HSR Health Services Research

DOI: 10.1111/1475-6773.12509
RESEARCH ARTICLE

Follow Your Heart: Survival Chances and Costs after Heart Attacks—An Instrumental Variable Approach

Alice Sanwald and Thomas Schober

Objective. To determine the effect of heart attack patients' access to intensive treatment on mortality and costs.
Data Sources. Administrative data of 4,920 patients with acute myocardial infarction from the Austrian Social Security Database and the Upper Austrian Sickness Fund for the period 2002–2011.
Study Design. As treatment intensity in a hospital largely depends on whether it has a catheterization laboratory, we explore the effects of patients' initial admission to such specialized percutaneous coronary intervention (PCI) hospitals. To account for the nonrandom selection of patients into hospitals, we exploit individuals' place of residence as a source of exogenous variation in an instrumental variable framework.
Principal Findings. We find that the initial admission to PCI hospitals increases patients' survival chances substantially. The effect on 3-year mortality is −9.5 percentage points. Subgroup analysis shows the strongest effects in relative terms for patients below the age of 65. We do not find significant effects on long-term inpatient costs and only marginal increases in outpatient costs.
Conclusions. Our findings suggest that place of residence affects the access of patients to invasive heart attack treatment and therefore their chance of survival. We conclude that that providing more patients immediate access to PCI hospitals should be beneficial.
Key Words. Acute myocardial infarction, mortality, costs, instrumental variables

Coronary artery disease (CAD) is the leading cause of death worldwide. The WHO (2014) estimates that 7.4 million people died from CADs in 2012, representing 13.2 percent of all global deaths. A heart attack, or acute myocardial infarction (AMI), is a common and life-threatening case of CAD requiring immediate treatment. The "gold standard" of treatment evaluation is randomized controlled trial (RCT). As different treatments are randomly assigned to patients, these trials promise a high internal validity. However, external validity is often disputable, in particular, if selective eligibility criteria determine the participation in trials. In the case of AMI treatment, for instance, better outcomes have been found for RCT participants compared to eligible but nonparticipating patients, and also compared to unselected cohorts of AMI patients (Terkelsen et al. 2005; Steg et al. 2007).

In this study, we extend the existing knowledge of heart attack treatment by analyzing observational data from Austrian administrative databases. Compared to RCTs, the analysis of observational data allows for a more general treatment evaluation of a real-world patient population. However, selection bias is a fundamental concern when using observational data. We use an instrumental variable (IV) framework to account for this potential bias. We focus on the role of catheterization laboratories (cath labs), which are necessary to perform invasive treatment procedures, and estimate the causal effects of an initial admission to a hospital equipped with a cath lab on mortality and follow-up costs. In contrast to evaluations of specific medical interventions, the estimated effect can be interpreted as the combined effect of being treated at a specialized hospital, including potential medical procedures, and the knowledge and skills of specialized hospital staff. We believe that these estimates are interesting from two perspectives. First, the initial hospital admission reflects the actual choices made in emergency cases. Second, the estimates are relevant from a health provision perspective because political decision makers do not choose between alternative treatment procedures, but decide on the regional allocation of medical facilities and hospital specializations.

As instruments, we use the information on individuals' place of residence, in line with previous studies. For instance, James, Li, and Ward (2007) use the distance from patients' residence to the nearest urban hospital to assess the differences in quality of care between rural and urban hospitals, while Frances et al. (2000) examine the effects of physician specialty on the mortality of elderly AMI patients. McClellan, McNeil, and Newhouse (1994) and Cutler (2007) exploit the differential distance to hospitals in an IV approach to analyze the effectiveness of alternative treatment procedures for elderly heart attack patients. Differential distance captures the additional distance between patients' closest hospital and the closest specialized hospital performing more invasive treatment procedures. The instrument is motivated by the idea that

Address correspondence to Thomas Schober, Ph.D., Christian Doppler Laboratory for Aging, Health and the Labor Market, Department of Economics, Johannes Kepler University Linz, Altenbergerstraße 69, Linz 4040, Austria; e-mail: thomas.schober@jku.at. Alice Sanwald, Ph.D., is with the Federal Ministry of Health, Friedrichstraße 108, 10117 Berlin, Germany.

patients often seek treatment at close hospitals, and thus, patients' residence should be highly predictive in determining treatment intensity.

A concern when using this instrument to evaluate specific treatments is that many treatments and other aspects of care at the hospital level are correlated (see, e.g., Cutler 2007), and it is difficult to attribute the observed effects to a single factor. In contrast to previous research, we distinguish between hospital types and use this IV to evaluate the effect of patients' initial admission to hospitals equipped with a cath lab versus the initial admission to hospitals without a cath lab. Furthermore, our dataset includes patients of all age groups, allowing reliable conclusions on the complete spectrum of patients and the analysis of effect heterogeneity.

Background and Methods

Heart Attack Treatment

The primary goal of infarction treatment is to reestablish proper blood flow to the heart. Depending on the type and severity of the AMI as well as the knowledge of specialized hospital staff and equipment of each hospital, patients receive different treatments. Thrombolytic therapy uses clot-busting medication that opens the artery by dissolving the blood clot. Percutaneous coronary intervention (PCI) encompasses more invasive procedures that necessitate a cath lab. These labs are equipped with diagnostic imaging equipment to identify the affected artery narrowing using cardiac catheterization. The result of the diagnostic procedure may lead to further clinical treatments including percutaneous transluminal coronary angioplasty (PTCA) and the use of stents. During a PTCA, a balloon catheter is introduced into the occluded vessel and expanded to minimize the blockage. Stents are small mesh tubes that are inserted into the vessel to reduce the probability of reocclusions. The most invasive AMI treatment is a coronary artery bypass grafting (CABG). However, its usage is less common than PCI (Babaev et al. 2005) in an emergency case and is often recommended only if PCI fails or cannot be performed (Hillis et al. 2011).

Electrocardiogram tracing can distinguish between two types of heart attacks. ST-elevation myocardial infarction patients require immediate opening of the artery with thrombolytic therapy, PCI, or CABG procedures. Non-ST-elevation myocardial infarction is treated with medication, but it may also be subsequently addressed using PCI procedures.

Methods

In this study, we compare the effects of initial admission to PCI hospitals, which are equipped with cath labs, with those of admission to non-PCI hospitals. A selection bias may arise owing to the endogenous choices of hospitals and treatments by physicians, paramedics, or patients. These choices may depend not only on observed factors (e.g., age and comorbidities) but also on unobserved factors (e.g., health status, type and severity of the heart attack, and preferences). We apply an IV framework to account for this potential bias and estimate the following equations:

$$p_i = \alpha_0 + \alpha_1 z_i + \alpha_2 X_i + v_i \tag{1}$$

$$y_i = \beta_0 + \beta_1 \hat{p}_i + \beta_2 X_i + \mu_i \tag{2}$$

Equation (1) represents the first stage of the two-stage least squares (2SLS) estimation. This is a linear probability model explaining hospital choice, where p_i is a dummy variable indicating whether patient i is initially admitted to a PCI hospital on the day of infarction. The second stage (2) estimates how the hospital type affects various patient outcomes y_i including mortality and costs in the inpatient and outpatient health care sector. The term X_i is a vector of control variables.

The instrument z_i measures the distance from the patient's residence to the closest PCI hospital. Following the literature (McClellan, McNeil, and Newhouse 1994; Newhouse and McClellan 1998; Cutler 2007), we construct a measure of differential distance as the distance between a patients' residence and the closest PCI hospital minus the distance from the residence to the closest hospital regardless of type. A differential distance of zero occurs if the closest hospital is equipped with a cath lab. A small differential distance indicates that the patient lives relatively close to a PCI hospital and therefore can be expected to have a higher probability of receiving more invasive AMI treatments compared to patients with larger differential distances. Differential distance is defined according to the ZIP code centroid of a patient's residence and the exact geographic location of the hospital facilities. Thus, the actual hospital choice of a patient does not affect the instrument value. We measure the distance in driving time rather than the straight-line or traveling distance to account for the quality of road connections. In our preferred specification, we divide the differential distance into nine groups and use the corresponding dummy variables as instruments.

In our main regressions, we focus on the first hospital a patient is admitted to and show how this initial decision influences the patient's outcomes. We therefore avoid potential selection bias in comparison to approaches that analyze hospital type at a specific point in time days after the infarction occurred. Necessarily, patients who are transferred between hospitals have already survived the first day(s) after the heart attack and represent an endogenously selected sample of patients.

The outcome of primary interest is mortality, which is measured as a binary variable (alive/dead) at different points in time after the heart attack was diagnosed. In separate second-stage regressions, we also estimate the effects on inpatient and outpatient expenditures. To explain the observed pattern of inpatient costs, additional results using the length of hospital stays as an outcome variable in the IV framework are provided.

Control variables X_i include age, gender, and the year of heart attack to control for systematic differences in the observed period. Further covariates are health proxies derived from the patient's medical history and proxies for the time until emergency care is available. The latter is measured by the driving time to the nearest ambulance station and to the hospital to which the patient was actually admitted.

Instrument Validity

We interpret the IV estimates as local average treatment effects (Imbens and Angrist 1994) providing the causal effect of an initial admission to a PCI hospital for patients affected by the differential distance. One requirement of a valid instrument is that it is correlated with the endogenous explanatory variable. We show in the first stage that distance has a strong impact on the probability that AMI patients are admitted to a given hospital.

The exclusion restriction requires that the instrument affects patients' outcomes only through hospital choice. This implies that differential distance must not correlate with the unobserved factors influencing mortality and follow-up costs. Our dataset provides important information on patient characteristics, but we cannot observe the actual severity and type of heart attack. These circumstances also determine the treatment and chance of survival. However, it seems a plausible assumption that the severity and type of heart attack are conditionally unrelated to patients' residence and differential distance is therefore a valid instrument.

The exclusion restriction also reveals why we refrain from using specific medical treatments as endogenous variables. A cardiac cath lab offers the possibility of several invasive treatments being frequently applied sequentially to the same patient. Moreover, there are unobserved factors, such as the availability of specialized staff, which might affect mortality independently from the actual treatment. These individual components of health care are jointly affected by the instrument and cannot be properly disentangled in the IV framework. We therefore focus on the initial admission to a PCI hospital as our explanatory variable of interest.

Finally, the assumption of monotonicity requires that all individuals be affected by the instrument in the same way. In our framework, this implies the plausible assumption that for any patient, the probability of being admitted to a PCI hospital should decrease with the distance to this hospital type.

Data

Our empirical analysis is based on 4,920 patients who were hospitalized with their first AMI in 2005–2008. The outcome and control variables draw on data from the 2002–2011 period.[1] All patients were insured with the Upper Austrian Sickness Fund (OÖGKK), which covers more than 1 million individuals (three-quarters of the total population) in the region of Upper Austria. Information on the date of death is derived from the Austrian Social Security Database and observed up to 3 years after the infarction.

Hospital data with detailed information on medical treatments and costs are obtained from the Upper Austrian Health Fund (Landesgesundheitsfonds). Costs represent payments from the fund to hospitals and are based on the Austrian Diagnosis-related Group (DRG) System, which groups hospital stays according to diagnoses and treatment. The payment per group is determined with internal cost data from a sample of representative hospitals; this system is reevaluated and adapted periodically (Hagenbichler 2010). The hospital sector in Austria is dominated by public and nonprofit hospitals. Hospital specializations and the allocation of large medical equipment such as cath labs are politically determined by the federal and provincial governments.

Additional variables regarding a given patient's socioeconomic characteristics and outpatient health-service utilization are provided by the OÖGKK. The dataset is used to construct different health proxies based on the patient's medical history prior to infarction and outcome variables for outpatient health expenditures based on information after the infarction. The health proxies are cumulative expenditures on outpatient medical care and medication and an indicator of whether the patient was admitted to a hospital because of a circulatory system disease. Each of these is measured for the 3 years prior to the AMI. As outcome variables, we look at outpatient health expenditures between the day of infarction and different points in time up to

2 years after the incidence. In contrast to the inpatient sector, expenditures in the outpatient sector are based on a fee-for-service reimbursement system. All health care expenditures are represented in Euros in 2010 prices.

The Google Maps service is used to calculate the differential distance, actual driving distance, and distance to the next ambulance station. The ambulance stations included in the analysis consist of establishments run by the Austrian Red Cross (Rotes Kreuz) and the Arbeiter-Samariter-Bund (ASBÖ) in Upper Austria.

Results

Descriptive Statistics

The dataset covers 18 hospitals in the region of Upper Austria, six of which are classified as PCI hospitals. Five of these specialized hospitals are located in two major cities. Another hospital in the west of the province opened a cath lab in July 2008 and is coded as a PCI hospital from this time onward.

The characteristics of the patient population are summarized in column 1 of Table 1. The average heart attack patient is 70.2 years old, 41.7 percent of patients are female, and 33.9 percent of patients died within 3 years after infarction. About half of the patients are initially admitted to PCI hospitals on the day of infarction. A comparison of PCI versus non-PCI hospitals (columns 2 and 3) indicates significant differences between the crude mortality rates, which accumulate to 17.4 percentage points higher 3-year mortality for patients being initially admitted to non-PCI hospitals. Patients admitted to non-PCI hospitals incur strictly lower inpatient and outpatient costs, and they receive invasive heart attack treatments less often within 1 year after the AMI. However, there are also differences in observable patient characteristics, which might contribute to differences in treatment intensity.

Columns 5 and 6 explore how the geographic location of patients' residence is related to characteristics, treatments, and outcomes. They present summary statistics when the median differential distance (9.73 minutes) is used as cut-off point to split patients into two roughly equal-sized groups. A driving distance below the median is associated with a higher likelihood of being admitted to a PCI hospital and of receiving more invasive treatments. Three years after the heart attack, the crude difference in mortality is about 8 percentage points in favor of patients facing distances below the median. Inpatient costs are almost equally distributed, but the long-run outpatient costs are significantly higher for the group of patients with distances below the median.

Table 1: Summary Statistics

	Full Sample (1)	Initial Admission to PCI Hospital (2) No	(3) Yes	(4) *p*-value*	Differential Distance (5) Below Median	(6) Above Median	(7) *p*-value*
Demographics and health proxies†							
Age	70.2	72.6	68.1	.000	69.2	71.2	.000
Female (%)	41.7	45.3	38.5	.000	39.4	44.0	.001
Past expenditures on medical attendance	1,411.2	1,448.1	1,378.2	.157	1,422.9	1,399.5	.635
Past expenditures on medication	2,270.4	2,397.9	2,156.6	.009	2,335.9	2,204.9	.156
Previous cardiovascular diseases (%)	28.6	30.5	27.0	.007	28.4	28.8	.787
Distances (min)							
Next hospital	12.6	13.1	12.2	.000	12.4	12.9	.027
Next PCI hospital	27.4	37.9	18.1	.000	13.8	41.1	.000
Differential distance	14.8	24.7	5.9	.000	1.4	28.2	.000
Next ambulance station	6.1	6.6	5.7	.000	5.5	6.8	.000
Actual driving time	17.0	14.8	18.9	.000	15.0	19.0	.000
Admission and treatments within 1 year (%)							
Initial admission to PCI hospital	52.8	0.0	100.0		84.9	20.7	.000
Coronary catheterization	65.7	48.4	81.1	.000	74.1	57.2	.000
PTCA	43.6	28.1	57.4	.000	51.2	35.9	.000
Stenting	47.4	30.2	62.7	.000	56.3	38.5	.000
Outcome variables							
Mortality (3 years)	33.9	43.1	25.7	.000	29.9	37.9	.000
Inpatient costs (2 years)	18,007.1	17,228.6	18,702.3	.003	18,359.2	17,654.7	.156
Outpatient costs (2 years)	3,606.6	3,284.2	3,894.5	.000	3,781.1	3,432.0	.002
N	4,920	2,289	2,631		2,461	2,459	

Notes. This table shows the average characteristics, treatments, and outcomes of the full patient sample (column 1), patients divided by hospital type (column 2–4), and patients divided by differential distance (column 5–7).

*The *p*-value is derived from a *t*-test for the difference between the two means. Expenditures are expressed in 2010 Euros.

†The health proxies capture expenditures and hospitalization rates owing to previous cardiovascular diseases within the last 3 years before the infarction.

First-Stage Results

We present distinct variations of the first-stage relationship and estimate the impact of differential distance on the probability of being admitted to a PCI hospital on the day of infarction.

Column 1 of Table 2 shows differential distance as a single scalar IV and reveals that one additional minute of driving time decreases the admission probability by 2 percentage points. A more flexible specification to account for variation in the distance measure is applied in column 2. Patients are stratified into groups according to their differential distance: 0–1, 1–2, 2–3, 3–5, 5–10, 10–20, 20–30, 30–40, and more than 40 minutes. This procedure results in nine dummy variables included in the regression, with 0–1 minutes as the base group. The coefficients show a decreasing probability of being admitted to a PCI hospital if the differential distance increases. With this first-stage specification, we derive all the following second-stage results.

Table 2: Effect of Distance on Admission to PCI Hospital (IV First Stage)

	(1)	*(2)*
Differential distance	−0.020*** (0.000)	
1–2 min		−0.113*** (0.016)
2–3 min		−0.357*** (0.033)
3–5 min		−0.405*** (0.054)
5–10 min		−0.659*** (0.036)
10–20 min		−0.776*** (0.020)
20–30 min		−0.820*** (0.013)
30–40 min		−0.851*** (0.014)
More than 40 min		−0.815*** (0.017)
Age	−0.003*** (0.000)	−0.003*** (0.000)
Female	0.012 (0.012)	0.020* (0.010)
Past expenditures on medical attendance	−0.000 (0.000)	−0.000 (0.000)
Past expenditures on medication	−0.000 (0.000)	−0.000* (0.000)
Previous cardiovascular diseases	−0.010 (0.012)	−0.008 (0.011)
Next ambulance station	−0.012*** (0.002)	−0.002 (0.001)
Actual driving time	0.010*** (0.001)	0.013*** (0.001)
AMI in 2006	0.029* (0.016)	0.021 (0.014)
AMI in 2007	0.089*** (0.015)	0.085*** (0.013)
AMI in 2008	0.090*** (0.015)	0.085*** (0.013)
N	4,920	4,920
Partial R^2	0.402	0.536
Cragg–Donald F-statistic	3,304	707

Notes. This table summarizes the first-stage relationships. Column 1 uses differential distance as a single scalar variable, column 2 uses nine dummy variables that take value 1 depending on the differential distance category into which the observation falls. Robust standard errors are provided in parentheses, $*p < .1$, $**p < .05$, $***p < .01$.

Main Results

Table 3 summarizes the results of the IV estimations alongside the sample mean of the respective outcome variables. Column 2 shows that initial admission to a PCI hospital has substantial effects on the chance of survival, beginning on the day of infarction. The 1-day mortality of heart attack patients decreases by 2 percentage points. The results further reveal a long-term survival benefit of −9.5 percentage points over the 3-year period following the infarction. The estimated effects are also sizable in comparison to the average mortality of heart attack patients (column 1). For instance, the estimated point estimate for the 3-year mortality represents 28 percent of the sample mean.

The estimation results for inpatient costs in column 4 show that the initial admission to a PCI hospital increases inpatient costs by €430 within 7 days after the infraction. However, the effect reverses over time and turns into cost savings of €815 within 90 days after the AMI. In the long run, the point estimate for inpatient costs is positive, though statistically insignificant. Considering the cumulative outpatient costs in column 6, the admission to a PCI hospital is associated with €426 higher expenditure 2 years after the infarction. In contrast to the mortality results, the magnitude of the cost effects

Table 3: Effects on Mortality and Costs (IV Second Stage)

	Mortality		*Inpatient Costs*		*Outpatient Costs*	
	(1) *Mean*	*(2)* *Estimate*	*(3)* *Mean*	*(4)* *Estimate*	*(5)* *Mean*	*(6)* *Estimate*
1 day	0.033	−0.0199*** (0.00736)				
7 days	0.113	−0.0515*** (0.0129)	6,490.4	430.3*** (160.7)		
30 days	0.171	−0.0881*** (0.0150)	9,716.2	−421.3 (289.2)		
90 days	0.205	−0.106*** (0.0156)	11,225.6	−815.1** (380.8)	670.1	−20.63 (27.55)
182 days	0.228	−0.0969*** (0.0160)	12,479.7	−640.0 (445.4)	1,186.4	34.69 (50.27)
1 year	0.260	−0.0986*** (0.0164)	14,655.8	−255.8 (540.7)	2,100.0	153.1* (87.35)
1.5 years	0.283	−0.0938*** (0.0166)	16,332.0	238.1 (618.0)	2,879.1	283.9** (119.5)
2 years	0.303	−0.0947*** (0.0167)	18,007.1	438.3 (695.8)	3,606.6	425.9*** (152.5)
3 years	0.339	−0.0953*** (0.0169)				
N		4,920		4,920		4,920

Notes. This table summarizes the effects of patients' admission to PCI hospitals on mortality and follow-up costs. Columns 1, 3, and 5 show the mean of the dependent variable, and columns 2, 4, and 6 show the coefficient estimates. Each cell represents the results from a separate regression. All regressions include controls for age, sex, past expenditures on medical attendance, past expenditures on medication, previous cardiovascular diseases, distance to the next ambulance station, actual driving distance, and year of the AMI. Robust standard errors are provided in parentheses, $^{*}p < .1$, $^{**}p < .05$, $^{***}p < .01$.

is smaller when compared to average costs. The point estimates for 2-year inpatient and outpatient costs correspond to approximately 2.4 percent and 11.8 percent of the sample mean, respectively.

Heterogeneous Effects and Supplementary Findings

To explore potential heterogeneous effects, we analyze subgroups of the patient population according to age, sex, and medical history. Table 4 shows the results when the sample is split with respect to age. Considering the effects of the initial admission to a PCI hospital on mortality, the estimations reveal larger point estimates for patients above the age of 65 at any time after the heart attack. However, when the effects are viewed in relation to diverging average mortality (columns 1 and 3), the comparison reveals that there are larger relative survival benefits for younger patients. Of the patients above 65 years of age, 45.1 percent die within 3 years after the AMI. The point estimate of −10.0 percentage points therefore represents 22 percent of the mean mortality. Considering the counterparts, the estimated effect of −6.7 percentage points corresponds to 59.8 percent of the 3-year mortality. While admission to a PCI hospital increases long-run inpatient costs for the elderly, it leads to cost savings for patients below the age of 65. The outpatient cost pattern is similar and suggests larger increases for patients above 65.

Tables S2 and S3 show further patient subgroups. A comparison of men and women reveals similar results considering relative effects on long-run mortality and statistically significant increases in outpatient costs only for women. With respect to the medical history of the patients, the relative effects on mortality are larger for symptom-free patients than for patients with past hospital visits owing to cardiovascular diseases. The second group also has the largest effects on long-run inpatient and outpatient costs among the considered subgroups.

Additional estimations offer possible explanations for the observed pattern of inpatient costs. Here, we use the number of days spent in hospital as an outcome variable in our IV framework. Table S1 in the Appendix summarizes the results and shows that the initial admission to a PCI hospital has a negative effect on the length of stay. For example, within the first 30 days after infarction, the difference between hospital types amounts to approximately 2 days (column 2). The effect is largely driven by hospital stays due to problems relating to the circulatory system (column 4). These results suggest that the initial admission to a non-PCI hospital implies, on average, longer inpatient treatment. This may explain the finding that admission to a PCI hospital decreases inpatient cost in the medium run (within 90 days after infarction).

Table 4: Effects on Mortality and Costs by Age of Patients (IV Second Stage)

	Younger than 65		*Older than 65*	
	(1) Mean	*(2) Estimate*	*(3) Mean*	*(4) Estimate*
Mortality				
1 day	0.024	−0.013 (0.012)	0.037	−0.023*** (0.009)
7 days	0.050	−0.040** (0.017)	0.145	−0.055*** (0.017)
30 days	0.067	−0.048** (0.019)	0.222	−0.103*** (0.020)
90 days	0.073	−0.054*** (0.019)	0.269	−0.125*** (0.021)
182 days	0.080	−0.055*** (0.020)	0.301	−0.112*** (0.021)
1 year	0.088	−0.064*** (0.021)	0.344	−0.108*** (0.022)
1.5 years	0.091	−0.068*** (0.021)	0.377	−0.098*** (0.022)
2 years	0.094	−0.074*** (0.021)	0.406	−0.096*** (0.022)
3 years	0.112	−0.067*** (0.023)	0.451	−0.100*** (0.022)
Inpatient costs				
7 days	8,458.1	−352.1 (326.5)	5,523.5	711.4*** (178.8)
30 days	11,044.1	−1,518.2*** (542.9)	9,063.7	7.2 (335.1)
90 days	12,240.0	−2,134.7*** (714.2)	10,727.1	−308.7 (444.4)
182 days	13,314.5	−2,483.1*** (820.2)	12,069.5	102.0 (522.0)
1 year	15,280.8	−2,592.4*** (968.6)	14,348.8	696.5 (644.0)
1.5 years	16,573.0	−2,749.6** (1,083.5)	16,213.6	1,478.0** (740.3)
2 years	18,031.9	−2,410.4** (1,194.3)	17,994.9	1,630.3* (839.8)
Outpatient costs				
90 days	692.6	−145.9*** (48.2)	659.1	30.5 (31.9)
182 days	1,247.8	−133.3 (88.2)	1,156.2	104.8* (57.3)
1 year	2,240.5	−152.6 (154.0)	2,031.0	285.6*** (99.6)
1.5 years	3,080.5	−155.9 (198.7)	2,780.1	473.1*** (141.6)
2 years	3,888.7	−26.6 (244.5)	3,468.0	613.4*** (183.5)
N		1,621		3,299

Notes. This table summarizes the effects of patients' admission to PCI hospitals on mortality and follow-up costs. Means of the dependent variable are shown in columns 1, 3, and columns 2 and 4 show the 2SLS estimates. Each cell represents the results from a separate regression. All regressions include controls for age, sex, past expenditures on medical attendance, past expenditures on medication, previous cardiovascular diseases, distance to the next ambulance station, actual driving distance, and year of the AMI. Robust standard errors are provided in parentheses, *$p < .1$, **$p < .05$, ***$p < .01$.

Robustness Checks

To determine the sensitivity of our results, we conducted robustness checks with different specifications or samples. The results for long-term outcomes are summarized in Table 5 and follow the IV framework outlined above.

The IV approach would be invalid if patients likely to have severe heart attacks choose their place of residence with respect to the differential distance

Table 5: Robustness Checks for IV Estimation

	(1) 3-year Mortality	(2) 2-year Inpatient Costs	(3) 2-year Outpatient Costs
Main results (N = 4,920)	−0.0953*** (0.0169)	438.3 (695.8)	425.9*** (152.5)
Nonmovers (N = 4,093)	−0.0950*** (0.0186)	981.5 (769.2)	542.8*** (168.9)
Symptom-free patients (N = 3,512)	−0.0885*** (0.0193)	−705.3 (758.9)	67.5 (162.2)
Urban patients I (N = 1,350)	−0.146*** (0.0345)	−620.5 (1,624.2)	748.4*** (264.8)
Urban patients II (N = 1,970)	−0.106*** (0.0269)	795.3 (1122.6)	315.1 (261.3)
PCI hospital within 7 days (N = 4,920)	−0.166*** (0.0283)	775.3 (1,186.1)	745.0*** (258.8)
PCI hospital within 30 days (N = 4,920)	−0.206*** (0.0345)	779.2 (1,472.2)	941.2*** (320.7)
PCI hospital within 90 days (N = 4,920)	−0.210*** (0.0351)	866.1 (1,499.4)	951.9*** (326.2)
Additional SES controls (N = 4,556)	−0.094*** (0.0177)	917.1 (722.0)	376.4** (158.8)
Entire patient population (N = 4,988)	−0.0959*** (0.0175)	632.3 (723.1)	435.8*** (157.6)
Additional comorbidity controls (N = 4,920)	−0.104*** (0.0165)	371.7 (691.7)	434.0*** (154.5)

Notes. This table summarizes the effects of patients' admission to PCI hospitals on mortality and follow-up costs. Each cell represents the results from a separate regression. All regressions include controls for age, sex, past expenditures on medical attendance, past expenditures on medication, previous cardiovascular diseases, distance to the next ambulance station, actual driving distance, and year of the AMI. Additional SES controls are gross yearly income and a variable indicating whether the individual has an academic degree. Additional comorbidity controls include dummy variables indicating the following comorbidities: Neoplasms, diseases of the respiratory system, dementia, diabetes, and renal diseases. Robust standard errors are provided in parentheses, $^{*}p < .1$, $^{**}p < .05$, $^{***}p < .01$.

to PCI hospitals. For example, elderly patients with poor health status may move toward larger cities because of the availability of nursing homes and increased access to health care facilities. As a first test to account for this potential residential sorting, we restrict the sample to nonmovers and focus on only those individuals who did not change their place of residence in the past 3 years before AMI. Second, we focus only on patients who did not have a heart-related disease in the past. Both samples yield similar results in comparison to the baseline model. The only exception relates to the effect on outpatient costs for symptom-free patients, for which the point estimate is smaller and statistically insignificant.

Garabedian, Zaslavsky, and Soumerai (2014) discuss further potential confounders that might bias the results when distance is used as an instrument in observational studies. To check the dependence on rural versus urban residence, we restrict the sample to 1,350 patients living in the three largest cities of Upper Austria. These patients should be similar with respect to unobserved factors such as available infrastructure, health, living conditions, and general access to health care. While there are hospitals in each city, residents in one of the cities have limited access to a PCI hospital, with a corresponding differential distance of 28.7 minutes. Using our IV approach, we find that the initial admission to a PCI hospital has a significant impact on the mortality outcomes of the urban population. The effect on the 3-year mortality is -14.6 percentage points. Moreover, the 95 percent confidence interval includes the corresponding point estimate of the full sample. The effects on cumulative costs are qualitatively similar with no statistically significant effect on long-term inpatient costs (Urban patients I in Table 5). When the sample is extended to include smaller cities with a population of over 10,000 (Urban patients II), the point estimates are even closer to the estimated baseline results. To allow for socioeconomic status (SES) as a potential confounder, we obtained additional information from the pay slips that firms and pension-paying entities send to the Austrian tax authorities. We include the gross yearly income of the year prior to the heart attack and a variable indicating whether the individual has an academic degree as further covariates (Additional SES controls). As an additional check, we include 68 patients whom we excluded from the analysis because they were treated in distant hospitals and presumably were not in their residential area at the time of infarction (Entire patient population). In another specification, we add dummy variables indicating typical comorbidities including neoplasms, diseases of the respiratory system, dementia, diabetes, and renal diseases (Additional comorbidity controls). Compared to the baseline model, all robustness checks yield qualitatively very similar results.

Following the literature on the effectiveness of heart attack treatment in similar frameworks (e.g., McClellan, McNeil, and Newhouse 1994; Cutler 2007), we redefine our endogenous variable and estimate models for which the time until admission to PCI hospitals is extended to 7, 30, or 90 days after the heart attack. For example, a PCI hospitalization within 7 days implies that the patient has an inpatient stay at a PCI hospital at some point between the heart attack and 7 days after the infarction. The results show that the point estimates for mortality and costs increase with the length of the potential hospitalization window. For instance, the effect on 3-year mortality increases from

−16.6 to −21 percentage points when the window is increased from 7 to 90 days. This result can be at least partly attributed to the survivorship bias. As only living patients are transferred to PCI hospitals, the stock of patients arriving within 90 days of infarction is more likely to survive compared to patients admitted on the day of infarction.

Discussion

Our results are in line with randomized trials, which generally find that heart attack patients benefit from invasive procedures. For example, Keeley, Boura, and Grines (2003) reviewed 23 trials and found that PTCA is better than thrombolytic therapy at reducing short-term mortality risk and other adverse outcomes. Studies with observational data using similar IV research designs also examine the effectiveness of invasive procedures. While McClellan, McNeil, and Newhouse (1994) find significant higher percentage point reductions in mortality for the first day after the heart attack, the use of catheterization procedures within 90 days reduces the cumulative mortality at 1–4 years by 5 percentage points at the most. Similarly, Cutler (2007) finds no statistically significant effect of revascularization procedures on cumulative mortality 3 years after infarction. Both studies rely on Medicare data for elderly AMI patients, and their findings contrast with ours that reveal large and significant effects for older heart attack patients.

In contrast to these studies, our identification strategy reveals the effect of an admission to a PCI hospital and not of medical procedures per se. PCI hospitals might improve the chance of survival from the combined treatment possibilities and skills of specialized hospital staff. In other words, the skills and knowledge of cardiologists might improve primary treatment, the quality of care, and patient mortality outcomes independently from the actual medical procedures. Furthermore, our analysis is based on a more recent dataset. Changes in medical practices and technology in previous decades may fortify the benefits of invasive health care.

Also related to our results are randomized trials that evaluate whether the transfer of patients to PCI hospitals is superior to on-site thrombolytic therapy for patients in hospitals without cath labs. De Luca, Biondi-Zoccai, and Marino (2008) showed in a meta-analysis that transfer to PCI hospitals is associated with a 1.2 percentage point reduction in 30-day mortality, which is small compared to our estimated effect of 8.8 percentage points. The difference in magnitude might be explained by the transfer-related time-delay to treatment, the exclusive considerations of ST-elevation myocardial infarction patients, and the selection of participants for these trials. For instance, the average mortality of heart attack patients participating in these trials is significantly lower in comparison to the patients in our administrative dataset.

A limitation of our study is that we only consider patients who survived until hospital admission. Individuals who die on the way to hospital affect our results to an unknown extent. If more individuals with severe heart attack die on the way to a PCI hospital than on the way to non-PCI hospitals, our estimates would be biased because the patients admitted to PCI hospitals represent a positively selected sample.[2]

A further question is how long-term survival of heart attack patients is related to medical interventions after the infarction. It is plausible that the hospital chosen for heart attack treatment is also more likely to be chosen for subsequent unrelated treatment. If PCI hospitals perform well in the former case, they might also perform well in treating other severe diseases such as stroke. The long-term survival of heart attack patients could therefore also depend on the quality of care for other diseases.

The estimated effects on inpatient and outpatient costs are also affected by survivorship bias, caused by the observed effects on mortality. Individuals who die do not induce any expenditure; therefore, ceteris paribus, a higher survival rate increases the probability that patients receive some medical treatment. Analogous to the results of the RCTs described here, one can question the generalizability of IV approaches. Following our identification strategy, we estimate the effect for the subpopulation of patients affected by the distance instrument. Without further assumptions, the effect cannot be translated to individuals for whom the initial admission is independent of their residence. Finally, despite the performed sensitivity tests which show that the results are robust with respect to changes in specification and sample, we cannot rule out the existence of unobserved confounding variables that bias the results.

Conclusion

We explore how cath labs affect the survival chances and follow-up costs of heart attack patients. The initial admission to PCI hospitals equipped with cath labs has significant and persisting causal effects on the chances of survival beginning on the day of infarction. The effect on 3-year mortality is −9.5 percentage points. Separating individuals into subgroups shows that patients below the age of 65 have the highest survival benefit in relative terms.

Considering costs, we find no statistically significant effect on long-term inpatient costs and that outpatient health care costs increased slightly.

We regard our results as complements to RCTs, which typically evaluate specific medical interventions. Compared to these studies, our estimates represent the interaction of treatment possibilities in a PCI hospital, including the use of AMI treatment procedures and the presence of specialized hospital staff. The approach thereby aims to address important policy-relevant questions concerning the organization of health care and the allocation of health care facilities. Our findings suggest that patients' place of residence affects their access to invasive heart attack treatments and therefore their chance of survival. We conclude that providing more heart attack patients immediate treatment at PCI hospitals should be beneficial. This could be achieved by for example, increasing the number of PCI hospitals or the number of direct admissions to existing PCI hospitals. In practice, expanding the number of PCI hospitals is a complex matter with presumably large (cost) implications for health care providers. Increasing the number of direct admissions, on the other hand, might increase the duration until patients receive invasive care and has to take capacity constraints of the existing hospitals into account, affecting patients' mortality to an unknown extend. Further research is necessary to assess potential consequences of changes in the treatment of heart attack patients.

The available data on hospital costs are DRG-based and therefore can only approximate actual therapy costs. More research with detailed cost data is needed for a thorough investigation of treatment efficiency. Questions on the generalizability of our results are also tasks for future research, using data from countries with different health care systems.

ACKNOWLEDGMENTS

Joint Acknowledgment/Disclosure Statement: Financial support by the Austrian Federal Ministry of Science, Research and Economy and the National Foundation for Research, Technology and Development is gratefully acknowledged. We thank Engelbert Theurl and Gerald J. Pruckner for helpful discussions and comments.

Disclosures: The authors declare that they have no conflicts of interest related to this study. No other disclosures.

Disclaimers: None.

Notes

1. We exclude patients with missing data, residing outside Upper Austria, and with a history of one or more heart attacks occurring prior to 2005. Patients treated in private hospitals and hospitals owned by the Austrian Social Insurance for Occupational Risks are not included in the dataset. Furthermore, we exclude 68 patients whose driving time to the admission hospital exceeds the driving time to the closest PCI hospital by 15 minutes. We assume that they were not in their residential area at the time of the AMI. We show the results for the entire patient population in section 3.5.
2. See Avdic (2014), for instance, who explores the role of distance to emergency care using data on inpatient and outpatient deaths.

References

Avdic, D. 2014. "A Matter of Life and Death? Hospital Distance and Quality of Care: Evidence from Emergency Hospital Closures and Myocardial Infarctions." Working Paper, IFAU-Institute for Evaluation of Labour Market and Education Policy.

Babaev, A., P. D. Frederick, D. J. Pasta, N. Every, T. Sichrovsky, J. S. Hochman, and N. Investigators. 2005. "Trends in Management and Outcomes of Patients with Acute Myocardial Infarction Complicated by Cardiogenic Shock." *Journal of the American Medical Association* 294 (4): 448–54.

Cutler, D. M. 2007. "The Lifetime Costs and Benefits of Medical Technology." *Journal of Health Economics* 26 (6): 1081–100.

De Luca, G., G. Biondi-Zoccai, and P. Marino. 2008. "Transferring Patients with ST-Segment Elevation Myocardial Infarction for Mechanical Reperfusion: A Meta-Regression Analysis of Randomized Trials." *Annals of Emergency Medicine* 52 (6): 665–76.

Frances, C. D., M. G. Shlipak, H. Noguchi, P. A. Heidenreich, and M. McClellan. 2000. "Does Physician Specialty Affect the Survival of Elderly Patients with Myocardial Infarction?" *Health Services Research* 35 (5 Pt 2): 1093–116.

Garabedian, L. F., A. M. Zaslavsky, and S. B. Soumerai. 2014. "Instrumental Variable Analyses for Observational Comparative Effectiveness Research: The Paired Availability Design." *Annals of Internal Medicine* 161 (11): 841.

Hagenbichler, E. 2010. *The Austrian DRG-System.* Vienna, Austria: Bundesministerium für Gesundheit.

Hillis, L. D., P. K. Smith, J. L. Anderson, J. A. Bittl, C. R. Bridges, J. G. Byrne, J. E. Cigarroa, V. J. DiSesa, L. F. Hiratzka, A. M. Hutter, M. E. Jessen, E. C. Keeley, S. J. Lahey, R. A. Lange, M. J. London, M. J. Mack, M. R. Patel, J. D. Puskas, J. F. Sabik, O. Selnes, D. M. Shahian, J. C. Trost, and M. D. Winniford. 2011. "2011 ACCF/AHA Guideline for Coronary Artery Bypass Graft Surgery: Executive Summary: A Report of the American College of Cardiology Foundation/

American Heart Association Task Force on Practice Guidelines." *Circulation* 124 (23): 2610–42.
Imbens, G., and J. Angrist. 1994. "Identification and Estimation of Local Average Treatment Effects." *Econometrica* 62 (2): 467–75.
James, P. A., P. Li, and M. M. Ward. 2007. "Myocardial Infarction Mortality in Rural and Urban Hospitals: Rethinking Measures of Quality of Care." *The Annals of Family Medicine* 5 (2): 105–11.
Keeley, E. C., J. A. Boura, and C. L. Grines. 2003. "Primary Angioplasty Versus Intravenous Thrombolytic Therapy for Acute Myocardial Infarction: A Quantitative Review of 23 Randomised Trials." *The Lancet* 361 (9351): 13–20.
McClellan, M., B. J. McNeil, and J. P. Newhouse. 1994. "Does More Intensive Treatment of Acute Myocardial Infarction in the Elderly Reduce Mortality?: Analysis Using Instrumental Variables." *Journal of the American Medical Association* 272 (11): 859–66.
Newhouse, J. P., and M. McClellan. 1998. "Econometrics in Outcomes Research: The Use of Instrumental Variables." *Annual Review of Public Health* 19 (1): 17–34.
Steg, P. G., J. López-Sendón, E. L. de Sa, S. G. Goodman, J. M. Gore, F. A. Anderson, D. Himbert, J. Allegrone, and F. Van de Werf. 2007. "External Validity of Clinical Trials in Acute Myocardial Infarction." *Archives of Internal Medicine* 167 (1): 68–73.
Terkelsen, C. J., J. F. Lassen, B. L. Nørgaard, J. C. Gerdes, T. Jensen, L. B. -H. Gøtzsche, T. T. Nielsen, and H. R. Andersen. 2005. "Mortality Rates in Patients with ST-Elevation vs. Non-ST-Elevation Acute Myocardial Infarction: Observations from an Unselected Cohort." *European Heart Journal* 26 (1): 18–26.
WHO. 2014. "The Top 10 Causes of Death Fact Sheet" [accessed on August 08, 2014]. Available at http://www.who.int/mediacentre/factsheets/fs310/en/

Supporting Information

Additional supporting information may be found in the online version of this article:

Appendix SA1: Author Matrix.

Table S1: Effects on Days in Hospital (IV Second Stage).

Table S2: Effects on Mortality and Costs by Sex of Patients (IV Second Stage).

Table S3: Effects on Mortality and Costs by Medical History (IV Second Stage).