waiting times do not lead to higher mortality, higher readmission rates or longer hospital stay for either CABG or PTCA during the pre-pandemic period. However, we find evidence that waiting times have a causal effect on mortality and length of stay for the CABG patients in the pandemic period. Specifically, an increase in referral-to-treatment waiting times by two months increases the probability of dying within 30 days and one year from discharge by 0.5 (44% of the mean) and 0.7 (29% of the mean) percentage points respectively. The same increase in wait leads to patients staying in hospital for about 0.2 days longer (2% of the mean). Heterogeneity analysis reveals that these effects manifest themselves in particular among older, more complex, and more deprived patients. We do not find any statistically significant relationship between waiting times and different outcomes for PTCA in the pandemic period.

We contribute to the existing literature in the following ways. We build on the study by Moscelli et al. (2016) who investigate the effect of waiting times on health outcomes for coronary bypass in England. Differently from this study, we measure waiting times more comprehensively from referral to treatment rather than considering only the inpatient waiting time. The outpatient waiting time (from referral to addition to the list during the specialist visit) is substantive. For CABG in our pre-COVID sample outpatient waiting time was 45 days, about 42% of the referral-to-treatment waiting time. For PTCA outpatient waiting time was 98 days, about 67% of the referral-to-treatment waiting time.

What matters to patients is how long they wait from the time they seek care to the time they receive the treatment. From a theoretical perspective, any delay along the patient pathway increases the potential for the patient's health to deteriorate and reduces the potential ability to benefit from treatment (Koopmanschap et al., 2005), and this is regardless of whether the wait occurs before or after seeing a specialist. Previous studies have typically focussed on the inpatient waiting time, from the specialist addition of the patient to the list to treatment.[2] This generates a bias in the measure of total waiting time as the deterioration in patient health can start earlier including between the time the patient seeks care from a primary care doctor and the specialist visit (the outpatient waiting time). The inpatient waiting time therefore underestimates the full duration of the delay. Moreover, as shown below, the correlation between inpatient and outpatient waiting time is generally low (<0.1), and therefore the inpatient wait is not a good predictor of the total wait. The literature has typically focussed on the inpatient waiting times because it is routinely recorded in administrative databases both in England (through the Hospital Episodes Statistics) and in other OECD countries (OECD, 2023). In contrast, from a policy perspective, in England a referral-to-treatment waiting time has been collected since 2008. Patients have a right to start a specialist-led treatment within a maximum of 18 weeks from referral by their GP. However, the referral-to-treatment waiting time is not available in the Hospital Episodes Statistics, which provides health records at the patient level. To mimic the referral-to-treatment waiting time, we link the outpatient and inpatient waiting time along the patient pathway to mirror the full patient journey. The policy acknowledges that there can be long gaps before the patient can see a specialist and that the inpatient waiting time is only a partial measure of access to health care. Our analysis contributes to the literature by developing a method to measure the referral-to-treatment waiting time using the Hospital Episodes Statistics, and brings the analysis in line both with the theory and policy objectives.

Furthermore, relative to Moscelli et al. (2016) in addition to CABG we also consider PTCA, which is a very common procedure and over time is increasingly used for patients with moderate severity (Baim and Ignatius, 1988; Topol and Teirstein, 2015). Moreover, we measure a range of health outcomes. Rather than measuring in-hospital mortality, we use 30-day and 1-year mortality, therefore capturing adverse events that arise either shortly after hospital discharge, which is missed by in-hospital mortality, or in the longer term within a year. We also measure length of stay as a proxy of resource use, and for PTCA we measure reintervention within six months from the initial procedure.

More broadly, we contribute to the limited but growing literature which addresses the endogeneity of waiting times on health outcomes through an instrumental variable approach. We follow the approach suggested by Godøy et al. (2024) to investigate the effect of long waiting times for orthopaedic surgery in Norway, and use a measure of congestion to instrument individual waiting time. Using a similar approach, Bar et al. (2024) investigate the effect of waiting times for a nursing home on healthcare utilisation in the Netherlands.

Our study relates to the broader literature on waiting times in the health sector. In the absence of price rationing, economists have modelled waiting times as a non-monetary price that brings demand for and supply of health services together (Lindsay and Feigenbaum, 1984; Martin and Smith, 1999; Iversen, 1997; Gravelle and Siciliani, 2008a). The demand and supply responsiveness to waiting times has also been estimated empirically with evidence suggesting that the demand for health care is generally inelastic to waiting times (Martin and Smith, 1999; 2003; Gravelle et al., 2003; Martin et al., 2007). Other studies have focused on the evaluation of specific policy interventions, in relation to maximum waiting time targets (Propper et al., 2010; Askildsen et al., 2011), the introduction of patient choice (Moscelli et al., 2023; Ge et al., 2024) or expansion of private health insurance (Yang et al., 2024).

There is a more limited but growing literature investigating the effect of waiting times on health outcomes. Godøy et al. (2024) find that longer waiting times for orthopaedic surgery do not increase healthcare utilisation but have persistent reductions in labour supply through an increase in work absences and permanent disability receipt.Bar at al. (2024) investigate the effect of waiting times for a nursing home on healthcare utilisation in the Netherlands, and find that longer waiting times increase the probability of an urgent hospitalisation. Nikolova et al. (2016) find that longer inpatient waiting time is associated with lower postoperative health for hip and knee replacement but this is not the case for varicose veins and hernia repair. Moscelli et al. (2016) find that waiting times for CABG in

[2] Several studies from England have focussed only on the inpatient waiting time for example in the context of estimating demand and supply elasticities (Martin and Smith, 1999; 2003; Martin et al., 2007), evaluation of specific policies (Propper et al., 2008; 2010) and waiting time prioritisation or socioeconomic inequalities (Gutacker et al., 2016; Moscelli et al., 2018).

England are not associated with higher in-hospital mortality but there is a weak association between waiting times and emergency readmission following a surgery. Reichert and Jacobs (2018) focus on individuals who need psychosis services in England. They find that longer waiting time is significantly associated with a deterioration in patient outcomes twelve months after acceptance for treatment for psychosis.

Our findings are important for policy. We show that when waiting times are very long (in the pandemic period) they can increase mortality and utilisation for patients requiring coronary bypass. Therefore, investing in higher supply for these services not only reduces the delay in receiving care through shorter waiting times but also augments the health outcomes through better survival and through lower resources used to treat each patient.

2. Institutional background

The National Health Service (NHS) in England is a publicly funded healthcare system that provides comprehensive medical care to all citizens, regardless of their ability to pay. Patients who require cardiovascular procedures such as percutaneous transluminal coronary angioplasty (PTCA) and coronary artery bypass grafting (CABG) can access them through the NHS without facing any co-payments.

PTCA and CABG are two different interventions used to treat cardiovascular diseases. PTCA is a minimally invasive procedure. It involves using a catheter to insert a small balloon into the narrowed or blocked artery. The balloon is then inflated to widen the artery and improve blood flow. If clinically appropriate, a stent is also placed in the artery to keep it open. PTCA is usually performed for patients with less severe blockages or narrowing of the arteries. Although PTCA is performed very frequently, there is conflicting evidence regarding its effectiveness and impact on patients' outcomes as opposed to medical therapy alone (Boden et al., 2007; De Bruyne et al., 2012; Maron et al., 2020; Vij et al., 2021).

CABG, on the other hand, is a more invasive and less common procedure, typically used for patients with more severe blockages or multiple blocked arteries, that involves open-heart surgery. During CABG, a surgeon takes a healthy blood vessel from another part of the patient's body, such as chest or leg, and uses it to bypass the blocked or narrowed artery. This creates a new pathway for blood to flow to the heart.

The process for accessing cardiovascular surgeries typically begins with a referral from a primary care physician, or other healthcare specialist, to a specialist cardiologist (Fig. 1). Following the referral, patients choose the provider for the outpatient appointment through a phone or online system (NHS England, 2025). The specialist will then assess a patient's clinical need through various diagnostic tests and medical assessments in the outpatient setting. If the patient needs a cardiovascular intervention (PTCA or CABG), they will be placed on a waiting list for the procedure. The time from the first referral to surgery constitutes the referral-to-treatment waiting time. The time between being placed on the waiting list and the procedure is the inpatient waiting time, while the time between the referral and being placed on the waiting list is the outpatient waiting time.

An 18-week target was first introduced in the NHS in December 2008. To reach this target, the Heart Improvement Programme started the "18 Weeks Whole Pathways" National Priority Project with the aim of accomplishing a referral to treatment waiting time of 18 weeks for cardiological services. The programme had a positive impact on waiting times and patients' outcomes, albeit with some heterogeneity across providers (NHS Improvement, 2018). The target in the NHS Constitution (2024) is for NHS patients to have the right to start treatment for non-urgent conditions within a maximum of 18 weeks from referral. Waiting times for cardiological services have increased over time. The median referral-to-treatment waiting times for completed admitted pathways for the Cardiology and Cardiothoracic Surgery specialties increased from 6.3 and 6.7 weeks respectively in March 2012 to 8.5 and 7.8 weeks in March 2019.[3]

The COVID-19 pandemic forced NHS Trusts to significantly change the way services were provided. On the 17th of March 2020, NHS England and Improvement instructed hospitals to maximise inpatient and critical care capacity for the expected surge in COVID patients.[4] This required postponing non-urgent elective procedures and discharging patients deemed medically fit to leave the hospital. Similarly, services in the outpatient and primary care settings had to adapt their ways of operation to contain the virus spread, which resulted in significant shifts of care from face-to-face to remote appointments. Such changes implied that diagnostic tests and procedures necessary before adding patients to waiting lists for surgery had to be postponed. All together, this resulted in an increase in the referral-to-treatment waiting times for elective procedures, with the NHS facing a significant backlog. Median waits in Cardiology and Cardiothoracic Surgery specialties for completed admitted pathways in March 2022 were 11 and 8.6 weeks respectively, which amounts to a 30% and a 10% increase since March 2019.[5]

3. Data

Our analysis uses two datasets from the Hospital Episode Statistics (HES), the Admitted Patient Care (inpatient data) and Outpatient datasets. They contain a range of clinical and socio-demographic patients' characteristics. Inpatient data covers all admissions to NHS hospital Trusts and admissions to private providers (known as the Independent Sector) paid for by the NHS. Outpatient data comprises outpatient appointments scheduled in NHS providers and NHS-commissioned outpatient activity by private providers.

[3] Based on the Referral to Treatment (RTT) Waiting Times statistics (last accessed 10/06/2024).
[4] The letter can be found here (last accessed 10/06/2024).
[5] Based on the Referral to Treatment (RTT) Waiting Times statistics (last accessed 10/06/2024).

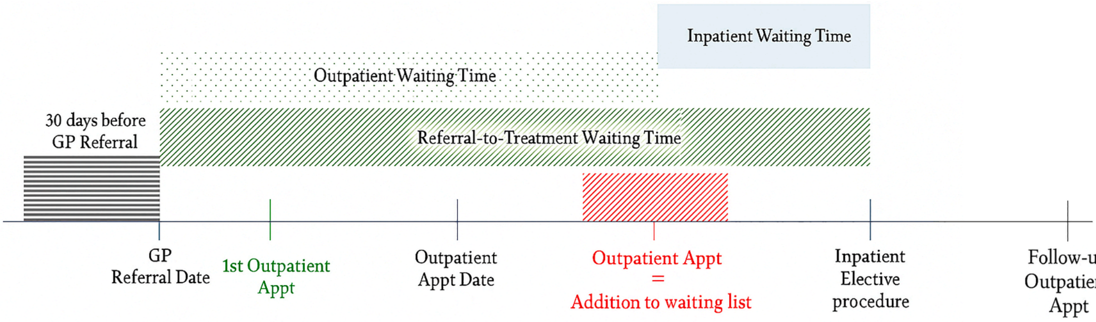

Fig. 1. Patient pathway and referral-to-treatment waiting time.

We focus on patients who were admitted for an elective, booked or planned intervention and had a CABG (OPCS-4 codes K40-K46) or a PTCA (OPCS-4 codes K49, K50, K75) as a main procedure during their hospital stay, with admission dates falling either between April 2015 and December 2019, which we refer to as pre-pandemic sample, or between January 2020 and March 2022, which we refer to as pandemic sample. For the CABG samples, we excluded patients who, in addition to CABG, also had a PTCA procedure during the same hospital stay. Similarly, for the PTCA samples we excluded patients who also had CABG during the same hospital stay. For both CABG and PTCA, we excluded patients who had the same procedure within two years prior to the current intervention, hospital transfers, and patients who had surgery in Trusts that performed less than 20 respective procedures per year.[6] Additionally, we removed patients with invalid or zero inpatient waiting times.

For each patient, we construct the following outcome variables: a binary variable equal to one if the patient was readmitted as an emergency with any diagnosis within 28 days following hospital discharge; a binary variable equal to one if the patient died within 30 days from discharge; a binary variable equal to one if the patient dies within 365 days from discharge, and length of stay measured in days of the hospital admission when the procedure was performed. For the PTCA samples, in addition to the above we add a reintervention indicator: a binary variable equal to one if an individual had another PTCA procedure performed within 180 days (six months) after the original PTCA intervention took place.

The referral-to-treatment waiting time is defined as the time patients have to wait between a referral and the time the patient is admitted to hospital for the procedure. The referral-to-treatment waiting time is the sum of the outpatient and the inpatient waiting time. The inpatient waiting time is the time from specialist addition to the list to the hospital admission for the procedure. We define the outpatient waiting time as the time between the referral (e.g. from a GP or a specialist) to the outpatient setting and the addition to the list by the specialist. We obtain the inpatient waiting time from the Inpatient dataset and the outpatient waiting time from the Outpatient dataset.

We merge each of the inpatient samples with the corresponding outpatient appointments data in the following way. The pre-pandemic samples are matched with outpatient appointments which took place from April 2014 to December 2019 (i.e. one year prior to the beginning of the inpatient samples). The pandemic samples are merged with outpatient appointments dated between January 2019 and March 2022. Appointments with invalid appointment date and/or referral request date are dropped. For each patient, we identify an outpatient appointment in the cardiovascular-related specialty (tretspef codes 170, 172, 300, 320) which happened on the day when the patient was placed on the waiting list. We allow for up to 60 days delay between the appointment date and the patient being placed on the elective inpatient waiting list.[7] The matching ratios are 90% and 80% for the CABG and PTCA samples respectively in the pre-pandemic period. For the pandemic period, 89% of the CABG and 78% of the PTCA inpatient sample have an outpatient match.

Finally, for each procedure and period, we remove outliers from the samples by dropping patients with either an inpatient or an outpatient waiting time exceeding three standard deviations from the mean. We also drop observations with values of continuous variables (age, number of diagnoses on admission, length of stay, number of previous emergency admissions within one year from the current admission, number of outpatient appointments in the outpatient spell prior to being placed on the waiting list) exceeding the 99th percentile in each sample.

In our baseline specification we control for the following patient characteristics: age (in bands), sex, number of diagnoses on admission (in bands), number of Elixhauser conditions (as a categorical variable), number of emergency admissions one year

[6] Applying this restriction yields 28 and 85 providers which perform CABG and PTCA procedures respectively for the pre-pandemic sample. We retain the same Trusts for the pandemic sample.

[7] We chose to allow for a lag between the outpatient appointment and placement on the procedure wait list to retain the majority of the sample. It may be argued that failing to match the waiting list placement data with a corresponding outpatient appointment indicates a data quality issue. However, we note that CABG and PTCA samples have different matching ratios: e.g. allowing for a 7 days lag would lead to losing about 30% of records for CABG and 60% of records for PTCA samples. This possibly indicates that the issue is in different practices in place for the two procedures, rather than a broader data issue. It is also unlikely that allowing for a 60 days delay would yield overestimated waiting times: as suggested by Marques et al. (2014), patients often wait longer in the outpatient setting than official waiting time statistics suggests. We also provide a robustness check allowing a 30-day lag instead of the 60-day lag, which yields similar results.

preceding the admission, income deprivation quintile (categorical variable), ethnicity, specific comorbidities (30 most frequent secondary diagnoses in each sample, listed in Table A1 in the Appendix). Additionally, we control for whether the first outpatient appointment in the referral-to-treatment pathway was marked as urgent, and the type of healthcare professional making the initial referral request (a GP, the same specialist who carried out the first appointment, another specialist, or other, which includes referrals from an A&E department, an allied health professional, self-referrals, etc.).

4. Methods

Our aim is to identify the causal effect of waiting times on patients' health outcomes and intensity of care. A linear regression model can only be interpreted as causal if, conditional on other covariates, the waiting times variable is exogenous. Although we include an extensive set of control variables, omitted variable bias may still remain. For example, unobserved dimensions of patient severity could reduce waiting time while increasing the risk of an emergency readmission or the length of stay in hospital therefore biasing the coefficient downwards.

To address this issue, we follow Godøy et al. (2024) and adopt an instrumental variable approach. For each patient, we instrument the referral-to-treatment waiting time with a measure of provider congestion, which is calculated as the average referral-to-treatment waiting time of all the patients who were admitted to the same hospital for the same procedure, and had been referred to the outpatient services in the 30 days preceding the referral of a given patient. This average wait of other patients seeking care at a similar time as a given individual is indicative of the health system congestion, and therefore predictive of this individual's waiting time. The instrument is then used in the 2SLS approach to provide consistent estimates of the impact of waiting time on outcomes separately for the four samples (CABG pre-pandemic and during the pandemic, and PTCA pre-pandemic and during the pandemic), as follows:

$$y_{ijt} = a + \beta\widehat{w}_i + x'_i\gamma + \sum_{j=2}^{J} d_j\delta_j + \sum_{m=2}^{12} d_m\delta_m + \sum_{d=2}^{7} d_d\delta_d + \sum_{t=2}^{T} d_t\delta_t + \varepsilon_{ijt} \tag{1}$$

where y_{ijt} is the health outcome of patient i, who had a procedure in hospital j in the year t, $\widehat{w_i}$ is the predicted referral-to-treatment waiting time from the first stage regression, x_i is a vector of patient characteristics described in the data section, accounting for patient casemix. The variables d_j, d_t, and d_d are the hospital, year, month and day of the week fixed effects, respectively, pertaining to the hospital admission date. Hospital fixed effects control for unobserved time-invariant hospital characteristics, for example, related to the quality of care. The financial year fixed effects d_t control for the time trend (e.g. due to technology development), the month fixed effects d_m control for seasonality, and the day of the week effects d_d account for variation of admissions at different times of the week. Finally, ε_{ijt} is the error term.

5. Instrument relevance, exclusion restriction, and independence

In this section, we investigate whether health system congestion meets the requirements necessary for the instrument to provide a causal estimate of the effect of waiting times on patients outcomes: independence, exclusion restriction, and relevance. We also briefly discuss the monotonicity assumption which, if it holds, allows interpreting the estimated effects as LATE.

5.1. Independence

In our set up, the independence assumption requires the instrument to be independent from the unobservable patients' characteristics. This assumption would be violated if some patients were able to self-select into hospitals with lower congestion. While it is not possible to test it formally, we provide suggestive evidence in support of the independence assumption.

First, we argue that at the time of the first referral patients have virtually no control over the process. The decision to refer a patient into the outpatient setting is made by a general practitioner or an outpatient specialist (patients cannot self-refer and therefore self-select into elective surgery). In most instances, the GP who makes the referral will not know in advance whether the patient will be placed on a waiting list for surgery or not. This decision is made by an outpatient specialist. Self-selection into hospitals with lower congestion may be possible at the point of placement on the waiting list. But this would be a concern only if we focused on the inpatient section of the waiting time (from the moment of placement on the list to surgery). Since we are using the referral-to-treatment waiting time, we believe it is plausible to assume that patients are unlikely to self-select into hospitals with lower congestion, since at the point of entry into the health system they may not know yet whether they would be placed on the waiting list at all.

Second, we include a wide range of observable characteristics of the patients, as well as hospital and time fixed effects, which leaves out only a few characteristics that we cannot control for. While we cannot rule out that the unobservable characteristics still exist and may affect both the outcomes and the instrument, conditioning on a large number of relevant covariates makes the independence assumption more plausible.

We further check how closely both the instrument (congestion) and the instrumented variable (waiting times) are related to observable covariates. Table A2 in the Appendix provides the results of this analysis. We conjecture that there should be little correlation between patients' characteristics and the instrument, and if there is any, it should be less prominent than that between the covariates and the waiting times. We find that for CABG, most patient-level covariates coefficients are insignificant with a few marginally significant coefficients for both pre-pandemic and pandemic samples. For PTCA, some coefficients are statistically significant, in particular those of the number of Elixhauser conditions for both periods and referral source pre-pandemic. However, these coefficients are much lower in magnitude than the respective coefficients in the waiting times regression. We hypothesise that the correlation between these variables and congestion may be due to the high correlation between congestion and waiting times.

Lastly, as a possible way of addressing the issue of self-selection into hospitals with longer waits, we estimate a model where congestion is defined not at a hospital Trust level, but at the Clinical Commissioning Group (CCG) level. The results of this analysis are discussed in more detail in the robustness checks section.

5.2. Exclusion restriction

The exclusion restriction assumption requires congestion to affect outcomes only through the endogenous variable (waiting times), and not directly or through any other unobservable channel. Exclusion will not hold if, for example, higher congestion puts more pressure on the hospitals and affects outcomes through quality of treatment. To understand whether this is the case, we follow Godøy et al. (2024) and investigate the relationship between congestion and outcomes of the patients who were admitted to hospital as an emergency for CABG or PTCA, at about the same time as the elective patients. For these emergency patients, congestion can only be related to their outcomes through quality of treatment, as they are not facing any waiting times.

We estimate the following model (for CABG and PTCA, pre-pandemic and pandemic periods separately):

$$y_{ijt} = a + \beta\overline{c}_t + x^{'}_i\gamma + \sum_{j=2}^{J} d_j\delta_j + \sum_{m=2}^{12} d_m\delta_m + \sum_{d=2}^{7} d_d\delta_d + \sum_{t=2}^{T} d_t\delta_t + \varepsilon_{ijt} \quad (2)$$

where y_{ijt} is a quality-related outcome (mortality or emergency readmission) of a patient i who was admitted to hospital j as an emergency on day t. The variable $\overline{c}_t$ is the average congestion of elective patients who were admitted for the same procedure to the same hospital up to seven days prior to time t.[8] The remaining covariates are the same as in Eq. (1). Table A3 in the Appendix presents the results. The coefficient of the average congestion is not statistically significant for any outcome, procedure and period, with the exception of 1-year mortality for PTCA in the pre-pandemic period, which is only marginally significant, and the coefficient has the opposite sign to the expected one. This allows us to conclude that the instrument does not affect the outcomes through the quality of care provided.

5.3. Relevance

Finally, for the instrument to be valid, it has to be relevant, i.e. correlated with the endogenous variable. Unlike the independence and exclusion restriction, relevance can be formally tested. When presenting the results in the next section, we include both the first stage regressions and the F statistics, which are above 100 in all the main analyses.

A visual representation of the close relationship between congestion and waiting times is depicted in Fig. 2. We first residualise both waiting times and congestion by regressing them on hospital and financial year fixed effects and obtaining predicted values. The histograms provide the distribution of residualised congestion, in days, whereas the solid lines are local linear regressions of residualised individual wait time on residualised congestion. It appears that individual waiting time increases with congestion for all subsamples, which indicates instrument relevance, and also suggests that the monotonicity assumption holds.[9] We further disaggregate the sample into sub-groups in the heterogeneity analysis section, and the first stage coefficients are always positive. This indicates that the monotonicity assumption is unlikely to be violated, and the estimated effects can therefore be treated as LATE.

6. Results

6.1. Descriptive statistics

Table 1 provides descriptive statistics for the four samples: CABG pre-pandemic (admitted between April 2015 and December 2019) and pandemic (admitted between January 2020 and March 2022), and PTCA pre-pandemic and pandemic. The CABG sample comprises 29,992 patients pre-pandemic and 7001 patients in the pandemic period. The outcome variables do not differ markedly between periods: 13.2% were readmitted within 28 days following discharge before the pandemic, compared to 12.3% during the pandemic. 1.2% of patients died within a month in both periods, 2.5% died within a year in the pre-pandemic sample and 2.8% died within a year in the pandemic period. On average, a patient undergoing CABG stayed in hospital for 8.4 days pre-pandemic, and 8.6 days during the pandemic period. The pre-pandemic sample for PTCA comprises 55,918 patients, while the pandemic sample has 16,808 observations. Only 5.6% were readmitted as an emergency within 28 days from discharge before and during the pandemic; 0.2% and 1.9% died within a month and a year respectively pre-pandemic, the corresponding figures for pandemic period were 0.3% and 2.2%. PTCA patients stayed in hospital for a much shorter period than CABG patients, 0.41 days on average pre-pandemic and 0.26 days during the

[8] We initially attempted to use the average congestion of elective patients admitted precisely on day t, but that yielded a significant number of emergency patients without a matching congestion value, as no elective patients were admitted on the exact same day.

[9] Note that the monotonicity assumption is not directly testable. But its implication is that the direction of the relationship between the instrument and the endogenous variables should be the same across different groups/subsamples.

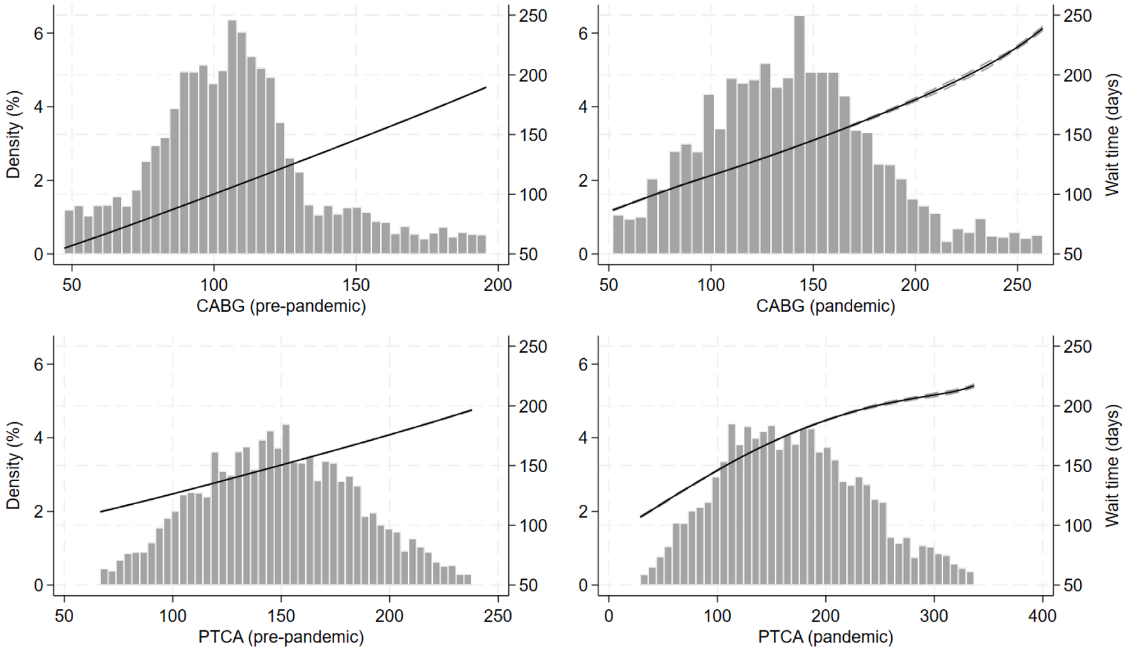

Fig. 2. Congestion and Referral-to-treatment waiting time.
Notes: The solid lines are local linear regressions of residualised (cleared from Trust, financial year, admission month and admission day of the week fixed effects) individual wait time on residualised congestion. Dashed lines represent 95 percent CIs. The histograms represent distribution of residualised congestion, in days (excluding top and bottom 1%).

pandemic. About 7.4% of PTCA patients underwent a reintervention within six months in the pre-pandemic sample, while during the pandemic reintervention rate was 7%.

On average, waiting times for CABG patients were about 107 days from referral to treatment to hospital admission before the pandemic: 45 days from referral to addition to the list, and 62 days from addition to the list to hospital admission for the surgery. PTCA patients waited longer: about 146 days in total, split into 98 days while awaiting the addition to the list, and another 48 days awaiting the procedure. The pandemic brought a substantial increase in waiting times: CABG patients had on average a 137 days wait and PTCA patients' waiting times reached 164 days, equivalent to a 28% and 12% increase respectively. In both cases this increase was largely driven by the rise in inpatient waiting times. Fig. 3 provides a deeper insight into the dynamics of the inpatient and outpatient waiting times illustrating how they have been changing over time. It is apparent that the pandemic resulted in a large increase in waits, especially for the CABG patients, which continued into the 2021/22 financial year. Importantly, inpatient and outpatient waiting times have low correlation. For CABG, the correlation is 0.07 before COVID-19, and 0.03 after. For PTCA, it is 0.08 before COVID-19 and 0.1 after. This suggests that the inpatient waiting time previously used in the literature is not a good predictor of the outpatient waiting time.

There are notable differences between the CABG and the PTCA samples in patients' demographics and clinical characteristics. CABG patients were less likely to be female (18% vs 25% for PTCA in the pre-pandemic sample), were slightly older, had higher numbers of Elixhauser conditions and diagnoses on admission, and slightly higher number of previous emergency admissions. As regards comorbidities, there are differences in which secondary diagnoses were present and their prevalence (see Table A1 in the Appendix).

Ethnic composition and deprivation appear to be similar across CABG and PTCA pre-pandemic samples. There are also almost identical patterns with regards to the likelihood of having an urgent first outpatient appointment (19% vs 18% for the PTCA sample). The same applies to the referral sources of the first appointment: in both samples, the vast majority (65%) were referred by a GP, about 17%−20% by a specialist, and the remaining patients by other referral sources.

The pandemic samples for both procedures have fairly similar characteristics with the pre-pandemic ones, with moderate differences across several dimensions. For CABG, an average patient was younger, less likely to be female, had more diagnoses on admission than pre-pandemic. PTCA patients during the pandemic had fewer Elixhauser conditions, but more diagnoses on admission than their pre-pandemic counterparts. For both CABG and PTCA samples, the average patient in the pandemic period had a higher number of previous emergency admissions, and was more likely to be referred to by sources other than a GP or an outpatient specialist, probably due to more frequent referrals from emergency departments. Finally, there was a significant increase in the number of cases with missing ethnicity records in the pandemic period.

Table 1
Descriptive statistics.

	CABG				PTCA			
	Pre-pandemic		*Pandemic*		*Pre-pandemic*		*Pandemic*	
Variable	mean	sd	mean	sd	mean	sd	mean	sd
28-day readmission	0.132*	0.338	0.123	0.329	0.056	0.230	0.056	0.229
30-day mortality	0.012	0.109	0.012	0.108	0.002	0.048	0.003	0.054
1-year mortality	0.025	0.157	0.028	0.164	0.019***	0.135	0.022	0.147
Length of Stay	8.397***	4.401	8.575	4.598	0.409***	0.691	0.259	0.620
Reintervention within 6 months					0.074**	0.262	0.070	0.255
Inpatient waiting time (days)	61.51***	47.68	86.51	75.81	48.49***	36.18	60.45	57.26
Outpatient waiting time (days)	45.14***	58.23	50.40	73.10	97.91***	125.60	103.44	139.02
Total waiting time (days)	106.65***	77.80	136.92	106.71	146.40***	133.56	163.89	154.46
Congestion (days)	107.73***	43.50	139.36	67.49	148.39***	75.86	168.82	117.93
Female	0.177***	0.382	0.157	0.364	0.250	0.433	0.246	0.431
Age (years)	67.478***	9.238	66.69	8.91	66.60**	10.19	66.776	10.222
Age: 35–44	0.012	0.107	0.012	0.111	0.017	0.130	0.018	0.132
Age: 45–54	0.086	0.280	0.086	0.281	0.116**	0.320	0.110	0.313
Age: 55–64	0.253***	0.435	0.289	0.453	0.273	0.446	0.281	0.449
Age: 65–74	0.400	0.490	0.401	0.490	0.351	0.477	0.343	0.475
Age: 75–84	0.245***	0.430	0.212	0.408	0.220	0.414	0.225	0.418
Age: 85–94	0.005***	0.071			0.022**	0.148	0.024	0.151
# of Elixhauser conditions	4.814	2.741	4.814	2.415	4.026***	2.862	3.587	2.608
# of Elix.cond: 0	0.014***	0.119	0.008	0.091	0.058***	0.233	0.068	0.251
# of Elix.cond: 1	0.071***	0.258	0.047	0.211	0.139***	0.346	0.160	0.366
# of Elix.cond: 2	0.124**	0.329	0.114	0.318	0.161***	0.368	0.176	0.381
# of Elix.cond: 3	0.154**	0.361	0.159	0.366	0.149***	0.357	0.167	0.373
# of Elix.cond: 4	0.153	0.360	0.171	0.376	0.125	0.331	0.129	0.336
# of Elix.cond: 5	0.133***	0.340	0.150	0.357	0.100***	0.301	0.091	0.288
# of Elix.cond: 6	0.104***	0.305	0.118	0.323	0.078***	0.269	0.071	0.257
# of Elix.cond: 7	0.082***	0.274	0.093	0.291	0.062***	0.240	0.048	0.214
# of Elix.cond: 8	0.058***	0.234	0.062	0.241	0.044***	0.205	0.035	0.184
# of Elix.cond: 9	0.040	0.196	0.036	0.186	0.032***	0.175	0.023	0.150
# of Elix.cond: 10	0.029*	0.169	0.021	0.144	0.022***	0.146	0.015	0.121
# of Elix.cond: 11	0.018***	0.134	0.012	0.109	0.013***	0.115	0.008	0.087
# of Elix.cond: 12	0.010***	0.097	0.004	0.064	0.008***	0.090	0.005	0.070
# of Elix.cond: 13	0.005***	0.069	0.002	0.049	0.005***	0.067	0.002	0.046
# of Elix.cond: 14+	0.004***	0.065	0.001	0.038	0.004***	0.061	0.002	0.046
# of previous emergency admissions	0.391***	0.655	0.430	0.671	0.334***	0.631	0.391	0.708
# of diagnoses at admission: 1–3	0.023***	0.149	0.006	0.075	0.141***	0.348	0.093	0.291
# of diagnoses at admission: 4–6	0.142***	0.349	0.046	0.210	0.398***	0.489	0.347	0.476
# of diagnoses at admission: 7–9	0.255***	0.436	0.140	0.347	0.302***	0.459	0.317	0.465
# of diagnoses at admission: 11–12	0.234***	0.423	0.206	0.404	0.119***	0.323	0.156	0.363
# of diagnoses at admission: 13+	0.347***	0.476	0.603	0.489	0.041***	0.197	0.087	0.281
Deprivation quintile (income)=1 (least deprived)	0.283	0.450	0.279	0.448	0.284	0.451	0.290	0.454
Deprivation quintile (income)=2	0.181	0.385	0.180	0.384	0.176	0.380	0.177	0.382
Deprivation quintile (income)=3	0.175	0.380	0.174	0.379	0.182	0.386	0.178	0.382
Deprivation quintile (income)=4	0.167	0.373	0.170	0.376	0.179	0.384	0.179	0.383
Deprivation quintile (income)=5 (most deprived)	0.195	0.396	0.197	0.398	0.179	0.383	0.176	0.381
Ethnicity: white	0.755***	0.430	0.633	0.482	0.753***	0.432	0.710	0.454
Ethnicity: black	0.006	0.078	0.005	0.071	0.007**	0.085	0.009	0.095
Ethnicity: asian	0.066	0.248	0.067	0.250	0.079	0.270	0.081	0.273
Ethnicity: mixed	0.003	0.057	0.003	0.056	0.005	0.068	0.005	0.072
Ethnicity: other	0.010	0.101	0.012	0.111	0.014***	0.118	0.017	0.130
Ethnicity: missing	0.160***	0.366	0.279	0.449	0.142***	0.349	0.177	0.382
Urgent first outpatient appointment	0.192***	0.394	0.174	0.379	0.179***	0.384	0.167	0.373
Referral source: other	0.152***	0.359	0.184	0.387	0.177***	0.381	0.196	0.397
Referral source: GP	0.646*	0.478	0.635	0.482	0.650*	0.477	0.644	0.479
Referral source: another consultant	0.148***	0.355	0.132	0.339	0.124***	0.330	0.117	0.321
Referral source: same consultant	0.053	0.225	0.050	0.217	0.049***	0.216	0.043	0.204
Number of observations	29,992		7001		55,918		16,808	

Notes. The data presented are obtained from the following sources: Hospital Episode Statistics (Admitted Patient and Outpatient Data) and Civil Registration of Death dataset, covering financial years from 2015/16 to 2021/22. The pre-pandemic period spans from April 2015 to December 2019, while the pandemic period from January 2020 to March 2022. Difference between pandemic and pre-pandemic periods is assessed via the standard *t*-test for each variable (significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$). For the 30 most common secondary diagnoses see Table A1 in the Appendix.

6.2. Regression analysis

Fig. 4 (left panel) and Table 2 provide the results of estimating Eq. (1) using the 2SLS approach - our preferred estimate - on the

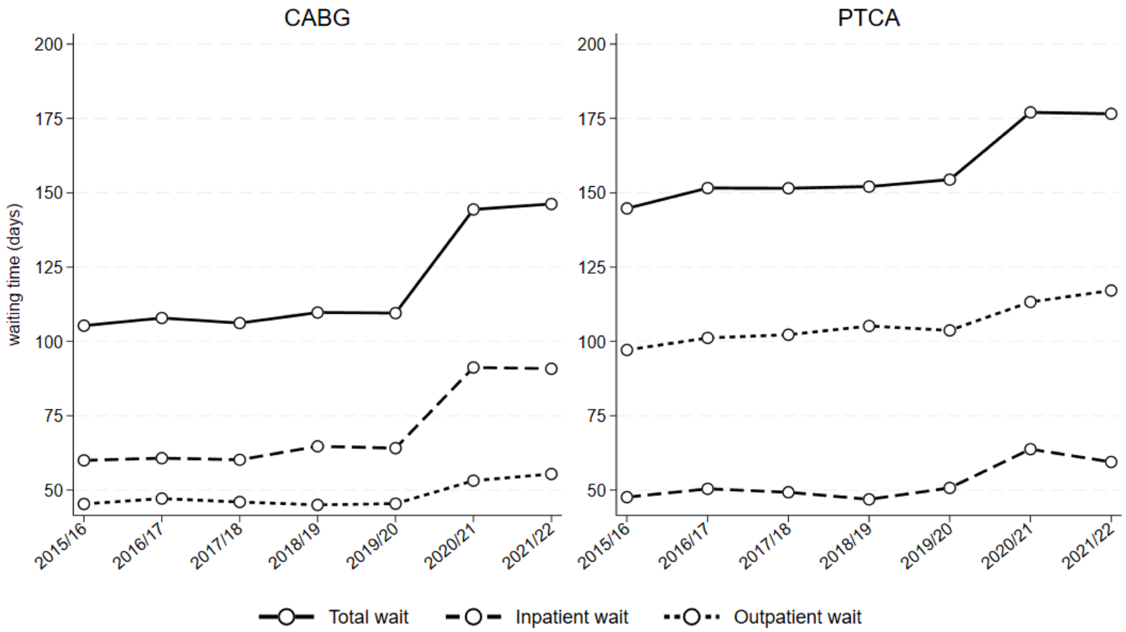

Fig. 3. Trends in inpatient, outpatient, and total waiting time for CABG and PTCA patients.

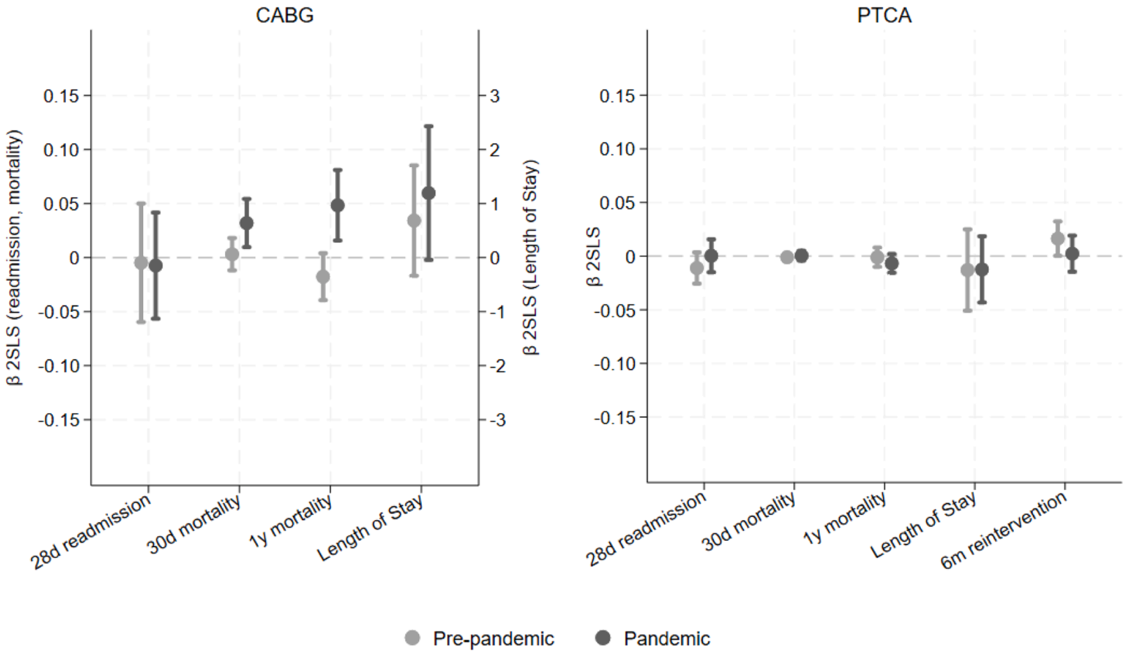

Fig. 4. IV-2SLS coefficients.
Notes: The coefficients of waiting time in the length of stay regressions for CABG patients are plotted against the right axis of the CABG graph.

CABG sample, separately for the pre-pandemic and pandemic periods, for four outcomes of interest: emergency readmission within 28 days from discharge, 30-day and 1-year mortality, and length of stay.[10] Pre-pandemic, waiting time does not appear to impact any of the patients' outcomes, while for the pandemic sample we find longer waits to increase 30-day mortality, 1-year mortality and length

[10] We measure waiting times and congestion in years when running the regressions for ease of coefficients' presentation in all tables with results of regression analysis.

Table 2
Regression results. IV-2SLS estimates for the CABG sample.

	Pre-pandemic				*Pandemic*			
	(1) 28 day readmission	(2) 30-day mortality	(3) 1-year mortality	(4) Length of stay	(1) 28 day readmission	(2) 30-day mortality	(3) 1-year mortality	(4) Length of stay
Total waiting time (years)	−0.005	0.003	−0.018	0.685	−0.007	0.032***	0.048***	1.194*
	(0.028)	(0.008)	(0.011)	(0.521)	(0.025)	(0.011)	(0.017)	(0.631)
Female	0.019***	0.005***	0.003	0.397***	−0.016	0.003	−0.004	0.482***
	(0.006)	(0.001)	(0.002)	(0.087)	(0.011)	(0.004)	(0.006)	(0.112)
Age: 35–44								
Age: 45–54	−0.006	0.001	0.007**	−0.193	0.015	0.009**	0.003	0.141
	(0.023)	(0.003)	(0.003)	(0.204)	(0.025)	(0.004)	(0.010)	(0.404)
Age: 55–64	−0.023	0.003	0.008***	−0.141	−0.012	0.006*	0.001	0.232
	(0.023)	(0.002)	(0.002)	(0.185)	(0.026)	(0.003)	(0.011)	(0.398)
Age: 65–74	−0.027	0.007**	0.016***	0.029	−0.010	0.011***	0.008	0.499
	(0.023)	(0.003)	(0.003)	(0.193)	(0.023)	(0.003)	(0.011)	(0.373)
Age: 75–84	−0.018	0.011***	0.028***	0.815***	−0.004	0.018***	0.023*	1.215***
	(0.024)	(0.004)	(0.004)	(0.215)	(0.027)	(0.006)	(0.013)	(0.461)
Age: 85–94	−0.010	0.011	0.027*	1.458***				
	(0.043)	(0.012)	(0.015)	(0.420)				
Num. of diagnoses on admission: 1–3								
4–6	0.004	0.006	0.009**	0.963***	−0.031	0.014***	0.024**	1.121***
	(0.011)	(0.004)	(0.004)	(0.188)	(0.043)	(0.005)	(0.009)	(0.409)
7–9	0.004	0.012***	0.019***	1.801***	−0.025	0.024***	0.029***	1.518***
	(0.013)	(0.004)	(0.005)	(0.252)	(0.048)	(0.005)	(0.007)	(0.524)
11–12	0.003	0.018***	0.026***	2.590***	−0.025	0.026***	0.037***	1.971***
	(0.014)	(0.005)	(0.006)	(0.337)	(0.048)	(0.007)	(0.009)	(0.628)
13–15	0.013	0.036***	0.048***	4.073***	−0.044	0.037***	0.045***	3.253***
	(0.014)	(0.007)	(0.008)	(0.402)	(0.051)	(0.010)	(0.013)	(0.746)
Num. of Elixhauser conditions: 0								
1	0.041***	0.002	0.006***	0.372***	0.048**	0.000	−0.000	0.616**
	(0.008)	(0.001)	(0.002)	(0.126)	(0.023)	(0.003)	(0.004)	(0.301)
2	0.059***	0.001	0.004	0.376***	0.078***	0.002	0.008	0.727**
	(0.009)	(0.002)	(0.003)	(0.124)	(0.021)	(0.004)	(0.006)	(0.302)
3	0.086***	0.002	0.006**	0.526***	0.081***	−0.002	0.002	0.805**
	(0.011)	(0.002)	(0.003)	(0.113)	(0.023)	(0.004)	(0.007)	(0.318)
4	0.112***	0.001	0.007**	0.638***	0.106***	−0.001	0.008	1.130***
	(0.009)	(0.002)	(0.003)	(0.136)	(0.023)	(0.004)	(0.008)	(0.372)
5	0.142***	0.002	0.013***	0.800***	0.132***	0.001	0.013	1.612***
	(0.014)	(0.003)	(0.004)	(0.143)	(0.027)	(0.006)	(0.011)	(0.378)
6	0.148***	0.001	0.016***	1.153***	0.201***	0.002	0.025***	1.840***
	(0.012)	(0.003)	(0.005)	(0.144)	(0.025)	(0.005)	(0.009)	(0.398)
7	0.177***	−0.004	0.016***	1.376***	0.218***	0.007	0.035***	2.499***
	(0.012)	(0.003)	(0.006)	(0.156)	(0.028)	(0.008)	(0.012)	(0.487)
8	0.188***	−0.005	0.013**	1.770***	0.255***	0.013	0.051***	2.236***
	(0.014)	(0.004)	(0.006)	(0.164)	(0.040)	(0.009)	(0.011)	(0.478)
9	0.212***	−0.013***	−0.000	2.104***	0.224***	0.035**	0.109***	3.090***
	(0.014)	(0.003)	(0.006)	(0.240)	(0.023)	(0.015)	(0.029)	(0.587)
10	0.236***	−0.008	0.005	2.374***	0.286***	0.006	0.054*	2.816***
	(0.017)	(0.006)	(0.008)	(0.231)	(0.042)	(0.017)	(0.032)	(0.761)
11	0.273***	−0.011	0.000	2.391***	0.304***	0.011	0.106**	3.346***
	(0.026)	(0.007)	(0.010)	(0.315)	(0.044)	(0.022)	(0.046)	(0.627)
12	0.234***	−0.024***	−0.026***	3.491***	0.378***	0.011	0.151**	4.265***
	(0.026)	(0.004)	(0.007)	(0.426)	(0.090)	(0.029)	(0.072)	(1.332)
13	0.359***	−0.031***	−0.015	2.882***	0.272***	−0.023***	0.041	5.713***
	(0.037)	(0.004)	(0.017)	(0.493)	(0.102)	(0.007)	(0.060)	(1.747)
14+	0.314***	−0.027***	−0.030**	2.498***	0.250*	−0.012	0.093	5.233**
	(0.039)	(0.008)	(0.012)	(0.401)	(0.148)	(0.008)	(0.089)	(2.460)
Number of previous emergency admissions	0.022***	0.002	0.003	0.128***	0.023***	0.002	0.003	0.191
	(0.002)	(0.001)	(0.002)	(0.034)	(0.007)	(0.002)	(0.003)	(0.125)
Urgent first outpatient appointment	−0.006	0.001	0.000	−0.018	−0.020**	−0.001	−0.002	0.001
	(0.005)	(0.002)	(0.002)	(0.047)	(0.008)	(0.003)	(0.005)	(0.122)
Referral source for the first OP appointment: other								
Referral source for the first OP appointment: GP	0.006	−0.002	−0.004	−0.030	0.017	−0.007**	−0.010**	−0.243
	(0.005)	(0.002)	(0.003)	(0.056)	(0.011)	(0.004)	(0.005)	(0.157)

(*continued on next page*)

Table 2 (*continued*)

	Pre-pandemic				*Pandemic*			
	(1) 28 day readmission	(2) 30-day mortality	(3) 1-year mortality	(4) Length of stay	(1) 28 day readmission	(2) 30-day mortality	(3) 1-year mortality	(4) Length of stay
Referral source for the first OP appointment: another consultant	−0.012*	−0.000	−0.001	0.018	−0.004	−0.004	−0.005	−0.021
	(0.006)	(0.003)	(0.004)	(0.056)	(0.016)	(0.006)	(0.007)	(0.192)
Referral source for the first OP appointment: same OP consultant	0.012	−0.001	−0.002	−0.029	0.023	−0.003	−0.003	−0.170
	(0.010)	(0.003)	(0.004)	(0.073)	(0.026)	(0.009)	(0.009)	(0.254)
Depriv. quintile (income)=1 (least deprived)								
Depriv. quintile (income)=2	−0.006	0.0001	−0.002	−0.017	−0.007	0.001	−0.001	0.010
	(0.004)	(0.002)	(0.003)	(0.073)	(0.015)	(0.005)	(0.007)	(0.133)
Depriv. quintile (income)=3	−0.012**	−0.001	−0.003	−0.005	0.001	−0.006**	−0.008*	0.208
	(0.005)	(0.002)	(0.002)	(0.079)	(0.013)	(0.003)	(0.004)	(0.133)
Depriv. quintile (income)=4	−0.003	0.002	0.002	0.021	−0.002	0.001	0.004	0.493***
	(0.006)	(0.002)	(0.003)	(0.097)	(0.012)	(0.004)	(0.006)	(0.133)
Depriv. quintile (income)=5 (most deprived)	−0.006	0.004**	0.004	0.249***	−0.001	0.001	−0.004	0.343***
	(0.004)	(0.002)	(0.003)	(0.062)	(0.012)	(0.003)	(0.004)	(0.116)
Ethnicity: white								
Ethnicity: black	0.032	−0.003	−0.007	1.205***	0.000	0.018	0.005	0.630
	(0.033)	(0.008)	(0.012)	(0.355)	(0.046)	(0.029)	(0.029)	(0.722)
Ethnicity: asian	0.034***	−0.001	−0.003	0.295***	0.052***	0.007	0.000	0.270
	(0.006)	(0.003)	(0.004)	(0.089)	(0.017)	(0.007)	(0.006)	(0.258)
Ethnicity: mixed	0.034	0.009	0.008	0.338	−0.052	−0.010**	−0.021***	0.474
	(0.035)	(0.015)	(0.016)	(0.345)	(0.044)	(0.005)	(0.006)	(1.152)
Ethnicity: other	0.028	−0.002	−0.008	0.457***	−0.005	0.006	0.043***	−0.374
	(0.018)	(0.004)	(0.006)	(0.166)	(0.025)	(0.008)	(0.011)	(0.494)
Ethnicity: missing	0.002	−0.001	−0.002	−0.217***	0.012	0.002	−0.001	−0.153
	(0.006)	(0.002)	(0.002)	(0.066)	(0.009)	(0.003)	(0.006)	(0.099)
Constant	0.032	−0.001	0.005	7.641***	0.012	−0.016**	−0.025	6.178***
	(0.037)	(0.007)	(0.008)	(0.411)	(0.050)	(0.008)	(0.018)	(0.908)
Observations	29,703	29,992	29,992	29,992	6933	6994	6994	6994

Notes. Each regression includes Trust, financial year, month of admission and day of the week of admission fixed effects, as well as patient-level control variables: age group, sex, number of diagnoses at admission group, number of Elixhauser conditions, previous emergency admissions within a year from the index admission, income deprivation quintile, ethnicity, an indicator of an urgent first referral, a referral source of the first outpatient appointment, and indicator variables for the 30 most common secondary diagnoses (see Table A1). Clustered s.e. in parentheses. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

of stay (albeit for the latter outcome the waiting times parameter is significant only at 10% level). The results suggest that, during the pandemic, a 2-month increase in waiting times would increase 30-day mortality by 0.5 percentage points, 1-year mortality by 0.8 percentage points, and length of stay by 0.2 days. In relative terms, these effects amount to 44%, 29% and 2.3% of the sample means respectively for the three outcomes.

Some patient characteristics have emerged to be important determinants of outcomes. Pre-pandemic, being female increased the probability of a 28-day emergency readmission by about 1.9 percentage points, and 30-day mortality risk by 0.5 percentage points. Female CABG patients also tended to stay in the hospital 0.4 days longer than their male counterparts. For the pandemic sample, however, only the relationship between sex and length of stay remained statistically significant with females staying in hospital 0.48 days longer than males.

Older patients appear to have worse mortality outcomes and longer length of stay. For example, before the pandemic, patients who were 75–84 years old, had a 1.1 and 2.8 percentage points higher probability of dying within 30 days and within one year from discharge respectively, relative to those who were 35–44 years old. They also stayed in hospital for 0.82 days longer. Similar patterns were found for the pandemic period as well.

For both pre-pandemic and pandemic samples, higher number of diagnoses on admission were found to increase both 30-day and 1-year mortality, as well as length of stay, whereas the number of Elixhauser conditions was generally positively associated with the readmission probability, 1-year mortality and length of stay. Before the pandemic, patients with more than 13 co-morbidities (diagnoses on admission) had a higher probability of dying within 30 days and one year from discharge by 3.6 and 4.8 percentage points, respectively, relative to patients with 1–3 co-morbidities, and stayed in hospital 4 days longer on average. Individuals with a history of an additional emergency admission in a year prior to the current admission were almost 2.2 and 2.3 percentage points more likely to experience an emergency readmission following the admission for CABG in the pre-pandemic and pandemic samples respectively. Before the pandemic, they were also discharged 0.13 days later.

We also find that Black, Asian and ‘other’ ethnic backgrounds were associated with longer length of stay before the pandemic, but the relationship was not present in the pandemic sample. Finally, patients living in more deprived areas had longer length of stay in both periods, especially during the pandemic.

Fig. 4 (right panel) and Table 3 provide 2SLS estimation results for the PTCA samples before and during the pandemic. Waiting times do not appear to impact patients outcomes, except for the probability of reintervention within six months from discharge in the pre-pandemic sample: an increase in waiting time by two months would raise the probability of reintervention by about 0.27 percentage points, which amounts to 3.6% of the average reintervention rate pre-pandemic (equal to 7.4%).

In both the pandemic and pre-pandemic samples, female patients had longer length of stay and were more likely to be readmitted as an emergency, but had better 1-year mortality outcomes and were less likely to have a reintervention. Age was not a predictor for reintervention probability, but was generally associated with worse mortality outcomes and longer length of stay. Interestingly, a nonlinear relationship between age and emergency readmission probability emerged in the pre-pandemic sample, with patients aged 65–74 less likely to be readmitted than their younger and older counterparts. Higher number of diagnoses on admission was generally associated with worse mortality outcomes, as well as increased length of stay, but was not related with reintervention probability. This might be due to collinearity between the number of diagnoses on admission and number of Elixhauser conditions, which appear to increase the likelihoods of reintervention and emergency readmission.

Having an additional emergency admission in the year prior to admission for PTCA was associated with higher probability of an emergency readmission and mortality and increased length of stay, but decreased reintervention probability in the pre-pandemic sample. However, in the pandemic sample, only the relationship with readmission probability and 1-year mortality remained significant. There does not appear to be any socio-economic gradient across income deprivation, with the exception of those living in the most deprived areas being less likely to experience a reintervention within six months from having PTCA performed in the pre-pandemic sample. Finally, ethnicity appears to have played different roles before and during the pandemic. Specifically, in the pre-pandemic sample, as compared to white ethnicity, Asian ethnic origin was associated with higher probability of being readmitted as an emergency, while being Black increased length of stay. During the pandemic, Asians were less likely to have a reintervention within 6 months, while Black ethnicities saw both lower reintervention probability and 30-days mortality.

To better understand whether and how using the IV approach allowed to eliminate the endogeneity problem, we present Tables 4 and 5, which compare OLS and IV-2SLS estimates for pre-pandemic and pandemic periods, as well as provide the first stage results to confirm the instrument's relevance, for the CABG and PTCA samples respectively.

For CABG, the OLS estimation (column (1) of Table 4) suggests that a 2-months increase in waiting time was negatively associated with the probability of being readmitted by about 0.4 percentage points, or 3.1% of the average readmission rate in the pre-pandemic sample, while for the pandemic period the implied impact was 0.6 percentage points, corresponding to 4.9% of the average. This might be driven by the omitted variable bias: failing to account for severity drives the waiting times coefficient downwards. Applying the IV-2SLS approach (column (3)) yields smaller (in absolute terms) and not statistically significant coefficients for both periods, suggesting no causal relationship between waiting time and emergency readmission probability. For the pre-pandemic period, the OLS and IV approaches indicate no relationship between waiting time and mortality indicators, although the IV approach yields wider confidence intervals. For the pandemic period, however, an insignificant relationship yielded by OLS becomes significant when the IV-2SLS is applied: a two-month increase in waiting time would increase the probability of death within 30 days and within a year from discharge by about 0.53 and 0.8 percentage points respectively.

Finally, the results for length of stay are different for the pandemic and pre-pandemic period. For the pre-pandemic sample, an OLS estimate of the relationship between waiting time and length of stay (column (9)) suggests a positive impact amounting to about 0.09 days increase in length of stay in response to a two-months increase in waiting time in the pre-pandemic period. The coefficient obtained via the IV-2SLS approach is slightly higher in magnitude, but not statistically significant. Conversely, in the pandemic sample, OLS yields an insignificant relationship between waiting time and length of stay, but the IV-2SLS coefficient is statistically significant at 10% level and indicates that a two-month longer waiting time would increase length of stay by 0.2 days.

Columns (2) and (4) of Table 4 provide first stage coefficients and F-statistics. Note that the sample for emergency readmissions is slightly smaller due to exclusion of patients who died in hospital (and hence could not have been readmitted). The first stage regressions suggest that a one day increase in congestion waiting times was associated with about 0.75 days increase in the individual's waiting time in the pre-pandemic sample, and about 0.83 days in the pandemic sample. The F-statistics are above 430 and 120 for the pre-pandemic and pandemic samples, indicating that the instrument is relevant.

Table 5 presents results for the PTCA sample. For the pandemic period, OLS and IV-2SLS estimates suggest that there is no relationship between waiting times and any of the outcomes (with the exception of a marginally significant negative OLS coefficient for length of stay). For the pre-pandemic sample, the OLS and IV-2SLS results are in agreement for both mortality indicators, suggesting no relationship between waiting times and probability of death within a month and a year from discharge. The OLS estimate for emergency readmission appears to be downward-biased and indicates that a two-month increase in waiting times would decrease the likelihood of being readmitted as an emergency by about 0.01 percentage points, which is 1.8% of the mean. This relationship is no longer significant when the IV approach is applied. Similarly, the OLS waiting times point estimate for the length of stay outcome suggests that a 2-month longer wait would decrease length of stay by about 0.004 days, which is close to 1% of the sample mean, while IV-2SLS coefficient is not statistically significant. Finally, while an OLS model yields a non-significant coefficient of waiting time for the reintervention probability outcome, the IV-2SLS suggests a positive impact: a two-months increase in wait would lead to a 0.27 percentage points increase in the probability of having a reintervention within six months from discharge. We also note that the first stage regressions are very similar to those for the CABG sample, with even higher F-statistics (above 700 and 940 for the pre-pandemic and pandemic samples).

Table 3
Regression results. IV-2SLS estimates for the PTCA sample.

	Pre-pandemic					*Pandemic*				
	(1) 28-day readmission	(2) 30-day mortality	(3) 1-year mortality	(4) Length of stay	(5) 6-month reintervention	(1) 28-day readmission	(2) 30-day mortality	(3) 1-year mortality	(4) Length of stay	(5) 6-month reintervention
Total waiting time (years)	−0.011	−0.001	−0.001	−0.013	0.016**	0.000	0.000	−0.007	−0.012	0.002
	(0.007)	(0.001)	(0.005)	(0.019)	(0.008)	(0.008)	(0.002)	(0.004)	(0.016)	(0.009)
Female	0.013***	−0.000	−0.003**	0.058***	−0.020***	0.013***	0.002	−0.008***	0.038***	−0.018***
	(0.002)	(0.001)	(0.001)	(0.006)	(0.003)	(0.004)	(0.001)	(0.002)	(0.014)	(0.005)
Age: 35–44										
Age: 45–54	−0.012	0.001**	0.004**	−0.019	0.004	−0.005	0.002**	−0.004	−0.040	0.002
	(0.009)	(0.000)	(0.002)	(0.019)	(0.008)	(0.012)	(0.001)	(0.006)	(0.032)	(0.015)
Age: 55–64	−0.019**	0.002***	0.005***	−0.019	0.009	−0.005	0.003***	0.000	−0.031	0.005
	(0.009)	(0.000)	(0.002)	(0.019)	(0.008)	(0.010)	(0.001)	(0.006)	(0.030)	(0.014)
Age: 65–74	−0.023***	0.002***	0.010***	−0.000	0.008	−0.014	0.002***	0.003	−0.006	0.014
	(0.009)	(0.000)	(0.002)	(0.021)	(0.007)	(0.011)	(0.001)	(0.007)	(0.030)	(0.015)
Age: 75–84	−0.020**	0.004***	0.024***	0.049**	0.006	−0.007	0.005***	0.016**	0.056*	0.019
	(0.009)	(0.001)	(0.002)	(0.021)	(0.008)	(0.011)	(0.001)	(0.007)	(0.033)	(0.015)
Age: 85–94	−0.006	0.005**	0.049***	0.117***	−0.008	0.005	0.007*	0.058***	0.155***	−0.002
	(0.010)	(0.002)	(0.007)	(0.031)	(0.010)	(0.016)	(0.004)	(0.017)	(0.052)	(0.020)
Num. of diagnoses on admission: 1–3										
4–6	0.000	0.002***	0.010***	0.146***	−0.000	−0.016**	0.002	0.008**	0.112***	−0.007
	(0.004)	(0.001)	(0.002)	(0.016)	(0.004)	(0.006)	(0.001)	(0.003)	(0.019)	(0.007)
7–9	0.006	0.005***	0.019***	0.274***	0.000	−0.023***	0.004**	0.013***	0.264***	−0.004
	(0.004)	(0.001)	(0.003)	(0.026)	(0.005)	(0.008)	(0.002)	(0.004)	(0.031)	(0.009)
11–12	0.014**	0.009***	0.037***	0.454***	0.008	−0.022***	0.008***	0.019***	0.413***	−0.001
	(0.006)	(0.002)	(0.004)	(0.037)	(0.007)	(0.008)	(0.003)	(0.007)	(0.045)	(0.011)
13–15	0.011	0.012***	0.045***	0.651***	0.006	−0.016	0.014***	0.038***	0.601***	−0.007
	(0.009)	(0.003)	(0.006)	(0.049)	(0.009)	(0.012)	(0.005)	(0.009)	(0.061)	(0.015)
Num. of Elixhauser conditions: 0										
1	0.012***	0.001	0.000	−0.012	0.020***	0.020***	0.000	0.006***	−0.007	0.011
	(0.003)	(0.001)	(0.002)	(0.012)	(0.006)	(0.006)	(0.000)	(0.002)	(0.017)	(0.009)
2	0.026***	0.000	−0.000	−0.012	0.028***	0.037***	0.001	0.009***	−0.026	0.025***
	(0.003)	(0.001)	(0.002)	(0.012)	(0.006)	(0.006)	(0.001)	(0.003)	(0.019)	(0.009)
3	0.034***	−0.001	0.002	−0.016	0.035***	0.046***	0.002	0.013***	−0.027	0.035***
	(0.004)	(0.001)	(0.002)	(0.011)	(0.005)	(0.007)	(0.001)	(0.003)	(0.020)	(0.010)

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Table 3 (*continued*)

	Pre-pandemic					*Pandemic*				
	(1) 28-day readmission	(2) 30-day mortality	(3) 1-year mortality	(4) Length of stay	(5) 6-month reintervention	(1) 28-day readmission	(2) 30-day mortality	(3) 1-year mortality	(4) Length of stay	(5) 6-month reintervention
4	0.043***	−0.001	0.005**	−0.013	0.038***	0.061***	0.004**	0.019***	−0.036*	0.036***
	(0.004)	(0.001)	(0.002)	(0.012)	(0.007)	(0.008)	(0.002)	(0.004)	(0.021)	(0.010)
5	0.048***	−0.001	0.007**	0.004	0.034***	0.078***	0.002	0.017***	−0.043*	0.034***
	(0.005)	(0.001)	(0.003)	(0.015)	(0.006)	(0.009)	(0.002)	(0.005)	(0.023)	(0.011)
6	0.059***	−0.001	0.012***	−0.002	0.042***	0.086***	0.001	0.035***	−0.057**	0.039***
	(0.006)	(0.001)	(0.003)	(0.015)	(0.007)	(0.010)	(0.002)	(0.007)	(0.027)	(0.010)
7	0.058***	−0.001	0.011**	0.008	0.032***	0.096***	0.005	0.059***	0.017	0.059***
	(0.006)	(0.001)	(0.004)	(0.015)	(0.006)	(0.013)	(0.003)	(0.008)	(0.031)	(0.015)
8	0.077***	−0.003**	0.007*	−0.009	0.032***	0.107***	0.000	0.063***	0.033	0.054***
	(0.007)	(0.002)	(0.004)	(0.016)	(0.008)	(0.014)	(0.003)	(0.012)	(0.036)	(0.014)
9	0.090***	−0.004***	0.003	0.006	0.043***	0.098***	0.003	0.077***	−0.058	0.064***
	(0.008)	(0.002)	(0.005)	(0.026)	(0.009)	(0.014)	(0.004)	(0.013)	(0.045)	(0.023)
10	0.070***	−0.007***	−0.009*	0.017	0.038***	0.176***	0.003	0.098***	−0.045	0.037**
	(0.008)	(0.001)	(0.005)	(0.026)	(0.012)	(0.029)	(0.005)	(0.020)	(0.052)	(0.017)
11	0.082***	−0.007***	−0.013**	−0.003	0.050***	0.159***	0.010	0.143***	0.072	0.050**
	(0.010)	(0.001)	(0.007)	(0.025)	(0.013)	(0.036)	(0.012)	(0.028)	(0.066)	(0.023)
12	0.083***	−0.008***	−0.005	0.032	0.039***	0.153***	0.007	0.126***	−0.106*	0.077**
	(0.015)	(0.001)	(0.008)	(0.047)	(0.015)	(0.039)	(0.011)	(0.039)	(0.056)	(0.037)
13	0.127***	−0.008***	−0.014	−0.048	0.049**	0.105**	−0.009***	0.071	−0.239***	0.034
	(0.022)	(0.001)	(0.010)	(0.041)	(0.021)	(0.048)	(0.003)	(0.051)	(0.080)	(0.045)
14+	0.133***	−0.007***	−0.034***	0.044	0.067***	0.305***	−0.008**	0.217***	−0.132	0.089*
	(0.027)	(0.001)	(0.004)	(0.059)	(0.019)	(0.076)	(0.003)	(0.077)	(0.091)	(0.050)
Number of previous emergency admissions	0.021***	0.001**	0.008***	0.018***	−0.007***	0.018***	0.001	0.006***	0.006	−0.005
	(0.002)	(0.000)	(0.001)	(0.005)	(0.002)	(0.004)	(0.001)	(0.002)	(0.008)	(0.003)
Urgent first outpatient appointment	−0.006**	0.001	−0.002	0.003	0.005*	−0.002	0.001	−0.001	0.029**	0.004
	(0.002)	(0.001)	(0.002)	(0.009)	(0.003)	(0.005)	(0.001)	(0.002)	(0.013)	(0.006)
Referral source for the first OP appointment: other										
Referral source for the first OP appointment: GP	0.002	−0.000	−0.003**	−0.022***	−0.007*	0.008*	0.000	−0.000	−0.009	0.000
	(0.003)	(0.001)	(0.002)	(0.008)	(0.004)	(0.004)	(0.001)	(0.003)	(0.012)	(0.006)
Referral source for the first OP appointment: another consultant	0.009**	0.001	0.004*	−0.016	−0.010**	0.012*	0.002	0.004	−0.028*	−0.002
	(0.004)	(0.001)	(0.002)	(0.011)	(0.005)	(0.006)	(0.002)	(0.005)	(0.016)	(0.007)

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Table 3 (*continued*)

	Pre-pandemic					*Pandemic*				
	(1) 28-day readmission	(2) 30-day mortality	(3) 1-year mortality	(4) Length of stay	(5) 6-month reintervention	(1) 28-day readmission	(2) 30-day mortality	(3) 1-year mortality	(4) Length of stay	(5) 6-month reintervention
Referral source for the first OP appointment: same OP consultant	0.004	−0.000	−0.001	−0.031*	−0.005	−0.000	0.001	−0.006	−0.019	−0.011
	(0.004)	(0.001)	(0.004)	(0.018)	(0.006)	(0.010)	(0.003)	(0.007)	(0.025)	(0.011)
Depriv. quintile (income)=1 (least deprived)										
Depriv. quintile (income)=2	0.000	0.001	0.003*	0.004	0.002	−0.004	−0.001	−0.002	0.010	−0.002
	(0.003)	(0.001)	(0.002)	(0.008)	(0.004)	(0.006)	(0.001)	(0.004)	(0.013)	(0.005)
Depriv. quintile (income)=3	−0.002	0.000	0.004**	0.011	−0.007	−0.006	−0.002	−0.000	0.009	−0.010*
	(0.003)	(0.001)	(0.002)	(0.008)	(0.004)	(0.005)	(0.001)	(0.004)	(0.012)	(0.005)
Depriv. quintile (income)=4	−0.001	−0.000	0.002	0.005	−0.004	0.003	−0.000	0.001	0.005	0.005
	(0.003)	(0.001)	(0.002)	(0.010)	(0.004)	(0.005)	(0.001)	(0.003)	(0.013)	(0.006)
Depriv. quintile (income)=5 (most deprived)	0.001	0.000	0.003*	0.004	−0.010***	−0.003	0.001	0.008**	−0.010	0.001
	(0.003)	(0.001)	(0.002)	(0.009)	(0.004)	(0.004)	(0.002)	(0.004)	(0.016)	(0.007)
Ethnicity: white										
Ethnicity: black	0.004	0.001	0.002	0.098***	−0.000	−0.009	−0.003***	0.005	0.002	−0.043***
	(0.014)	(0.002)	(0.007)	(0.035)	(0.012)	(0.021)	(0.001)	(0.012)	(0.053)	(0.014)
Ethnicity: asian	0.011***	0.001	−0.003	0.000	−0.006	0.015*	0.003	0.004	0.003	−0.016***
	(0.004)	(0.001)	(0.002)	(0.016)	(0.005)	(0.009)	(0.002)	(0.003)	(0.018)	(0.005)
Ethnicity: mixed	0.010	0.006	−0.004	−0.033	0.002	0.036	0.009	0.004	0.029	−0.008
	(0.013)	(0.005)	(0.007)	(0.030)	(0.015)	(0.028)	(0.011)	(0.015)	(0.058)	(0.029)
Ethnicity: other	−0.004	0.004	0.001	0.037	0.014	−0.010	−0.001	−0.006	0.043	0.008
	(0.006)	(0.003)	(0.006)	(0.023)	(0.011)	(0.010)	(0.001)	(0.006)	(0.030)	(0.015)
Ethnicity: missing	−0.003	0.000	0.001	0.009	−0.002	0.004	0.002*	0.007***	0.037**	−0.006
	(0.003)	(0.001)	(0.002)	(0.010)	(0.004)	(0.005)	(0.001)	(0.003)	(0.015)	(0.007)
Constant	0.033**	−0.004**	0.005	1.363***	0.060***	−0.010	0.014	−0.014	0.565**	0.077
	(0.016)	(0.002)	(0.011)	(0.192)	(0.021)	(0.021)	(0.013)	(0.012)	(0.271)	(0.049)
Observations	55,874	55,918	55,918	55,918	55,874	16,786	16,808	16,808	16,808	16,786

Notes. Each regression includes Trust, financial year, month of admission and day of the week of admission fixed effects, as well as patient-level control variables: age group, sex, number of diagnoses at admission group, number of Elixhauser conditions, previous emergency admissions within a year from the index admission, income deprivation quintile, ethnicity, an indicator of an urgent first referral, a referral source of the first outpatient appointment, and indicator variables for the 30 most common secondary diagnoses (see Table A1). Clustered s.e. in parentheses. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 4
OLS, First Stage, IV-2SLS estimates for the CABG sample.

Panel A: Pre-pandemic	(1)	(2) 28-day readmission	(3)	(4)	(5) 30-day mortality	(6)	(7) 1-year mortality	(8)	(9) Length of Stay	(10)
	OLS	First Stage	IV-2SLS	OLS	First Stage	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS
Total waiting time (years)	-0.024***		-0.005	0.004		0.003	0.003	-0.018	0.523***	0.685
	(0.007)		(0.028)	(0.004)		(0.008)	(0.005)	(0.011)	(0.176)	(0.521)
Congestion (years)		0.752***			0.754***					
		(0.036)			(0.036)					
F-stat		437			444					
Observations	29,703	29,703	29,703	29,992	29,992	29,992	29,992	29,992	29,992	29,992
Panel B: Pandemic	(1)	(2) 28-day readmission	(3)	(4)	(5) 30-day mortality	(6)	(7) 1-year mortality	(8)	(9) Length of Stay	(10)
	OLS	First Stage	IV-2SLS	OLS	First Stage	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS
Total waiting time (years)	-0.036***		-0.007	0.004		0.032***	0.003	0.048***	0.071	1.194*
	(0.011)		(0.025)	(0.005)		(0.011)	(0.006)	(0.017)	(0.344)	(0.631)
Congestion (years)		0.833***			0.831***					
		(0.075)			(0.075)					
F-stat		123			121					
Observations	6940	6940	6940	7001	7001	7001	7001	7001	7001	7001

Notes. Each regression includes Trust, financial year, month of admission and day of the week of admission fixed effects, as well as patient-level control variables: age group, sex, number of diagnoses at admission group, number of Elixhauser conditions, previous emergency admissions within a year from the index admission, income deprivation quintile, ethnicity, an indicator of an urgent first referral, a referral source of the first outpatient appointment, and indicator variables for the 30 most common secondary diagnoses (see Table A1). Clustered s.e. in parentheses. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

7. Disaggregating waiting times into inpatient and outpatient components

To gain further insights on whether one of the two components comprising the referral-to-treatment waiting time (inpatient and outpatient) is driving the results, we run two additional IV-2SLS estimations. In the first one, our dependent variable is the inpatient waiting time, which is the time spanning from the placement on the waiting list to admission for surgery. Previous literature generally adopts this measure of waiting time. When establishing the impact of inpatient waiting time on outcomes, the endogeneity problem is still present, analogously to the referral-to-treatment waiting time analysis. To address endogeneity, we adopt a similar instrumental variables approach, but the instrument is calculated differently for the inpatient waiting time. In particular, we use the average inpatient wait of patients admitted to the same hospital, who were placed on the waiting list up to 30 days prior to a given patient. Note that this is different from the way the instrument is calculated for the total waiting time, in that the cutoff date used is the date of placement on the waiting list, rather than the first referral.

Table 6 presents the results for the CABG samples. It shows that using only the inpatient section of the waiting time is not sufficient to capture the effects of longer waits on mortality during the pandemic period as none of the second stage coefficients are statistically significant in Panel B of the table. This suggests that using only inpatient waiting time may not be sufficient to capture the impact of waits on certain patient outcomes, such as mortality. However, we find inpatient waiting time to have a positive causal effect on length of stay in the pre-pandemic period (Panel A, column 10). Recall that when using total waiting time the IV-2SLS approach suggested no impact of waiting time on length of stay. This may indicate that for length of stay specifically, only the inpatient section of the total waiting time is relevant. We hypothesise that this may be due to CABG patients requiring a wide range of pre-operative assessments (also more extensive than needed for PTCA patients), some of which can be done before placing the patient on a waiting list. If the patient stays for too long on the waiting list, to get the correct clinical picture those diagnostics may need to be performed again shortly before the surgery, in the inpatient setting, thereby increasing length of stay.

Table 7 presents analogous results for PTCA. Overall, the findings are consistent with Table 5, in that for most outcomes no statistically significant impact of waiting time is detected. However, for 1-year mortality, there is a statistically significant effect of inpatient waiting time on mortality, albeit of a counterintuitive, negative sign. This might suggest that singling out only the inpatient wait may lead to misleading conclusions.

In the second part of this analysis we include both the inpatient and outpatient waiting time as two separate endogenous variables, which are instrumented by inpatient and outpatient congestion. Outpatient congestion is calculated as the average outpatient waiting time of patients referred to the cardiological service up to 30 days prior to the given patient. The results for CABG are presented in Table 8. Adding outpatient waiting time yields results very similar to when only the inpatient waiting time is included: longer inpatient wait appears to increase the length of stay in the pre-pandemic period, but yet again this specification does not allow to uncover the effects on

Table 5
OLS, First Stage, IV-2SLS estimates for the PTCA sample.

Panel A: Pre-pandemic	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	28-day readmission			30-day mortality			1-year mortality		Length of Stay		6-month reintervention	
	OLS	First Stage	IV-2SLS	OLS	First Stage	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS
Total waiting time (years)	-0.006**		-0.011	-0.000		-0.001	-0.000	-0.001	-0.021**	-0.013	0.001	0.016**
	(0.003)		(0.007)	(0.001)		(0.001)	(0.002)	(0.005)	(0.009)	(0.019)	(0.003)	(0.008)
Congestion (years)		0.750***			0.750***							
		(0.028)			(0.028)							
F-stat		710			710							
Observations	55,874	55,874	55,874	55,919	55,918	55,918	55,918	55,918	55,918	55,918	55,874	55,874

Panel B: Pandemic	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	28-day readmission			30-day mortality			1-year mortality		Length of Stay		6-month reintervention	
	OLS	First Stage	IV-2SLS	OLS	First Stage	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS
Total waiting time (years)	0.002		0.000	0.001		0.000	-0.004	-0.007	-0.021*	-0.012	-0.002	0.002
	(0.005)		(0.008)	(0.001)		(0.002)	(0.003)	(0.004)	(0.012)	(0.016)	(0.005)	(0.009)
Congestion (years)		0.983***			0.983***							
		(0.032)			(0.032)							
F-stat		946			940							
Observations	16,786	16,786	16,786	16,808	16,808	16,808	16,808	16,808	16,808	16,808	16,786	16,786

Notes. Each regression includes Trust, financial year, month of admission and day of the week of admission fixed effects, as well as patient-level control variables: age group, sex, number of diagnoses at admission group, number of Elixhauser conditions, previous emergency admissions within a year from the index admission, income deprivation quintile, ethnicity, an indicator of an urgent first referral, a referral source of the first outpatient appointment, and indicator variables for the 30 most common secondary diagnoses (see Table A1). Clustered s.e. in parentheses. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 6
Inpatient waiting time only; OLS, First Stage, IV-2SLS estimates for the CABG sample.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Panel A: Pre-pandemic	28-day readmission			30-day mortality			1-year mortality		Length of Stay	
	OLS	First Stage	IV-2SLS	OLS	First Stage	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS
Inpatient waiting time (years)	-0.052***		-0.066	0.004		0.022	-0.005	-0.009	-0.077	2.535***
	(0.016)		(0.066)	(0.005)		(0.017)	(0.008)	(0.021)	(0.324)	(0.809)
Inpatient congestion (years)		0.712***			0.711***					
		(0.027)			(0.027)					
F-stat		699			678					
Observations	29,657	29,657	29,657	29,944	29,944	29,944	29,944	29,944	29,944	29,944
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Panel B: Pandemic	28-day readmission			30-day mortality			1-year mortality		Length of Stay	
	OLS	First Stage	IV-2SLS	OLS	First Stage	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS
Inpatient waiting time (years)	-0.056***		-0.021	0.01		0.023	0.010	0.006	-0.369	1.493
	(0.019)		(0.068)	(0.008)		(0.019)	(0.010)	(0.026)	(0.552)	(1.013)
Inpatient congestion (years)		0.750***			0.747***					
		(0.060)			(0.059)					
F-stat		156			168					
Observations	6873	6873	6873	6931	6931	6931	6931	6931	6931	6931

Notes. Each regression includes Trust, financial year, month of admission and day of the week of admission fixed effects, as well as patient-level control variables: age group, sex, number of diagnoses at admission group, number of Elixhauser conditions, previous emergency admissions within a year from the index admission, income deprivation quintile, ethnicity, an indicator of an urgent first referral, a referral source of the first outpatient appointment, and indicator variables for the 30 most common secondary diagnoses (see Table A1). Clustered s.e. in parentheses. Significance levels: * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table 7
Inpatient waiting time only; OLS, First Stage, IV-2SLS estimates for the PTCA sample.

Panel A: Pre-pandemic	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	28-day readmission			30-day mortality			1-year mortality		Length of Stay		6-month reintervention	
	OLS	First Stage	IV-2SLS	OLS	First Stage	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS
Inpatient waiting time (years)	-0.024**		-0.063	0.001		0.000	-0.013**	-0.058**	-0.058	-0.296	-0.011	0.035
	(0.011)		(0.041)	(0.002)		(0.008)	(0.006)	(0.025)	(0.051)	(0.183)	(0.017)	(0.046)
Inpatient congestion (years)		0.586***			0.586***							
		(0.028)			(0.028)							
F-stat		424			425							
Observations	55,653	55,653	55,653	55,697	55,697	55,697	55,697	55,697	55,697	55,697	55,653	55,653
Panel B: Pandemic	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	28-day readmission			30-day mortality			1-year mortality		Length of Stay		6-month reintervention	
	OLS	First Stage	IV-2SLS	OLS	First Stage	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS
Inpatient waiting time (years)	-0.007		0.043	-0.005**		-0.014*	-0.022**	-0.022	0.036	-0.001	-0.042***	0.032
	(0.005)		(0.037)	(0.002)		(0.007)	(0.009)	(0.022)	(0.040)	(0.090)	(0.015)	(0.039)
Inpatient congestion (years)		0.709***			0.709***							
		(0.041)			(0.041)							
F-stat		305			304							
Observations	16,538	16,538	16,538	16,560	16,560	16,560	16,560	16,560	16,560	16,560	16,538	16,538

Notes. Each regression includes Trust, financial year, month of admission and day of the week of admission fixed effects, as well as patient-level control variables: age group, sex, number of diagnoses at admission group, number of Elixhauser conditions, previous emergency admissions within a year from the index admission, income deprivation quintile, ethnicity, an indicator of an urgent first referral, a referral source of the first outpatient appointment, and indicator variables for the 30 most common secondary diagnoses (see Table A1). Clustered s.e. in parentheses. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 8
Inpatient and outpatient waiting time; OLS, First Stage, IV-2SLS estimates for the CABG sample.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Panel A: Pre-pandemic	28-day readmission			30-day mortality			1-year mortality				Length of Stay	
	OLS	FS IP wait	FS OP wait	IV-2SLS	OLS	FS IP wait	FS OP wait	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS
Inpatient WT	-0.052***			-0.071	0.004			0.023	-0.005	-0.007	-0.087	2.546***
	(0.016)			(0.067)	(0.005)			(0.018)	(0.008)	(0.022)	(0.331)	(0.856)
Outpatient WT	-0.008			0.047	0.003			-0.009	0.007	-0.021	0.888***	-0.119
	(0.009)			(0.047)	(0.004)			(0.012)	(0.005)	(0.027)	(0.245)	(1.218)
Inpatient congestion (yrs)		0.688***	-0.073*			0.687***	-0.073*					
		(0.029)	(0.040)			(0.029)	(0.04)					
Outpatient congestion (yrs)		0.105***	0.601***			0.105***	0.604***					
		(0.016)	(0.047)			(0.016)	(0.047)					
F-stat				626				607		607		607
Observations	29,657	29,657	29,657	29,657	29,944	29,944	29,944	29,944	29,944	29,944	29,944	29,944
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Panel B: Pandemic	28-day readmission			30-day mortality			1-year mortality				Length of Stay	
	OLS	FS IP wait	FS OP wait	IV-2SLS	OLS	FS IP wait	FS OP wait	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS
Inpatient WT	-0.057***			-0.023	0.010			0.024	0.010	0.005	-0.354	1.472
	(0.019)			(0.069)	(0.008)			(0.020)	(0.009)	(0.026)	(0.553)	(1.018)
Outpatient WT	-0.019			0.070	-0.006			-0.011	-0.010	0.040	0.471*	0.975
	(0.021)			(0.080)	(0.008)			(0.019)	(0.008)	(0.036)	(0.254)	(0.934)
Inpatient congestion (yrs)		0.716***	-0.079**			0.713***	-0.083**					
		(0.060)	(0.032)			(0.059)	(0.032)					
Outpatient congestion (yrs)		0.193***	0.562***			0.192***	0.564***					
		(0.034)	(0.073)			(0.034)	(0.073)					
F-stat				156				158		158		158
Observations	6873	6873	6873	6873	6931	6931	6931	6931	6931	6931	6931	6931

Notes. Each regression includes Trust, financial year, month of admission and day of the week of admission fixed effects, as well as patient-level control variables: age group, sex, number of diagnoses at admission group, number of Elixhauser conditions, previous emergency admissions within a year from the index admission, income deprivation quintile, ethnicity, an indicator of an urgent first referral, a referral source of the first outpatient appointment, and indicator variables for the 30 most common secondary diagnoses (see Table A1). Clustered s.e. in parentheses. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 9
Inpatient and outpatient waiting time; OLS, First Stage, IV-2SLS estimates for the PTCA sample.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Panel A: Pre-pandemic	28-day readmission				30-day mortality				1-year mortality		Length of Stay		6-month reintervention	
	OLS	FS IP wait	FS OP wait	IV-2SLS	OLS	FS IP wait	FS OP wait	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS
Inpatient WT	−0.023**			−0.062	0.001			0.001	−0.013**	−0.058**	−0.054	−0.297	−0.012	0.031
	(0.010)			(0.041)	(0.002)			(0.009)	(0.006)	(0.026)	(0.051)	(0.185)	(0.017)	(0.046)
Outpatient WT	−0.005			−0.007	−0.000			−0.002	0.001	0.003	−0.018**	0.006	0.003	0.018**
	(0.003)			(0.008)	(0.001)			(0.001)	(0.002)	(0.005)	(0.008)	(0.023)	(0.003)	(0.009)
Inpatient congestion (yrs)		0.578***	−0.096**			0.579***	−0.095**							
		(0.028)	(0.047)			(0.028)	(0.047)							
Outpatient congestion (yrs)		0.028***	0.731***			0.028***	0.731***							
		(0.003)	(0.027)			(0.003)	(0.027)							
F-stat				453				454		454		454		453
Observations	55,653	55,653	55,653	55,653	55,697	55,697	55,697	55,697	55,697	55,697	55,697	55,697	55,697	55,697
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Panel B: Pandemic	28-day readmission				30-day mortality				1-year mortality		Length of Stay		6-month reintervention	
	OLS	FS IP wait	FS OP wait	IV-2SLS	OLS	FS IP wait	FS OP wait	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS
Inpatient WT	−0.007			0.043	−0.005**			−0.014*	−0.021**	−0.022	0.039	−0.001	−0.043***	0.032
	(0.014)			(0.037)	(0.002)			(0.008)	(0.008)	(0.022)	(0.040)	(0.090)	(0.015)	(0.039)
Outpatient WT	0.004			−0.005	0.002			0.004	−0.003	−0.002	−0.031**	−0.016	0.003	−0.000
	(0.005)			(0.009)	(0.001)			(0.003)	(0.003)	(0.006)	(0.013)	(0.021)	(0.005)	(0.010)
Inpatient congestion (yrs)		0.681***	−0.344***			0.681***	−0.345***							
		(0.039)	(0.053)			(0.039)	(0.054)							
Outpatient congestion (yrs)		0.078***	0.904***			0.078***	0.904***							
		(0.008)	(0.031)			(0.008)	(0.032)							
F-stat				338				335		335		335		338
Observations	16,538	16,538	16,538	16,538	16,560	16,560	16,560	16,560	16,560	16,560	16,560	16,560	16,560	16,560

Notes. Each regression includes Trust, financial year, month of admission and day of the week of admission fixed effects, as well as patient-level control variables: age group, sex, number of diagnoses at admission group, number of Elixhauser conditions, previous emergency admissions within a year from the index admission, income deprivation quintile, ethnicity, an indicator of an urgent first referral, a referral source of the first outpatient appointment, and indicator variables for the 30 most common secondary diagnoses (see Table A1). Clustered s.e. in parentheses. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

mortality observed in the pandemic period when total waiting time is used instead of a split into inpatient and outpatient components.

The analogous analysis for PTCA, presented in Table 9, suggests that the link between waiting times and likelihood of a reintervention within six months in the pre-pandemic period is due to the outpatient component of the waiting time. This may be in line with expectations as for the PTCA sample outpatient waiting time constitutes about two thirds of the total referral-to-treatment waiting time.

8. Robustness checks

We perform a range of checks to test whether the results are robust to different definitions of the sample. First, we tighten the matching criterion: instead of allowing a 60-days lag between the outpatient appointment date and the date of placement on the procedure waiting list, we now allow a maximum of 30 days gap between these two events. Tables A4 and A5 in the Appendix provide results with these restrictions in place for CABG and PTCA respectively. As expected, the sample sizes are lower, but the effect of imposing a stricter matching restriction is different for the two procedures. For CABG, the sample sizes for both periods reduce by about 7%, whereas for PTCA the pre-pandemic sample by 19% and the pandemic one by 16% - a significant reduction by more than 10,500 and 2700 observations respectively for the two periods. The results remain consistent with our baseline estimation. For CABG procedures during the pandemic, the causal effect of waiting times on mortality is confirmed, and the effect of wait on length of stay is now larger in magnitude and statistically significant at 5% level, as opposed to only marginally significant coefficient in the baseline model. For PTCA in the pre-pandemic period the link between waiting and the probability of a reintervention is still present, but the coefficient, though similar in magnitude, is now only significant at 10% level (instead of 5%), possibly due to smaller sample size.

Our next two robustness checks are related to the construction of the instrumental variable. First, we apply an additional restriction demanding the number of patients used to calculate congestion for a given individual to exceed four patients. In other words, if an individual was referred to a specialist on the 1st of May and fewer than four other patients were referred in the 30 days before that (April 1st to April 30th), this observation is dropped from the sample. This slightly decreases the size of the original samples. Tables A6 and A7 in the Appendix report the results of this robustness check for CABG and PTCA respectively. For CABG, the main conclusions are very similar to what we obtain with the baseline samples: the COVID period recorded a positive effect of waiting times on mortality and length of stay. For PTCA pre-pandemic, the causal link between waiting times and reintervention probability within six months from discharge is only marginally significant, compared with the baseline estimate in Table 5.

Second, we vary the window preceding the referral to treatment date: instead of measuring congestion as an average waiting time of the patients who were first referred to a specialist up to 30 days prior to the given patient, we extend this window to 60 days. For example, in the baseline specification, congestion for a patient referred to a specialist on the 1st of May is measured as an average waiting time of those who were first referred in the month of April, while in this robustness check specification it is an average waiting time of those who were referred from 2nd of March to 30th of April. The analysis is then conducted on the exact same sample as the baseline. Tables A8 and A9 in the Appendix present the results for CABG and PTCA respectively. For the CABG pandemic sample, the impact of waiting times on mortality and length of stay is confirmed, while for the PTCA pre-pandemic sample the effect of waiting times on reintervention probability is only marginally significant.

Finally, one possible concern is that patients may choose hospitals based on average waiting times. Gaynor et al. (2016) show that following the introduction of the patient choice policy in England waiting times do not affect patient choice of hospital, and therefore this should not invalidate our identification strategy. To further investigate this issue in our sample, we adopt an alternative (geographic) definition of the instrumental variable, where congestion is defined not at the hospital, but at the Clinical Commissioning Group (CCG) level.[11] In this specification the instrument is defined as the average waiting time of patients admitted to hospitals belonging to the same CCG. Averaging waiting times at the CCG level is less likely to be affected by individual hospital choices, but may result in a weaker instrument, as it implies averaging across patients whose waiting times may be less relevant for the congestion faced by a given patient. Tables A10 and A11 in the Appendix provide the results of this analysis for CABG and PTCA respectively, which are very similar to the baseline estimation: the IV-2SLS approach suggests that longer waiting times increased mortality for CABG patients in the COVID period.

In addition to the above checks, we tested the robustness of our results to alternative confidence intervals. First, we have considered the *tF* adjustment proposed by Lee et al. (2022). The F statistics in the first stage regressions are larger than 104.67, hence the *tF* correction is not necessary. Second, we have explored the implications of the "power asymmetry" phenomenon described by Keane and Neal (2023). In our context – where the true parameter value is of opposite sign to the OLS bias – this implies that the conventional *t*-test for the IV-2SLS estimator may exhibit lower statistical power than the Anderson-Rubin (AR) test in detecting significant effects. However, as noted by Keane and Neal (2025), when the IV-2SLS coefficient is sufficiently large in magnitude, the *t*-test and Anderson-Rubin test tend to produce comparable results. To ensure that our results are robust, we computed the Anderson-Rubin confidence intervals, which are nearly identical to the conventional ones. Fig. A1 in the Appendix mimics Fig. 4, but plots the 95% Anderson-Rubin confidence intervals. The Anderson-Rubin confidence intervals are very similar to the Wald ones plotted in Fig. 4. The only noticeable difference occurs for the impact of waiting times on length of stay for the pandemic CABG sample, which, as expected, becomes more precisely estimated, and is statistically significant at the 5% level instead of the 10% level suggested by Wald confidence intervals.

[11] CCGs are clinically-led statutory bodies responsible for planning and commissioning most hospital and community NHS services within their local areas. In 2022 they were replaced by Integrated Care Systems.

Table 10
Heterogeneity analysis for CABG, COVID.

Age	**age >= 68**						**age < 68**					
	First Stage	28-day readmission	First Stage	30-day mortality	1-year mortality	Length of Stay	First Stage	28-day readmission	First Stage	30-day mortality	1-year mortality	Length of Stay
Congestion (years)	0.810***		0.806***				0.856***		0.855***			
	(0.080)		(0.080)				(0.076)		(0.076)			
Total waiting time (years)		0.000		0.040***	0.055**	1.442**		-0.015		0.028*	0.046**	0.754
		(0.045)		(0.015)	(0.025)	(0.713)		(0.037)		(0.016)	(0.022)	(0.693)
Constant	0.033	0.037	0.045	-0.002	0.006	7.613***	-0.283***	-0.018	-0.283***	-0.011*	-0.024	6.227***
	(0.138)	(0.097)	(0.139)	(0.014)	(0.026)	(1.311)	(0.067)	(0.056)	(0.066)	(0.006)	(0.019)	(0.813)
F-stat	103		101				127		127			
Observations	3456	3502	3502	3502	3502	3484	3484	3499	3499	3499	3499	3456

Complexity	**number of Elixauser cond >= 4**						**number of Elixhauser cond <4**					
	First Stage	28-day readmission	First Stage	30-day mortality	1-year mortality	Length of Stay	First Stage	28-day readmission	First Stage	30-day mortality	1-year mortality	Length of Stay
Congestion (years)	0.835***		0.832***				0.822***		0.821***			
	(0.090)		(0.091)				(0.066)		(0.066)			
Total waiting time (years)		0.007		0.050***	0.074***	1.596**		-0.012		0.019***	0.026**	0.515
		(0.052)		(0.019)	(0.028)	(0.754)		(0.035)		(0.007)	(0.010)	(0.632)
Constant	-0.063	0.155	-0.055	-0.059***	0.036	7.924***	-0.203*	0.066	-0.199*	-0.000	-0.011	7.297***
	(0.167)	(0.227)	(0.167)	(0.022)	(0.124)	(2.459)	(0.106)	(0.050)	(0.106)	(0.005)	(0.008)	(0.989)
F-stat	87		85				156		157			
Observations	3452	3452	3507	3507	3507	3507	3488	3488	3494	3494	3494	3494

Deprivation	**in the three most deprived quintiles**						**in the two least deprived quintiles**					
	First Stage	28-day readmission	First Stage	30-day mortality	1-year mortality	Length of Stay	First Stage	28-day readmission	First Stage	30-day mortality	1-year mortality	Length of Stay
Congestion (years)	0.849***		0.850***				0.816***		0.811***			
	(0.080)		(0.080)				(0.077)		(0.078)			
Total waiting time (years)		-0.027		0.040***	0.061***	1.026**		0.021		0.029	0.038	1.439
		(0.043)		(0.014)	(0.018)	(0.506)		(0.050)		(0.018)	(0.029)	(0.894)
Constant	-0.234	-0.018	-0.228	-0.031***	-0.047*	4.696***	-0.116	0.026	-0.112	0.005	-0.026	7.159***
	(0.152)	(0.094)	(0.152)	(0.011)	(0.026)	(0.857)	(0.092)	(0.092)	(0.092)	(0.012)	(0.023)	(1.356)
F-stat	112		113				113		110			
Observations	3762	3762	3792	3792	3792	3792	3178	3178	3209	3209	3209	3209

Notes. Each regression includes Trust, financial year, month of admission and day of the week of admission fixed effects, as well as patient-level control variables: age group, sex, number of diagnoses at admission group, number of Elixhauser conditions, previous emergency admissions within a year from the index admission, income deprivation quintile, ethnicity, an indicator of an urgent first referral, a referral source of the first outpatient appointment, and indicator variables for the 30 most common secondary diagnoses (see Table A1). Clustered s.e. in parentheses. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Overall, these additional analyses suggest that the results for CABG are very stable, while for PTCA the link between waiting times and likelihood of reintervention within 6 months from discharge is less robust.

9. Heterogeneity analysis

In this section, we investigate whether the results are heterogenous for CABG in the pandemic period along three dimensions: age, patient complexity, and deprivation. To this end, we split the sample into two groups for each heterogeneity domain. For age, the first group includes patients whose age is above or equal to the median (68 years old) and the second group comprises those whose age is below the median. For complexity, we include the patients who have a number of Elixhauser conditions equal to or above the median (four conditions) in the first group, and those below the median in the second group. As regards deprivation, we include those living in the areas in the three most income deprived quintiles in the first group, and those in the two least income deprived quintiles in the second group.

Table 10 provides the results of estimating Eq. (1) for each outcome by subgroups specified above, for those who underwent CABG procedure during the pandemic. The starkest differences are observed across the deprivation dimension: the impact of waiting time on mortality and length of stay is statistically significant for those living in more deprived areas, while for the least deprived sample the coefficients are not statistically significant. As regards age, older individuals were more likely to die within 30 days from discharge and stay longer in hospital as a result of increased waiting times. However, the impact of longer wait on probability of death within a year is statistically significant for both the younger and the older subsamples. Finally, we find that increased waiting time leads to longer length of stay for the subsample of more complex patients, while the impact of waits on mortality is statistically significant for both more complex and less complex patients.

10. Discussion

Cardiovascular diseases are a leading cause of morbidity and mortality globally. Policies that promote timely access to common and effective treatment such as coronary bypass and angioplasty can contribute to reducing the incidence of severe health shocks, like heart attacks or strokes. Delayed access to cardiovascular treatment was a policy concern before COVID-19, which has been exacerbated after the pandemic. Quantifying and assessing the impact of delayed access to care on health outcomes is therefore important for policymakers to ensure an efficient allocation of limited resources across different clinical areas or to identify areas of care where patients require additional support while waiting to mitigate possible adverse effects.

Waiting times generate a health loss because the health benefits from health care are postponed. But the health loss is augmented if the patient reduces the ability to benefit from health care – for example, in extreme cases when they die while waiting due to cardiac events which could have been prevented with faster access. Our analysis can therefore inform policy by testing the impact of waiting times for common cardiovascular treatments on adverse health outcomes. One additional concern is that because patient health can deteriorate while waiting, longer delays can make it more costly to treat patients once they receive treatment, and detract health system resources which could be used elsewhere – a form of negative externality. Our analysis can shed some light on whether waiting times lead to higher resource use. The main policy implication is that investing in boosting supply to reduce waiting times will be more impactful if shorter waiting times help to avoid adverse health events, prevent hospitalisations or save costs.

More specifically, this study has investigated the impact of referral-to-treatment waiting times on health outcomes and length of stay for patients undergoing CABG and PTCA. We employ a causal inference framework and use a measure of congestion as an instrumental variable for the waiting time. The findings for coronary bypass are markedly different before and after COVID-19. Before the pandemic, waiting times had no effect on health outcomes or length of stay. Instead, in the pandemic period, we find waiting times to increase 30-day and 1-year mortality, and length of stay for CABG patients. The results appear quantitatively important. An increase in referral-to-treatment waiting times by two months increases 30-day mortality by 0.5 percentage points (44%), 1-year mortality by 0.8 percentage points (29%), and length of stay by 0.2 days (2.3%) for CABG patients during the pandemic.

The most immediate explanation for the differing findings is that before the pandemic waiting times might not have been sufficiently long to impact health outcomes or length of stay. The pandemic increased waiting times by 28% for CABG and 12% for PTCA. An alternative explanation is that patients received less support during the pandemic while waiting, including from primary care, as health systems were experiencing backlogs and congestion with reduced access to health services and less reliance on in-person visits. Yet another explanation is that COVID-19 impacted patients' health making some patients more frail and more susceptible to adverse events. This is also consistent with our heterogeneity analysis, which suggests that the negative impact of waiting was stronger among more vulnerable groups, such as older and more complex patients (with higher number of comorbidities and Elixhauser conditions), and those living in more deprived areas.

Instead, we do not find any effects of waiting times on health outcomes and resource use for the PTCA samples, either before or during the pandemic, albeit average waiting times were higher for PTCA than for CABG, both before and during the pandemic (by 37% and 20% respectively). This may reflect that patients undergoing PTCA are less severe than those who need CABG, and at a lower risk of death (see Boden et al., 2007; Vij et al., 2021), meaning that even with extended waits, the likelihood of deterioration is lower.

The policy implications of these differences are important. While PTCA is more frequently performed and contributes substantially to overall cardiac procedure volumes, our findings suggest that clinical risk—not just volume—should guide prioritisation policies. There are several policy implications that arise from these findings. The first implication is that reducing delays for access to coronary bypass should be prioritised. Our analysis suggests that increasing supply of CABG and reducing waiting times will generate positive spillover effects both in terms of improving health and reducing costs, in addition to reducing the health loss due to postponing the health benefits that arise from longer waits. One way to operationalise this policy would be by tightening or introducing a maximum waiting time target for CABG. Expanding capacity can however be costly. A second policy option is to better support patients while waiting, perhaps through better coordination between secondary and primary care, in particular for patients who are more vulnerable.

A third policy option, within a given capacity, is to enhance waiting time prioritisation on the list by reducing the wait of patients at a higher risk of an adverse cardiovascular event and increasing it for those with low risk who can afford to wait longer (Gravelle and Siciliani, 2008b).[12] This could also apply to patients with higher income deprivation. Our study shows that more deprived patients are impacted more strongly by longer waiting times and a previous study showed they tend to wait longer both for coronary bypass and angioplasty in England (Moscelli et al., 2018). Waiting time prioritisation policies would also require good communication and co-ordination between primary and secondary care to ensure that GPs are able to flag more urgent cases, and these patients receive an outpatient appointment more quickly, thereby reducing the outpatient wait, which accounts for a significant share of the patient journey.

Our results for the COVID-19 period differ from those reported in Moscelli et al. (2016) who found that there was no association between inpatient waiting time and in-hospital mortality, which instead is in line with the results in our pre-COVID period. It is important to emphasise that our study goes beyond Moscelli et al. (2016) by focusing on referral-to-treatment waiting time: outpatient waiting time accounts for a significant share of the wait and it is not correlated with inpatient waiting time. Finally, differently from Moscelli et al. (2016), our study measures 30-day and one-year mortality, which captures mortality more comprehensively by including deaths following discharge; and it implements an instrumental variable approach. Our results for the pandemic period also contrast those of Godoy et al. (2024) who find no effect of waiting times on healthcare utilisation or mortality for orthopaedic patients in Norway. We focus on a very different clinical area where the risk of adverse health effects such as a heart attack or a stroke are much more prevalent and where care is more urgent. Our findings have some similarities with a recent study that finds that longer waiting time for mental health care for veterans in the US increases mortality (Costantini, 2025). However, our study is in the context of physical health rather than mental health within a National Health Service providing coverage to the whole population.

11. Limitations

Our study has some limitations. We use a large administrative dataset which allows us to cover the whole population of patients in need of cardiovascular treatment. However, this limits the range of health outcomes to mortality, readmissions and reinterventions. Access to registry data would allow analysing a wider range of clinical outcomes. Second, we only use two years of data following COVID-19, which were the latest available data at the time of the study. Future work could explore the robustness of the findings using more recent data once the health system has had more time to recover and patients are not hesitant to attend hospitals due to the risk of contracting COVID-19. The waiting list has however kept growing and was over seven million in April 2024. Last, we were limited in the ability to investigate possible mechanisms behind our findings. For example, we did not investigate whether support from primary or community care for patients on the list differed before and after COVID-19. These could be pursued in future research.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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[12] Existing evidence suggests that there is only limited waiting times prioritisation based on need. For example, Gutacker et al. (2016) show that patients in higher pain and reduced mobility wait less by only a few days for a hip replacement.

Appendix

Table A1
Most common secondary diagnoses.

	CABG				PTCA			
	Pre-pandemic		*Pandemic*		*Pre-pandemic*		*Pandemic*	
	mean	sd	mean	sd	mean	sd	mean	sd
Essential (Primary) Hypertension	0.617	0.486	0.754	0.431	0.525	0.499	0.535	0.499
Pure hypercholesterolemia	0.509	0.500	0.577	0.494	0.389	0.488	0.403	0.490
Angina pectoris, unspecified	0.319	0.466	0.349	0.477	0.299	0.458	0.236	0.425
Personal history of psychoactive substance abuse	0.331	0.471	0.417	0.493	0.274	0.446	0.282	0.450
Personal history of drug therapy	0.256	0.437	0.381	0.486	0.252	0.434	0.261	0.439
Family history of ischemic heart disease and other diseases of the circulatory system	0.258	0.437	0.330	0.470	0.269	0.443	0.282	0.450
Type 2 diabetes mellitus without complications	0.223	0.417	0.288	0.453	0.200	0.400	0.212	0.409
Old myocardial infarction	0.198	0.398	0.276	0.447	0.151	0.358	0.157	0.364
Surgical operation with anastomosis, bypass or graft as the cause of abnormal reaction of the patient, or of later complication, without mention of misadventure at the time of the procedure	0.149	0.356	0.198	0.399				
Chronic ischemic heart disease, unspecified	0.166	0.372	0.243	0.429	0.121	0.327	0.145	0.352
Unspecified atrial fibrillation and atrial flutter	0.166	0.372	0.273	0.446	0.039	0.193	0.053	0.225
Pleural effusion, not elsewhere classified	0.150	0.357	0.314	0.464				
Obesity, unspecified	0.136	0.343	0.276	0.447	0.111	0.314	0.133	0.339
Other physical therapy	0.074	0.262	0.403	0.490				
Pulmonary collapse	0.105	0.306	0.260	0.438				
Presence of coronary angioplasty implant and graft	0.116	0.320	0.152	0.359	0.133	0.340	0.131	0.337
Cardiomegaly	0.092	0.288	0.154	0.361				
Nonrheumatic aortic (valve) stenosis	0.085	0.279	0.078	0.268	0.022	0.148	0.029	0.168
Other forms of angina pectoris	0.080	0.271	0.163	0.369	0.127	0.333	0.200	0.400
Anemia, Unspecified	0.070	0.256	0.167	0.373				
Mental and behavioural disorders due to use of tobacco harmful use	0.066	0.248	0.077	0.267	0.083	0.276	0.084	0.277
Personal history of antineoplastic chemotherapy	0.062	0.241	0.084	0.278	0.073	0.261	0.090	0.287
Personal history of diseases of the circulatory system	0.064	0.244	0.077	0.267	0.051	0.220	0.060	0.238
Other ill-defined heart diseases	0.055	0.227	0.087	0.282				
Hypotension, unspecified	0.054	0.227	0.112	0.316				
Left ventricular failure, unspecified	0.061	0.239	0.128	0.334	0.027	0.161	0.032	0.177
Atrial fibrillation and flutter	0.064	0.244	0.000	0.000				
Peripheral vascular disease, unspecified	0.052	0.222	0.063	0.243	0.031	0.172	0.032	0.176
Other and unspecified asthma	0.055	0.227	0.075	0.263	0.054	0.226	0.062	0.240
Acute kidney failure, unspecified	0.055	0.228	0.093	0.291				
Presence of aortocoronary bypass graft					0.071	0.256	0.061	0.240
Atherosclerotic heart disease of native coronary artery					0.054	0.227	0.066	0.248
Hyperlipidemia, Unspecified					0.056	0.230	0.046	0.209
Chronic obstructive pulmonary disease, unspecified					0.051	0.220	0.055	0.228
Allergy status to penicillin					0.033	0.177	0.039	0.193
Hypothyroidism, unspecified					0.031	0.173	0.036	0.187
Personal history of diseases of the nervous system and sense organs					0.025	0.157	0.033	0.178
Osteoarthritis, unspecified site					0.021	0.142	0.031	0.172
Presence of cardiac pacemaker					0.022	0.148	0.024	0.152
Major depressive disorder, single episode, unspecified					0.023	0.151	0.036	0.186

Table A2
Congestion and patients' observable characteristics.

	CABG				PTCA			
	Pre-pandemic		*Pandemic*		*Pre-pandemic*		*Pandemic*	
	Congestion	total_wait	Congestion	total_wait	Congestion	total_wait	Congestion	total_wait
female	−0.116	5.604***	2.834	5.159	1.269	5.837***	3.845**	7.509***
	(0.526)	(0.992)	(1.920)	(3.209)	(0.764)	(1.353)	(1.785)	(2.703)
Age: 35–44								
Age: 45–54	2.709	−0.707	−4.204	6.276	0.631	0.713	−0.647	10.163
	(1.638)	(4.119)	(4.503)	(11.738)	(2.121)	(3.968)	(6.317)	(8.784)
Age: 55–64	3.214**	0.963	−1.858	10.951	0.351	3.769	−0.344	13.023
	(1.453)	(3.951)	(4.845)	(11.650)	(2.134)	(3.606)	(5.629)	(8.130)
Age: 65–74	3.129*	0.013	−1.572	11.739	0.141	4.989	1.195	16.735*
	(1.744)	(3.814)	(4.056)	(11.369)	(2.129)	(3.577)	(5.998)	(8.412)
Age: 75–84	3.424**	1.826	−3.053	10.695	1.194	7.661**	5.460	24.310***

(*continued on next page*)

Table A2 (*continued*)

	CABG				PTCA			
	Pre-pandemic		*Pandemic*		*Pre-pandemic*		*Pandemic*	
	Congestion	total_wait	Congestion	total_wait	Congestion	total_wait	Congestion	total_wait
	(1.579)	(3.858)	(4.347)	(10.130)	(2.090)	(3.745)	(6.237)	(8.338)
Age: 85–94	5.638*	−2.575			0.362	6.561	3.755	23.519**
	(3.136)	(7.111)			(2.893)	(6.390)	(7.432)	(11.294)
Number of diagnoses on admission: 1–3								
Number of diagnoses on admission: 4–6	0.801	2.114	6.189	−12.290	1.904*	6.471***	−0.175	−3.395
	(1.335)	(2.039)	(5.999)	(20.537)	(1.079)	(2.172)	(2.553)	(4.209)
Number of diagnoses on admission: 7–9	3.398**	6.139*	0.421	−14.573	3.178*	11.403***	3.770	2.832
	(1.556)	(3.543)	(6.039)	(20.972)	(1.883)	(3.493)	(3.672)	(5.890)
Number of diagnoses on admission: 11–12	4.220**	8.575**	1.227	−11.722	2.762	13.856***	0.139	4.009
	(1.735)	(3.945)	(6.461)	(23.407)	(2.606)	(4.232)	(4.252)	(5.932)
Number of diagnoses on admission: 13–15	4.244*	12.610***	2.254	−6.229	1.914	19.534***	2.219	−1.408
	(2.235)	(4.118)	(7.414)	(23.468)	(3.350)	(5.854)	(5.176)	(7.498)
Number of Elixhauser conditions: 0								
1	1.898	−0.955	−10.328	−14.207	2.223**	11.217***	3.493	9.053*
	(1.170)	(2.404)	(7.202)	(12.534)	(1.076)	(2.236)	(3.375)	(4.627)
2	1.153	1.577	−8.846	−14.107	2.791***	19.973***	11.309***	25.072***
	(1.111)	(2.160)	(7.215)	(11.254)	(1.013)	(2.138)	(3.273)	(5.287)
3	2.013*	7.213***	−5.973	−12.691	3.038***	26.370***	8.731**	22.590***
	(1.112)	(2.256)	(6.793)	(10.387)	(1.098)	(2.369)	(3.793)	(5.925)
4	2.411	9.684***	−6.402	−8.370	5.122***	33.694***	17.456***	39.140***
	(1.484)	(2.432)	(6.376)	(12.220)	(1.242)	(2.922)	(4.033)	(6.626)
5	1.974	9.518***	−3.355	−5.437	5.069***	36.781***	13.210***	37.439***
	(1.402)	(2.581)	(6.867)	(12.689)	(1.338)	(3.102)	(4.641)	(6.588)
6	2.978*	10.638***	−7.489	−4.367	6.323***	35.708***	20.524***	40.081***
	(1.592)	(2.049)	(6.128)	(11.763)	(1.601)	(3.326)	(5.226)	(7.678)
7	2.307	12.817***	−7.365	−4.086	5.827***	41.749***	18.982***	55.276***
	(1.709)	(2.878)	(6.877)	(10.611)	(1.372)	(2.653)	(4.810)	(8.731)
8	2.216	13.359***	−4.068	6.775	6.802***	44.213***	24.665***	64.206***
	(1.540)	(3.471)	(6.026)	(12.682)	(1.708)	(3.438)	(7.637)	(13.485)
9	2.279	19.387***	−6.592	4.499	9.786***	49.073***	32.010***	75.205***
	(1.732)	(3.013)	(6.762)	(14.022)	(2.682)	(4.434)	(7.281)	(11.181)
10	2.605	17.872***	0.538	8.336	8.150***	50.122***	26.691***	60.617***
	(2.116)	(3.656)	(7.624)	(14.186)	(2.773)	(4.628)	(8.651)	(12.843)
11	3.187	15.879***	2.249	19.816	7.743**	46.855***	29.500**	84.735***
	(2.426)	(3.958)	(9.458)	(20.359)	(3.043)	(6.489)	(12.802)	(19.772)
12	0.038	15.294***	−3.790	−3.222	14.613***	53.425***	4.750	35.077**
	(2.677)	(5.439)	(13.304)	(16.624)	(4.694)	(7.928)	(9.454)	(17.286)
13	−0.131	6.835	−11.219	53.056*	7.207	73.718***	32.277	148.256***
	(3.146)	(5.402)	(9.287)	(28.033)	(5.791)	(10.772)	(19.738)	(38.230)
14+	7.548*	16.192*	16.336	47.259	12.257	64.368***	56.451***	112.800***
	(4.174)	(8.678)	(24.771)	(28.466)	(7.719)	(11.692)	(18.045)	(25.072)
Number of previous emergency admissions	−0.233	−7.069***	−2.731**	−16.932***	−0.396	−6.116***	−5.724***	−15.469***
	(0.316)	(0.986)	(1.161)	(2.402)	(0.600)	(1.123)	(1.187)	(2.472)
Essential (Primary) Hypertension	−0.499	0.060	2.054	7.104**	−0.432	−0.782	−1.537	1.775
	(0.596)	(1.088)	(1.270)	(2.634)	(0.824)	(1.436)	(1.737)	(2.475)
Pure hypercholesterolemia	−0.213	−1.384	−2.568*	−2.302	−0.078	−5.007***	−0.472	−2.897
	(0.456)	(1.324)	(1.396)	(2.747)	(0.969)	(1.522)	(2.156)	(3.147)
Angina pectoris, unspecified	−0.635	−5.440***	−2.928*	−8.117**	−0.694	−4.184**	−3.469	−3.941
	(0.731)	(1.218)	(1.498)	(3.126)	(1.091)	(1.729)	(2.130)	(2.733)
Personal history of psychoactive substance abuse	−0.270	−0.536	−0.832	−6.064*	−0.142	−3.752**	2.796	2.141
	(0.644)	(0.972)	(1.352)	(3.012)	(0.856)	(1.688)	(2.005)	(2.478)
Personal history of drug therapy	−1.934	−4.877***	−0.268	−2.946	0.783	−0.235	1.218	4.495
	(1.354)	(1.739)	(2.038)	(3.759)	(1.192)	(1.615)	(2.453)	(3.102)
Family history of ischemic heart disease and other diseases of the circulatory system	−0.626	−4.665***	−0.418	−3.296	−1.645*	−6.746***	−1.799	−4.448*
	(0.508)	(1.269)	(1.244)	(2.848)	(0.835)	(1.357)	(2.145)	(2.601)
Type 2 diabetes mellitus without complications	−0.306	0.251	5.025***	5.285	−0.618	−6.001***	0.038	−1.167
	(0.425)	(1.075)	(1.571)	(3.208)	(0.858)	(1.589)	(2.073)	(3.027)
Old myocardial infarction	−0.914	1.418	−0.240	5.481	2.132**	7.376***	6.011**	12.952***
	(0.546)	(1.321)	(1.608)	(3.624)	(0.870)	(1.561)	(2.617)	(4.567)
Surgical operation with anastomosis, bypass or graft as the cause of abnormal reaction of the patient, or of later complication, without	−1.709**	−1.574	3.411*	0.622				
	(0.747)	(1.249)	(1.758)	(3.734)				

(*continued on next page*)

Table A2 (*continued*)

	CABG				PTCA			
	Pre-pandemic		*Pandemic*		*Pre-pandemic*		*Pandemic*	
	Congestion	total_wait	Congestion	total_wait	Congestion	total_wait	Congestion	total_wait
mention of misadventure at the time of the procedure								
Chronic ischemic heart disease, unspecified	0.805	1.649	−2.571	0.436	1.832	5.970**	5.815**	3.300
	(1.340)	(1.787)	(2.422)	(2.673)	(1.434)	(2.547)	(2.854)	(4.524)
Unspecified atrial fibrillation and atrial flutter	−1.940**	−2.790	−0.033	2.576	−1.488	2.447	0.230	−2.993
	(0.909)	(1.687)	(1.633)	(2.437)	(1.652)	(4.527)	(4.246)	(6.360)
Pleural effusion, not elsewhere classified	−1.509	0.049	−0.873	−1.127				
	(0.894)	(1.804)	(1.279)	(1.898)				
Obesity, unspecified	−1.027	−2.882**	−1.117	0.499	−0.131	−0.330	−1.078	−6.678**
	(0.810)	(1.107)	(1.888)	(2.998)	(1.142)	(2.011)	(2.420)	(3.239)
Other physical therapy	−4.505	−4.285	1.131	8.048				
	(3.302)	(3.473)	(1.961)	(4.817)				
Pulmonary collapse	−2.522*	−1.824	−1.718	−3.229				
	(1.326)	(2.488)	(1.829)	(3.117)				
Presence of coronary angioplasty implant and graft	0.311	1.061	−0.914	−2.754	−0.286	4.005*	0.376	1.575
	(0.510)	(1.733)	(2.017)	(2.169)	(1.088)	(2.052)	(2.941)	(6.270)
Cardiomegaly	−2.439**	2.025	1.181	2.095				
	(0.977)	(2.204)	(1.776)	(3.429)				
Nonrheumatic aortic (valve) stenosis	0.447	6.663***	0.469	0.439	4.112	11.465**	6.503	1.695
	(0.673)	(2.255)	(2.065)	(2.872)	(2.660)	(5.286)	(5.419)	(7.947)
Other forms of angina pectoris	−4.083***	−8.802***	−0.900	−3.358	1.624	−3.770	−5.346**	−9.276**
	(0.894)	(2.005)	(1.880)	(4.164)	(2.055)	(2.425)	(2.497)	(3.647)
Anemia, Unspecified	−3.940***	−2.768	0.535	4.717				
	(1.221)	(1.928)	(3.430)	(6.473)				
Mental and behavioural disorders due to use of tobacco	0.078	1.580	4.514*	2.699	−2.673**	−4.753**	−0.078	4.123
	(0.873)	(1.633)	(2.216)	(3.702)	(1.089)	(2.097)	(3.136)	(5.204)
Personal history of antineoplastic chemotherapy	−1.072	6.339***	3.041	11.782**	2.841*	11.816***	8.194**	13.228**
	(1.328)	(2.248)	(2.399)	(4.307)	(1.635)	(2.747)	(3.612)	(5.204)
Personal history of diseases of the circulatory system	0.053	5.170***	2.791	7.042	0.034	0.528	−0.117	−7.336
	(0.754)	(1.541)	(2.442)	(4.939)	(1.246)	(2.352)	(3.878)	(4.974)
Other ill-defined heart diseases	0.179	3.313	−1.779	−4.326				
	(1.441)	(3.293)	(1.602)	(3.939)				
Hypotension, unspecified	−3.024*	−2.026	−4.383**	−1.569				
	(1.762)	(2.054)	(1.615)	(4.814)				
Left ventricular failure, unspecified	0.108	1.418	4.567**	2.798	4.020*	10.085***	2.320	13.687
	(1.462)	(2.626)	(1.916)	(4.438)	(2.096)	(3.647)	(6.364)	(10.349)
Atrial fibrillation and flutter	7.179**	3.031	0.000	0.000				
	(2.794)	(2.536)	(.)	(.)				
Peripheral vascular disease, unspecified	0.200	1.768	−0.934	0.044	−0.606	3.017	−5.940	−8.882
	(0.908)	(2.503)	(1.810)	(3.859)	(1.864)	(3.138)	(3.945)	(6.711)
Other and unspecified asthma	−1.199	−1.063	3.275	−0.580	−2.565**	−1.912	4.156	7.547
	(0.953)	(2.140)	(2.506)	(3.502)	(1.097)	(2.591)	(3.050)	(4.614)
Acute kidney failure, unspecified	−0.025	−1.540	0.977	−2.549				
	(1.111)	(2.068)	(1.721)	(3.657)				
Presence of aortocoronary bypass graft					2.706	19.630***	12.300***	32.893***
					(1.655)	(2.760)	(3.272)	(5.247)
Atherosclerotic heart disease of native coronary artery					−2.217	−1.806	−2.615	−6.184
					(1.872)	(2.382)	(2.879)	(4.676)
Hyperlipidemia, Unspecified					−1.589	−7.634***	−6.500	−11.661**
					(1.408)	(2.550)	(3.940)	(4.990)
Chronic obstructive pulmonary disease, unspecified					−1.455	1.774	−0.302	−7.643
					(1.301)	(3.332)	(4.161)	(5.532)
Allergy status to penicillin					0.793	−0.240	−2.703	2.311
					(1.808)	(3.823)	(4.691)	(5.857)
Hypothyroidism, unspecified					2.411	−2.239	2.439	−10.094
					(1.766)	(3.464)	(4.497)	(7.208)
Personal history of diseases of the nervous system and sense organs					−0.719	4.681	3.883	−1.043
					(1.705)	(3.583)	(4.826)	(6.519)
Osteoarthritis, unspecified site					2.116	3.719	−5.102	−1.969
					(1.810)	(4.460)	(3.875)	(6.102)
Major depressive disorder, single episode, unspecified					−1.088	−4.465	−4.934	−5.820
					(1.946)	(4.254)	(3.366)	(6.096)
Presence of cardiac pacemaker					3.878	23.815***	5.295	8.525
					(2.369)	(4.656)	(5.610)	(8.406)
Depriv. quintile (income)=1 (least deprived)								

(*continued on next page*)

Table A2 (*continued*)

	CABG				PTCA			
	Pre-pandemic		*Pandemic*		*Pre-pandemic*		*Pandemic*	
	Congestion	total_wait	Congestion	total_wait	Congestion	total_wait	Congestion	total_wait
Depriv. quintile (income)=2	0.478	1.307	−2.108	1.074	1.455*	2.380	1.294	4.934
	(0.503)	(1.370)	(2.095)	(4.117)	(0.814)	(1.817)	(2.104)	(3.377)
Depriv. quintile (income)=3	−0.235	2.745*	−0.694	4.812	2.217***	4.306**	1.161	7.792**
	(0.502)	(1.547)	(1.503)	(3.718)	(0.740)	(1.756)	(2.181)	(3.166)
Depriv. quintile (income)=4	−0.394	2.648*	−0.528	6.087	2.869***	8.508***	2.988	12.399***
	(0.535)	(1.509)	(1.785)	(4.057)	(0.954)	(1.494)	(2.446)	(3.140)
Depriv. quintile (income)=5 (most	−0.218	4.674**	−1.637	7.781	3.795***	12.079***	8.391***	20.704***
deprived)	(0.556)	(2.128)	(2.022)	(4.551)	(0.827)	(2.252)	(2.802)	(4.580)
Ethnicity: white								
Ethnicity: black	3.805	7.821	1.226	4.470	−2.221	−2.749	−2.716	4.564
	(2.917)	(6.598)	(5.424)	(13.975)	(2.295)	(6.926)	(4.928)	(12.482)
Ethnicity: asian	1.629**	3.744	0.082	2.470	2.155*	9.108***	−0.359	−1.945
	(0.632)	(2.543)	(3.662)	(5.330)	(1.249)	(2.868)	(3.839)	(6.004)
Ethnicity: mixed	5.415**	5.471	15.569	13.811	5.222	2.418	−6.202	1.760
	(2.599)	(5.126)	(9.585)	(21.419)	(4.612)	(7.422)	(7.819)	(18.525)
Ethnicity: other	−2.795**	−9.018	8.080	5.858	−2.256	−1.602	4.987	4.563
	(1.076)	(5.520)	(6.036)	(10.859)	(2.519)	(4.405)	(7.216)	(10.090)
Ethnicity: missing	2.895*	9.621**	5.347	9.149**	−1.607	−6.793***	1.065	−2.023
	(1.650)	(3.677)	(4.105)	(4.253)	(1.160)	(2.304)	(2.321)	(3.587)
Urgent first outpatient appointment	0.792*	−0.223	−1.309	0.833	0.110	0.670	1.502	5.761*
	(0.390)	(1.065)	(1.345)	(2.701)	(0.797)	(1.436)	(2.244)	(3.400)
Referral source for the first OP appointment: other								
Referral source for the first OP	−0.019	0.642	−0.819	4.982	2.609***	9.900***	2.809	7.077**
appointment: GP	(0.362)	(1.415)	(1.213)	(2.926)	(0.758)	(1.695)	(1.799)	(2.760)
Referral source for the first OP	0.892*	0.784	−3.567	−1.136	3.016***	12.285***	1.512	6.324
appointment: another consultant	(0.519)	(1.958)	(2.225)	(4.622)	(1.124)	(2.525)	(2.485)	(4.082)
Referral source for the first OP	1.729*	5.083*	−2.244	10.298*	4.824***	12.959***	1.218	5.321
appointment: same OP consultant	(0.868)	(2.906)	(2.352)	(5.964)	(1.757)	(2.884)	(4.148)	(5.818)
Constant	143.298***	122.175***	216.320***	120.899***	199.013***	110.097***	129.340***	−60.166***
	(5.129)	(8.914)	(13.328)	(31.068)	(7.141)	(13.401)	(16.076)	(17.618)
Observations	29,992	29,992	7001	7001	55,918	55,918	16,808	16,808

Notes. Each regression includes Trust, financial year, month of admission and day of the week of admission fixed effects, and patient-level control variables: age group, sex, number of diagnoses at admission group, number of Elixhauser conditions, previous emergency admissions within a year from the index admission, income deprivation quintile, ethnicity, an indicator of an urgent first referral, a referral source of the first outpatient appointment, and indicator variables for the 30 most common secondary diagnoses (see Table A1). Clustered s.e. in parentheses. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A3

7-days average congestion and outcomes for emergency patients.

	CABG			PTCA		
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Pre-pandemic	30-day mortality	1-year mortality	28-day readmission	30-day mortality	1-year mortality	28-day readmission
7-days average congestion	0.041	0.048	0.093	−0.005	−0.009*	0.011
	(0.032)	(0.036)	(0.071)	(0.004)	(0.005)	(0.007)
Observations	6794	6794	7282	138,722	138,722	133,979
Panel B: Pandemic	30-day mortality	1-year mortality	28-day readmission	30-day mortality	1-year mortality	28-day readmission
7-days average congestion	0.007	0.005	0.032	−0.002	−0.001	0.005
	(0.027)	(0.036)	(0.099)	(0.004)	(0.005)	(0.007)
Observations	2699	2699	2621	61,320	61,320	59,249

Notes. 7-days average congestion for each emergency patient is calculated as the average congestion value for elective patients admitted for the same procedure in the same hospital up to 7 days prior to the given emergency patient. Each regression includes Trust, financial year, month of admission and day of the week of admission fixed effects, and patient-level control variables: age group, sex, number of diagnoses at admission group, number of Elixhauser conditions, previous emergency admissions within a year from the index admission, income deprivation quintile, ethnicity, and indicator variables for the 30 most common secondary diagnoses (note they may differ from those presented in Table A1 as the sample comprises emergency patients). Clustered s.e. in parentheses. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A4
OLS, First Stage, IV-2SLS estimates for the CABG sample (maximum 30 days matching lag).

Panel A: Pre-pandemic	(1) 28-day readmission	(2)	(3)	(4) 30-day mortality	(5)	(6)	(7) 1-year mortality	(8)	(9) Length of Stay	(10)
	OLS	First Stage	IV-2SLS	OLS	First Stage	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS
Total waiting time (yrs)	-0.025***		-0.009	0.003		0.006	0.002	-0.019	0.610***	0.865
	(0.007)		(0.034)	(0.004)		(0.010)	(0.005)	(0.013)	(0.183)	(0.589)
Congestion (yrs)		0.708***			0.708***					
		(0.035)			(0.035)					
F-stat		401			403					
Observations	27,696	27,696	27,696	27,965	27,965	27,965	27,965	27,965	27,965	27,965
Panel B: Pandemic	(1) 28-day readmission	(2)	(3)	(4) 30-day mortality	(5)	(6)	(7) 1-year mortality	(8)	(9) Length of Stay	(10)
	OLS	First Stage	IV-2SLS	OLS	First Stage	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS
Total waiting time (yrs)	-0.038***		0.004	0.004		0.034**	0.005	0.054***	0.108	1.324**
	(0.009)		(0.026)	(0.007)		(0.014)	(0.008)	(0.020)	(0.326)	(0.654)
Congestion (yrs)		0.775***			0.775***					
		(0.068)			(0.069)					
F-stat		129			127					
Observations	6427	6427	6427	6482	6482	6482	6482	6482	6482	6482

Notes. Each regression includes Trust, financial year, month of admission and day of the week of admission fixed effects, as well as patient-level control variables: age group, sex, number of diagnoses at admission group, number of Elixhauser conditions, previous emergency admissions within a year from the index admission, income deprivation quintile, ethnicity, an indicator of an urgent first referral, a referral source of the first outpatient appointment, and indicator variables for the 30 most common secondary diagnoses (see Table A1). Clustered s.e. in parentheses. Significance levels: * p < 0.1, ** p < 0.05, *** p < 0.01.

Table A5
OLS, First Stage, IV-2SLS estimates for the PTCA sample (maximum 30 days matching lag).

Panel A: Pre-pandemic	(1) 28-day readmission	(2)	(3)	(4) 30-day mortality	(5)	(6)	(7) 1-year mortality	(8)	(9) Length of Stay	(10)	(11) 6-month reintervention	(12)
	OLS	First Stage	IV-2SLS	OLS	First Stage	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS
Total waiting time (yrs)	-0.005*		-0.013*	-0.000		-0.002	-0.000	-0.001	-0.016	0.018	0.001	0.017*
	(0.003)		(0.007)	(0.001)		(0.001)	(0.002)	(0.005)	(0.010)	(0.025)	(0.004)	(0.009)
Congestion (yrs)		0.711***			0.711***							
		(0.030)			(0.030)							
F-stat		577			578							
Observations	45,304	45,304	45,304	45,339	45,339	45,339	45,339	45,339	45,339	45,339	45,304	45,304
Panel B: Pandemic	(1) 28-day readmission	(2)	(3)	(4) 30-day mortality	(5)	(6)	(7) 1-year mortality	(8)	(9) Length of Stay	(10)	(11) 6-month reintervention	(12)
	OLS	First Stage	IV-2SLS	OLS	First Stage	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS
Total waiting time (yrs)	0.002		-0.001	0.000		0.001	-0.004	-0.006	-0.020	-0.010	-0.003	0.001
	(0.005)		(0.008)	(0.001)		(0.003)	(0.003)	(0.005)	(0.014)	(0.019)	(0.004)	(0.007)
Congestion (yrs)		0.961***			0.961***							
		(0.031)			(0.031)							
F-stat		967			964							
Observations	14,057	14,057	14,060	14,076	14,076	14,076	14,076	14,076	14,076	14,076	14,057	14,057

Notes. Each regression includes Trust, financial year, month of admission and day of the week of admission fixed effects, as well as patient-level control variables: age group, sex, number of diagnoses at admission group, number of Elixhauser conditions, previous emergency admissions within a year from the index admission, income deprivation quintile, ethnicity, an indicator of an urgent first referral, a referral source of the first outpatient appointment, and indicator variables for the 30 most common secondary diagnoses (see Table A1). Clustered s.e. in parentheses. Significance levels: * p < 0.1, ** p < 0.05, *** p < 0.01.

Table A6
OLS, First Stage, IV-2SLS estimates for the CABG sample (4 or more neighbours).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Panel A: Pre-pandemic	28-day readmission			30-day mortality			1-year mortality		Length of Stay	
	OLS	First Stage	IV-2SLS	OLS	First Stage	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS
Total waiting time (yrs)	-0.024***		-0.001	0.004		0.003	0.003	-0.023	0.544***	1.185*
	(0.007)		(0.034)	(0.004)		(0.010)	(0.005)	(0.014)	(0.188)	(0.616)
Congestion (yrs)		0.694***			0.694***					
		(0.043)			(0.043)					
F-stat		256			258					
Observations	29,402	29,402	29,402	29,684	29,684	29,684	29,684	29,684	29,684	29,684
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Panel B: Pandemic	28-day readmission			30-day mortality			1-year mortality		Length of Stay	
	OLS	First Stage	IV-2SLS	OLS	First Stage	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS
Total waiting time (yrs)	-0.035***		-0.006	0.000		0.037***	0.000	0.058**	0.142	1.789**
	(0.009)		(0.032)	(0.005)		(0.014)	(0.006)	(0.023)	(0.350)	(0.788)
Congestion (yrs)		0.862***			0.859***					
		(0.087)			(0.088)					
F-stat		98			95					
Observations	6431	6431	6431	6485	6485	6485	6485	6485	6485	6485

Notes. Each regression includes Trust, financial year, month of admission and day of the week of admission fixed effects, as well as patient-level control variables: age group, sex, number of diagnoses at admission group, number of Elixhauser conditions, previous emergency admissions within a year from the index admission, income deprivation quintile, ethnicity, an indicator of an urgent first referral, a referral source of the first outpatient appointment, and indicator variables for the 30 most common secondary diagnoses (see Table A1). Clustered s.e. in parentheses. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A7
OLS, First Stage, IV-2SLS estimates for the PTCA sample (4 or more neighbours).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Panel A: Pre-pandemic	28-day readmission			30-day mortality			1-year mortality		Length of Stay		6-month reintervention	
	OLS	First Stage	IV-2SLS	OLS	First Stage	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS
Total waiting time (yrs)	−0.006**		−0.021*	0.000		0.001	0.000	0.003	−0.026***	−0.034	0.001	0.018*
	(0.003)		(0.012)	(0.001)		(0.003)	(0.002)	(0.007)	(0.010)	(0.043)	(0.004)	(0.011)
Congestion (yrs)		0.648***			0.648***							
		(0.040)			(0.040)							
F-stat		264			263							
Observations	52,680	52,680	52,680	52,723	52,723	52,723	52,723	52,723	52,723	52,723	52,680	52,680
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Panel B: Pandemic	28-day readmission			30-day mortality			1-year mortality		Length of Stay		6-month reintervention	
	OLS	First Stage	IV-2SLS	OLS	First Stage	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS
Total waiting time (yrs)	0.004		0.004	−0.000		−0.002	−0.007**	−0.014**	−0.021	0.011	−0.001	−0.001
	(0.005)		(0.012)	(0.002)		(0.002)	(0.003)	(0.007)	(0.016)	(0.020)	(0.007)	(0.015)
Congestion (yrs)		1.167***			1.167***							
		(0.040)			(0.040)							
F-stat		870			858							
Observations	14,187	14,187	14,187	14,206	14,206	14,206	14,206	14,206	14,206	14,206	14,187	14,187

Notes. Each regression includes Trust, financial year, month of admission and day of the week of admission fixed effects, as well as patient-level control variables: age group, sex, number of diagnoses at admission group, number of Elixhauser conditions, previous emergency admissions within a year from the index admission, income deprivation quintile, ethnicity, an indicator of an urgent first referral, a referral source of the first outpatient appointment, and indicator variables for the 30 most common secondary diagnoses (see Table A1). Clustered s.e. in parentheses. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A8
OLS, First Stage, IV-2SLS estimates for the CABG sample (60-days window).

Panel A: Pre-pandemic	(1)	(2) 28-day readmission	(3)	(4)	(5) 30-day mortality	(6)	(7) 1-year mortality	(8)	(9) Length of Stay	(10)
	OLS	First Stage	IV-2SLS	OLS	First Stage	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS
Total waiting time (yrs)	−0.024***		−0.017	0.004		0.003	0.003	−0.015	0.523***	0.758
	(0.007)		(0.027)	(0.004)		(0.007)	(0.005)	(0.010)	(0.176)	(0.462)
Congestion (yrs)		0.848***			0.849***					
		(0.035)			(0.034)					
F-stat		604			613					
Observations	29,703	29,703	29,703	29,992	29,992	29,992	29,992	29,992	29,992	29,992
Panel B: Pandemic	(1)	(2) 28-day readmission	(3)	(4)	(5) 30-day mortality	(6)	(7) 1-year mortality	(8)	(9) Length of Stay	(10)
	OLS	First Stage	IV-2SLS	OLS	First Stage	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS
Total waiting time (yrs)	−0.036***		−0.006	0.004		0.027**	0.003	0.033**	0.071	1.031*
	(0.011)		(0.027)	(0.005)		(0.011)	(0.006)	(0.016)	(0.344)	(0.539)
Congestion (yrs)		1.031			1.029***					
		(0.076)			(0.076)					
F-stat		183			185					
Observations	6940	6940	6940	7001	7001	7001	7001	7001	7001	7001

Notes. Each regression includes Trust, financial year, month of admission and day of the week of admission fixed effects, as well as patient-level control variables: age group, sex, number of diagnoses at admission group, number of Elixhauser conditions, previous emergency admissions within a year from the index admission, income deprivation quintile, ethnicity, an indicator of an urgent first referral, a referral source of the first outpatient appointment, and indicator variables for the 30 most common secondary diagnoses (see Table A1). Clustered s.e. in parentheses. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A9
OLS, First Stage, IV-2SLS estimates for the PTCA sample (60-days window).

Panel A: Pre-pandemic	(1)	(2) 28-day readmission	(3)	(4)	(5) 30-day mortality	(6)	(7) 1-year mortality	(8)	(9) Length of Stay	(10)	(11) 6-month reintervention	(12)
	OLS	First Stage	IV-2SLS	OLS	First Stage	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS
Total waiting time (yrs))	−0.006**		−0.011*	−0.000		−0.001	−0.000	0.001	−0.021**	−0.009	0.001	0.013*
	(0.003)		(0.007)	(0.001)		(0.001)	(0.002)	(0.004)	(0.009)	(0.019)	(0.003)	(0.007)
Congestion (yrs)		0.908***			0.908***							
		(0.021)			(0.021)							
F-stat		1786			1784							
Observations	55,874	55,874	55,874	55,918	55,918	55,918	55,918	55,918	55,918	55,918	55,874	55,874
Panel B: Pandemic	(1)	(2) 28-day readmission	(3)	(4)	(5) 30-day mortality	(6)	(7) 1-year mortality	(8)	(9) Length of Stay	(10)	(11) 6-month reintervention	(12)
	OLS	First Stage	IV-2SLS	OLS	First Stage	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS
Total waiting time (yrs)	0.002		0.001	0.001		0.001	−0.004	−0.008**	−0.021*	−0.014	−0.002	−0.000
	(0.005)		(0.007)	(0.001)		(0.002)	(0.003)	(0.004)	(0.012)	(0.014)	(0.005)	(0.007)
Congestion (yrs)		1.1427***			1.1430***							
		(0.031)			(0.032)							
F-stat		1280			1273							
Observations	16,786	16,786	16,786	16,808	16,808	16,808	16,808	16,808	16,808	16,808	16,786	16,786

Notes. Each regression includes Trust, financial year, month of admission and day of the week of admission fixed effects, as well as patient-level control variables: age group, sex, number of diagnoses at admission group, number of Elixhauser conditions, previous emergency admissions within a year from the index admission, income deprivation quintile, ethnicity, an indicator of an urgent first referral, a referral source of the first outpatient appointment, and indicator variables for the 30 most common secondary diagnoses (see Table A1). Clustered s.e. in parentheses. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A10
CCG-based congestion; OLS, First Stage, IV-2SLS estimates for the CABG sample.

Panel A: Pre-pandemic	(1)	(2) 28-day readmission	(3)	(4)	(5) 30-day mortality	(6)	(7)	(8) 1-year mortality	(9)	(10) Length of Stay
	OLS	First Stage	IV-2SLS	OLS	First Stage	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS
Total waiting time (yrs)	−0.022***		0.018	0.005		−0.002	0.005	−0.051**	0.552***	0.578
	(0.006)		(0.042)	(0.004)		(0.012)	(0.005)	(0.020)	(0.182)	(0.772)
Congestion (yrs)		0.338***			0.338***					
		(0.036)			(0.035)					
F-stat		89			91					
Observations	29,802	28,652	28,652	30,095	28,929	28,929	30,095	28,929	30,095	28,929
Panel B: Pandemic	(1)	(2) 28-day readmission	(3)	(4)	(5) 30-day mortality	(6)	(7)	(8) 1-year mortality	(9)	(10) Length of Stay
	OLS	First Stage	IV-2SLS	OLS	First Stage	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS
Total waiting time (yrs)	−0.029***		0.001	0.003		0.065**	0.003	0.107***	0.226	1.558
	(0.009)		(0.045)	(0.004)		(0.033)	(0.006)	(0.033)	(0.304)	(0.981)
Congestion (yrs)		0.385***			0.379***					
		(0.044)			(0.045)					
F-stat		77			71					
Observations	7033	6132	6132	7095	6181	6181	7095	6181	7095	6181

Notes. Each regression includes Trust, financial year, month of admission and day of the week of admission fixed effects, as well as patient-level control variables: age group, sex, number of diagnoses at admission group, number of Elixhauser conditions, previous emergency admissions within a year from the index admission, income deprivation quintile, ethnicity, an indicator of an urgent first referral, a referral source of the first outpatient appointment, and indicator variables for the 30 most common secondary diagnoses (see Table A1). Clustered s.e. in parentheses. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A11
CCG-based congestion; OLS, First Stage, IV-2SLS estimates for the PTCA sample.

Panel A: Pre-pandemic	(1)	(2) 28-day readmission	(3)	(4)	(5) 30-day mortality	(6)	(7)	(8) 1-year mortality	(9)	(10) Length of Stay	(11)	(12) 6-month reintervention
	OLS	First Stage	IV-2SLS	OLS	First Stage	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS
Total waiting time (yrs)	−0.006**		−0.019**	−0.000		−0.004***	0.001	−0.004	−0.017**	−0.003	−0.000	−0.002
	(0.003)		(0.008)	(0.001)		(0.001)	(0.002)	(0.007)	(0.008)	(0.025)	(0.003)	(0.009)
Congestion (yrs)		0.639***			0.639***							
		(0.034)			(0.035)							
F-stat		343			343							
Observations	56,473	55,403	55,403	56,517	55,447	55,447	56,517	55,447	56,517	55,447	56,473	55,403
Panel B: Pandemic	(1)	(2) 28-day readmission	(3)	(4)	(5) 30-day mortality	(6)	(7)	(8) 1-year mortality	(9)	(10) Length of Stay	(11)	(12) 6-month reintervention
	OLS	First Stage	IV-2SLS	OLS	First Stage	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS	OLS	IV-2SLS
Total waiting time (yrs)	0.003		0.004	0.001		0.000	−0.002	−0.008*	−0.027***	−0.017	−0.003	−0.008
	(0.004)		(0.007)	(0.001)		(0.002)	(0.003)	(0.005)	(0.010)	(0.018)	(0.004)	(0.009)
Congestion (yrs)		0.877***			0.877***							
		(0.034)			(0.034)							
F-stat		676			675							
Observations	17,389	16,355	16,355	17,412	16,377	16,377	17,412	16,377	17,412	16,377	17,389	16,355

Notes. Each regression includes Trust, financial year, month of admission and day of the week of admission fixed effects, as well as patient-level control variables: age group, sex, number of diagnoses at admission group, number of Elixhauser conditions, previous emergency admissions within a year from the index admission, income deprivation quintile, ethnicity, an indicator of an urgent first referral, a referral source of the first outpatient appointment, and indicator variables for the 30 most common secondary diagnoses (see Table A1). Clustered s.e. in parentheses. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

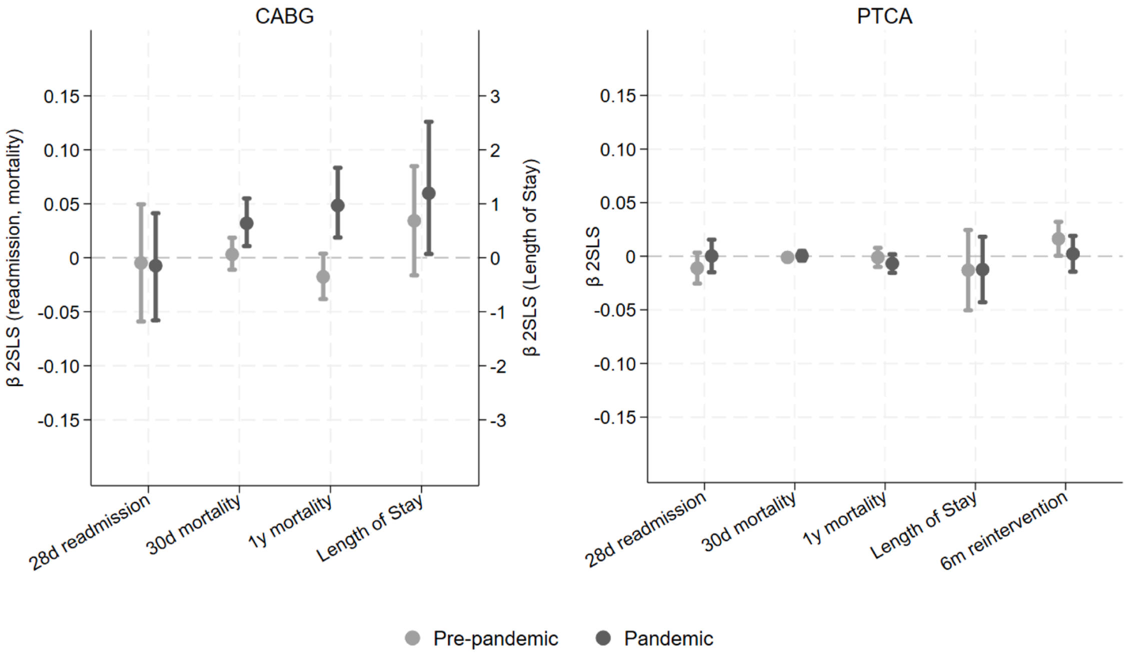

Fig. A1. IV-2SLS coefficients and their 95% Anderson-Rubin confidence intervals.
Notes: The coefficients of waiting time in the length of stay regressions for CABG patients are plotted against the right axis of the CABG graph.

Data availability

The authors do not have permission to share data.

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