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Follow your Heart: Survival Chances and Costs after Heart Attacks - An Instrumental Variable Approach

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Follow your Heart: Survival Chances and Costs after Heart Attacks - An Instrumental Variable Approach

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Abstract

We analyze mortality and follow-up costs of heart attack patients using administrative data from Austria from 2002-2011. As treatment intensity in a hospital largely depends on whether it has a catheterization laboratory, we focus on the effects of patients' initial admission to these specialized 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. We find that the initial admission to specialized hospitals increases patients' survival chances substantially. The effect on 3-year mortality is -9.5 percentage points. A separation of the sample into subgroups 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 find only marginal increases in outpatient costs.

JEL Classification: I11, I12.
Keywords: Acute myocardial infarction, mortality, costs, instrumental variables.

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1 Introduction

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% of all global deaths. Furthermore, CAD significantly contributes to the global disease burden through related ill-health, disability, or premature death (Mendis et al., 2011). Acute myocardial infarction (AMI), termed "heart attack", is a common and life-threatening presentation of CAD. As medical treatment is an important factor in determining patients' mortality, it is critical to understand the effectiveness of heart attack treatments.

The "gold standard" of treatment evaluation is the randomized controlled trial (RCT). As different treatments are randomly assigned to patients, these trials promise a high internal validity. However, the external validity is often disputable, in particular, if selective eligibility criteria determine participation in trials. In the case of AMI treatments for instance, better outcomes have been found for RCT participants compared to eligible, but non-participating patients and also compared to unselected cohorts of AMI patients (Steg et al., 2007; Terkelsen et al., 2005). Therefore, the resulting patient population may be too narrow and the extension of findings to a broader spectrum of patients is questionable (Rothwell, 2005).

In this study, we extend the existing knowledge of heart attack treatment evaluations 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. The comprehensive dataset allows for the determination of survival chances of AMI patients and follow-up costs separated into inpatient and outpatient health care expenditures. We focus on the role of catheterization laboratories (cath labs), which are necessary to perform invasive treatment procedures, in heart attack treatment and estimate the causal effects of an initial admission to a hospital equipped with a cath lab. 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 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 information on individuals' place of residence, in line with previous studies. For instance, James et al. (2007) use the distance from patients' residence to the nearest urban hospital to assess differences in the quality of care between rural and urban hospitals, while Frances et al. (2000) examine the effects of physician specialty on mortality of elderly AMI patients. McClellan et al. (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 patients often seek treatment at close hospitals, and thus, patients' residence should be highly predictive in determining treatment intensity.

In contrast to previous research comparing specific treatments, we use differential distance as an IV to evaluate the effect of patients' initial admission to hospitals equipped with a cath lab. Furthermore, our dataset includes patients of all age groups, which allows reliable conclusions that relate to the complete spectrum of patients. We also analyze subgroups of patients according to their characteristics (age, sex, and medical history) to explore potential effect heterogeneity.

The remainder of this paper is organized as follows. Section 2 presents a brief definition of a heart attack, the corresponding treatment methods, and presents our empirical approach. Section 3 describes the used dataset. Section 4 presents the empirical results for the total sample, subgroups of patients, and the performed robustness checks. Section 5 discusses the results, and Section 6 concludes.

2 Background & Methods

2.1 Heart Attack Treatments

An AMI occurs if blood is not flowing properly to the coronary artery or its branches owing to a blockage (e.g. blood clots) in one or more blood vessels. The lack of blood flow results in oxygen deficiency in the heart muscle and has both immediate and delayed health effects on the heart (Cleland and McGowan, 1999).

The primary goal of infarction treatment is to re-establish blood flow immediately. Depending on the type and severity of the AMI, as well as on 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 by 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 re-occlusions.

The most invasive AMI treatment is a coronary artery bypass grafting (CABG). In this surgical procedure, a vessel from other parts of the body is removed and grafted to the coronary arteries to "bypass" the narrowed artery and to improve the blood flow. CABG is performed as a planned surgery or in emergency cases. The use of emergency bypass surgery for AMI treatment is less common than PCI (Babaev et al., 2005) and often only recommend if PCI has failed 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 may also be subsequently addressed using PCI procedures.

To reduce the risk of reinfarctions, participation in cardiac rehabilitation programs subsequent to inpatient care is recommended to patients. This following-up health care consists of lifestyle modification, regular medical check-ups, and medication to both reduce the risk of a subsequent heart attack and to prevent a deterioration of the damaged heart muscle. Potential complications after a heart attack might lead to heart failures, an abnormal heart rhythm, valve problems, cardiogenic shocks, and heart ruptures. If such complications occur after an AMI, patients might require further inpatient treatment, which increases follow-up costs.

2.2 Methods

In this study, we compare the effects of initial admissions to PCI hospitals, which are equipped with a cath lab, to that of admissions to non-PCI hospitals. When comparing patients treated in different hospitals, one has to account for potential selection bias. Selection bias may arise owing to the endogenous choices of hospitals and treatments by physicians, paramedics, or patients. These choices may depend on observed factors (e.g., age and co-morbidities), but also on unobserved factors (e.g., health status, type and severity of the heart attack, and preferences). We apply an IV framework to avoid this potential bias and estimate the following equations:

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

$$y_i = \beta_0 + \beta_1 p_i + \beta_2 X_i + \mu_i \tag{2}$$

Equation (1) represents the first stage of the two-stage least squares estimation. It is a linear probability model explaining hospital choice, where p_i is a dummy variable indicating if 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 of the patients' residence to the closest PCI hospital. Following the literature (McClellan et al., 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 its 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.

In contrast to the previous literature, we account for transport infrastructure and use distance in driving time instead of straight-line distances or traveling distance. This measure reflects regional transport infrastructure advantages of patients living in rural areas with excellent connections to road networks compared to patients with less developed connections. Neglecting the quality of road connections might lead to imprecise estimations of the first stage owing to the veiling of patient's actual hospital choice in the event of an acute heart attack.

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 year of the 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 driving time to the hospital to which the patient was actually admitted.

2.3 Instrument Validity

We interpret the IV estimates as local average treatments effects (Imbens and Angrist, 1994) providing the causal effect of an initial admission to a PCI hospital for patients who were 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 affect patients' outcomes only through hospital choice. This implies that differential distance must not correlate with 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 the heart attack. These circumstances also determine the treatment and chance of survival. However, it seems a plausible assumption that the severity and the type of the heart attack are conditionally unrelated to patients' residence and the differential distance therefore is a valid instrument.[1]

The exclusion restriction also reveals why we refrain from using specific medical treatments as endogenous variables. A cardiac catheterization laboratory offers the possibility for several invasive treatments that are 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.

3 Data

Our empirical analysis is based on 4,920 patients who were hospitalized with their first AMI[2] in 2005-2008. The outcome and control variables draw on data from the 2002-2011 period.[3] All patients were insured within the Upper Austrian Sickness Fund (OÖGKK),

[1] We address the potential issue of residential sorting in the robustness section.

[2] Primary diagnosis: code I21 in the International Classification of Diseases (ICD)-10 version.

[3] 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 patients who are treated in distant hospitals (i.e., driving time to the admission hospitals exceeds

which covers more than one 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. Our main outcome variable is mortality, which is measured beginning on the first day after the infarction and at several points thereafter. The observation period ends three years after the heart attack occurred.

Hospital data with detailed information on medical treatments and costs are derived from the Upper Austrian Health Fund (Landesgesundheitsfonds) and build upon the Austrian DRG system (Hagenbichler, 2010). The cost calculations in this database are based on the norm costs of a representative sample of Austrian hospitals in the near past and on the budget of the Upper Austrian Health Fund.

Additional variables regarding a given patient's socio-economic 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 the 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 (code I in the ICD-10 version). Each of these is measured for the three years prior to the AMI. As outcome variables, we look at outpatient health expenditures between the day of the infarction and different points in time up to two years after the incidence. 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.

4 Results

4.1 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.

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 % of patients are female, and 33.9 %

the driving time to the closest PCI hospital by 15 minutes).

of patients died within three years after the infarction. About half of the patients are initially admitted to PCI hospitals on the day of the infarction. The 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 have strictly lower inpatient and outpatient costs, and they receive invasive heart attack treatments less often within one year after the AMI. However, there are also differences considering observable patient characteristics, which might contribute to differences in the treatment intensity. For instance, patients of non-PCI hospitals are on average 4.5 years older and have a significant worse medical history.

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 the 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. Of patients with distances below the median differential distance, 51.2 % receive PTCA and 56.3 %, stenting within one year after the infarction, compared to 35.9 % and 38.5 % in the group of patients with distances above the median differential distance. 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 and accumulate to roughly 18,000 Euros after two years. In contrast, the long-run outpatient costs are significantly higher in the group of patients with distances below the median.

4.2 First-Stage Results

In the first stage of our two-stage least squares framework, we present distinct variations of the differential distance measurement to estimate the impact of the differential distance on the probability of being initially admitted to a PCI hospital at the day of infarction.

Column 1 of Table 2 uses the differential distance as a single scalar IV and reveals that one additional minute of driving time decreases the admission probability by 2 percentage points. In column 2, we regress admission on a dummy variable that is 1 when the patient's differential distance lies above the population median and 0 otherwise. The estimate suggests that these patients have a 67.5 percentage point lower probability of being admitted to PCI hospitals in comparison to patients below the median. A more flexible specification to account for variation in the distance measure is applied in column 3. 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 9 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. For instance, patients for whom the differential distance is more than 20 minutes face an 82 percentage points decreased likelihood of being admitted to a PCI hospital compared to patients for whom the next hospital is a PCI hospital. We use this first-stage specification to derive all following second-stage results.

The lower panel of Table 2 shows the CraggDonald F-statistics to test for weak instruments. The results suggest strong first-stage relationships, so we abstract from weak-IV concerns in the following discussion (Staiger and Stock, 1997).

4.3 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 the infarction. The 1-day mortality of heart attack patients is decreased by 2 percentage points. The effect increases over time and peaks at a 10.6 percentage point reduction in the probability of dying within 90 days after the heart attack. 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 % of the sample mean.

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 two years after the infarction. In contrast to the mortality results, the magnitude of the cost effects is smaller when compared to average costs. The point estimates for 2-year inpatient and outpatient costs correspond to approximately 2.4 % and 11.8 % of the sample mean.

For comparison, Table 4 shows the results of corresponding ordinary least squares (OLS) regressions, where hospital choice is related directly to patient outcomes. Despite modest differences in the point estimates for mortality, the 95 % confidence intervals of the IV estimates include the corresponding OLS point estimates. Comparing the cost estimates, the IV confidence intervals include the corresponding OLS point estimates except for the 7-day inpatient and 90-day outpatient costs. One explanation for the similarities might be that there is only a minor selection bias in the OLS estimates and/or the sample size is too small to reveal the differences between the estimation strategies. However, there may also be offsetting effects in the selection mechanisms at work.

4.4 Heterogeneous Effects

To explore potential heterogeneous effects, we analyze subgroups of the patient population according to age, sex, and medical history. Table 5 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 % die within three years after the AMI. The point estimate of -10.0 percentage points therefore represents 22 % of the mean mortality. Considering the counterparts, the estimated effect of -6.7 percentage points corresponds to 59.8 % 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. Three years after the infarction, the gap between both groups accumulates to €4,040 per capita. The outpatient cost pattern is similar and suggests larger increases for patients above 65; long-run estimates for younger patients are statistically insignificant.

Table 6 shows larger survival benefits for female patients, for whom the peak is reached 90 days after the AMI. The corresponding effect on mortality is -11.8 percentage points, and the effect persists over time. However, in the long run there are only minor differences between men and women in relative terms. Estimations on inpatient and outpatient costs reveal modest gender differences. While there are no long-run effects on inpatient costs for both sexes and on outpatient costs for men, there is a statistically significant effect on outpatient health care costs for women. The initial admission to a PCI hospital leads to increased outpatient costs amounting to 17.2 % of the sample mean.

Among all considered subgroups, patients with past hospital visits owing to diseases of the cardiovascular system have the lowest probability of surviving a heart attack (Table 7). More than half of the patients die within three years after the infarction. The benefit of an initial admission to a PCI hospital for this group is 15.3 percentage points after 90 days, which represents the largest point estimate of all subgroups. Patients without symptoms in the past also reach their highest survival benefit after 90 days. This effect remains approximately constant over time. In comparison to the baseline mortality in the subgroups, the effects of admission to a PCI hospital on long-run mortality are 32.8 % for symptom-free patients and 22.4 % for patients with previous heart diseases. Patients with previous heart diseases furthermore have the largest effects on long-run inpatient and outpatient costs among the considered subgroups. Two years after the heart attack, the estimate is €3,030 for inpatient and €1,255 for outpatient treatment, or 15.4 % and 32.6 % of the respective sample mean.

4.5 Supplementary Findings

Supplementary 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 9 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 the infarction, the difference between hospital types amounts to approximately two days (column 2). The effect is largely driven by hospital stays because of 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 the infarction).

The positive effect on short-term inpatient costs on the other hand can be attributed to cost measurements. Hospital expenditures are derived from the Austrian DRG System and reflect not only the length of stay but also the treatment intensity. For instance, considering heart attack patients in 2005, hospitals earned 3901 DRG-points for the most frequently used DRG-group that included catheter based treatments, but only 2601 DRG-points for the most frequently used group without these treatments.[4]

4.6 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 8 and follow the IV framework outlined above.

The IV approach would be invalid if patients who can be expected to have severe heart attacks choose their place of residence with respect to the differential distance to PCI hospitals. For example, elderly patients with worse 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 non-movers and focus on only those individuals who did not change their place of residence in the past three years before the 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.

As a further sensitivity check, 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

[4]For both groups, the length of stay is expected to range from 5 to 15 days and points are subtracted or added for shorter or longer hospital stays.

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, 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 % 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.

Following the literature on the effectiveness of heart attack treatment in similar frameworks (e.g. McClellan et al., 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 days 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 who arrive within the 90 days after the infarction is more likely to survive compared to patients who are admitted at the day of the infarction.

5 Discussion

Our results are in line with randomized trials, which generally find that heart attack patients benefit from invasive procedures. For example, Keeley et al. (2003), review 23 trials and find 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 and find positive impact on the survival chances (McClellan et al., 1994; Cutler, 2007). However, in comparison to these previous findings, the magnitude of our estimated effects appears large. While McClellan et al. (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 cumulative mortality at one to four years by 5 percentage points at most. Similarly, Cutler (2007) finds no statistically significant effect of revascularization procedures on cumulative mortality three years after the 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.

One explanation for the differences between these findings might be that our analysis is based on a more recent dataset. Changes in medical practice and technological advances in AMI treatments in the previous decades may fortify the benefits of invasive health care. For example, the share of patients receiving PTCA procedures within 90 days after the heart attack is 5.3 % in McClellan et al. (1994) compared to 42.8 % in our dataset. More importantly, our identification strategy is based on the effect of an admission to a PCI hospital and not of medical procedures per se. PCI hospitals might improve the chance of survival because of combined treatment possibilities and skills of specialized hospital staff. In other words, the skills and knowledge of cardiologists might improve primary treatment, quality of care, and patients' mortality outcomes independently from the actual medical procedures.

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 admitted to hospitals without cath labs. De Luca et al. (2008) show 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 the 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 data set.

A limitation of our study is that we only consider patients who survived until hospital admission. Individuals who die on the way to the hospital affect our results to an unknown extent. If more individuals with severe heart attacks die on the way to the 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. [5]

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 the heart attack treatment is also more likely to be chosen for subsequent unrelated treatments. 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 further diseases.

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 general-

[5]See Advic (2014), for instance, who explores the role of distance to emergency care using data on in-hospital and out-of-hospital deaths.

izability 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. However, the strong association between distance and hospital choice seen in the first-stage estimations suggests that the results are relevant for a broad class of patients.

6 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 find 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 show that a patient's geographic location affects their access to invasive heart attack treatments and therefore their chance of survival. The results indicate that giving more heart attack patients immediate access to catheterization laboratories would be beneficial. This could be achieved by increasing the number of laboratories or the number of direct admissions to existing PCI hospitals. However, in practice, a reorganization of health care would need to take capacity constraints and potential volume-outcome relationships into account.

The available data on hospital costs is 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.

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7 Tables and Figures

Table 1: Summary Statistics by Hospital Type and Differential Distance

	Full sample	Initial admission to PCI Hospital			Differential distance		
	(1)	(2) No	(3) Yes	(4) p-Value[b]	(5) Below median	(6) Above median	(7) p-Value[b]
Demographics & health proxies[a]							
Age	70.2	72.6	68.1	0.000	69.2	71.2	0.000
Female (%)	41.7	45.3	38.5	0.000	39.4	44.0	0.001
Past exp. on medical attendance	1,411.2	1,448.1	1,378.2	0.157	1,422.9	1,399.5	0.635
Past exp. on medication	2,270.4	2,397.9	2,156.6	0.009	2,335.9	2,204.9	0.156
Previous cardiovascular diseases (%)	28.6	30.5	27.0	0.007	28.4	28.8	0.787
Distances (min)							
Next hospital	12.6	13.1	12.2	0.000	12.4	12.9	0.027
Next PCI hospital	27.4	37.9	18.1	0.000	13.8	41.1	0.000
Differential distance	14.8	24.7	5.9	0.000	1.4	28.2	0.000
Next ambulance station	6.1	6.6	5.7	0.000	5.5	6.8	0.000
Actual driving time	17.0	14.8	18.9	0.000	15.0	19.0	0.000
Admission & treatments within one year (%)							
Initial admisson to PCI hospital	52.8	0.0	100.0	.	84.9	20.7	0.000
Coronary catheterization	75.3	59.7	87.6	0.000	82.1	68.1	0.000
PTCA	43.6	28.1	57.4	0.000	51.2	35.9	0.000
Stenting	47.4	30.2	62.7	0.000	56.3	38.5	0.000
Outcome variables							
Mortality (three years)	33.9	43.1	25.7	0.000	29.9	37.9	0.000
Inpatient costs (two years)	18,007.1	17,228.6	18,702.3	0.003	18,359.2	17,654.7	0.156
Outpatient costs (two years)	3,606.6	3,284.2	3,894.5	0.000	3,781.1	3,432.0	0.002
N	4,920	2,289	2,631		2,461	2,459	

Notes: [a] The health proxies capture expenditures and hospitalization rates owing to previous cardiovascular diseases within the last three years before the infarction. [b] The p-value is derived from a t-test for the difference between the two means. Expenditures are expressed in 2010 Euros.

Table 2: Effect of Distance on Admission to PCI Hospital (IV 1^{st} Stage)

	(1)	(2)	(3)
Differential distance	-0.020***		
	(0.000)		
Above median DDist		-0.675***	
		(0.010)	
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***	-0.003***	-0.003***
	(0.000)	(0.000)	(0.000)
Female	0.012	0.017	0.020*
	(0.012)	(0.011)	(0.010)
Past exp. on medical attendance	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)
Past exp. on medication	-0.000	-0.000*	-0.000*
	(0.000)	(0.000)	(0.000)
Previous cardiovascular diseases	-0.010	-0.010	-0.008
	(0.012)	(0.012)	(0.011)
Next ambulance station	-0.012***	-0.007***	-0.002
	(0.002)	(0.002)	(0.001)
Actual driving time	0.010***	0.012***	0.013***
	(0.001)	(0.001)	(0.001)
AMI in 2006	0.029*	0.024	0.021
	(0.016)	(0.015)	(0.014)
AMI in 2007	0.089***	0.085***	0.085***
	(0.015)	(0.014)	(0.013)
AMI in 2008	0.090***	0.087***	0.085***
	(0.015)	(0.014)	(0.013)
N	4,920	4,920	4,920
Partial R^2	0.402	0.466	0.536
Cragg-Donald F statistic	3,304	4,277	707

Notes: This table summarizes the first-stage relationships. Column 1 uses differential distance as a single scalar variable, while column 2 uses a dummy variable that takes the value 1, if patient's differential distance lies above the population median. Column 3 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, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 3: Effects on Mortality and Costs (IV 2^{nd} Stage)

	Mortality		Inpatient costs		Outpatient costs	
	(1) Mean	(2) Estimate	(3) Mean	(4) Estimate	(5) Mean	(6) Estimate
1 day	0.0327	-0.0199***				
		(0.00736)				
7 days	0.113	-0.0515***	6,490.4	430.3***		
		(0.0129)		(160.7)		
30 days	0.171	-0.0881***	9,716.2	-421.3		
		(0.0150)		(289.2)		
90 days	0.205	-0.106***	11,225.6	-815.1**	670.1	-20.63
		(0.0156)		(380.8)		(27.55)
182 days	0.228	-0.0969***	12,479.7	-640.0	1,186.4	34.69
		(0.0160)		(445.4)		(50.27)
1 year	0.260	-0.0986***	14,655.8	-255.8	2,100.0	153.1*
		(0.0164)		(540.7)		(87.35)
1.5 years	0.283	-0.0938***	16,332.0	238.1	2,879.1	283.9**
		(0.0166)		(618.0)		(119.5)
2 years	0.303	-0.0947***	18,007.1	438.3	3,606.6	425.9***
		(0.0167)		(695.8)		(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, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 4: Effects on Mortality and Costs using OLS

	(1) Mortality	(2) Inpatient costs	(3) Outpatient costs
1 day	-.0212***		
	(.00527)		
7 days	-.0625***	1,091***	
	(.00947)	(121)	
30 days	-.0933***	183	
	(.011)	(215)	
90 days	-.105***	-140	33.8*
	(.0116)	(283)	(19.8)
182 days	-.104***	-21	97.9***
	(.0119)	(337)	(35.3)
1 year	-.107***	445	261***
	(.0122)	(410)	(63)
1.5 years	-.105***	839*	395***
	(.0123)	(464)	(88.5)
2 years	-.107***	1,037**	526***
	(.0124)	(525)	(113)
3 years	-.105***		
	(.0126)		
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. 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, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 5: Effects on Mortality and Costs by Age of Patients (IV 2^{nd} Stage)

	Younger than 65		Older than 65	
	(1) Mean	(2) Estimate	(3) Mean	(4) Estimate
Mortality				
1 day	0.024	-0.013	0.037	-0.023***
		(0.012)		(0.009)
7 days	0.050	-0.040**	0.145	-0.055***
		(0.017)		(0.017)
30 days	0.067	-0.048**	0.222	-0.103***
		(0.019)		(0.020)
90 days	0.073	-0.054***	0.269	-0.125***
		(0.019)		(0.021)
182 days	0.080	-0.055***	0.301	-0.112***
		(0.020)		(0.021)
1 year	0.088	-0.064***	0.344	-0.108***
		(0.021)		(0.022)
1.5 years	0.091	-0.068***	0.377	-0.098***
		(0.021)		(0.022)
2 years	0.094	-0.074***	0.406	-0.096***
		(0.021)		(0.022)
3 years	0.112	-0.067***	0.451	-0.100***
		(0.023)		(0.022)
Inpatient costs				
7 days	8,458.1	-352.1	5,523.5	711.4***
		(326.5)		(178.8)
30 days	11,044.1	-1,518.2***	9,063.7	7.2
		(542.9)		(335.1)
90 days	12,240.0	-2,134.7***	10,727.1	-308.7
		(714.2)		(444.4)
182 days	13,314.5	-2,483.1***	12,069.5	102.0
		(820.2)		(522.0)
1 year	15,280.8	-2,592.4***	14,348.8	696.5
		(968.6)		(644.0)
1.5 years	16,573.0	-2,749.6**	16,213.6	1,478.0**
		(1,083.5)		(740.3)
2 years	18,031.9	-2,410.4**	17,994.9	1,630.3*
		(1,194.3)		(839.8)
Outpatient costs				
90 days	692.6	-145.9***	659.1	30.5
		(48.2)		(31.9)
182 days	1,247.8	-133.3	1,156.2	104.8*
		(88.2)		(57.3)
1 year	2,240.5	-152.6	2,031.0	285.6***
		(154.0)		(99.6)
1.5 years	3,080.5	-155.9	2,780.1	473.1***
		(198.7)		(141.6)
2 years	3,888.7	-26.6	3,468.0	613.4***
		(244.5)		(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 and 3, 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, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 6: Effects on Mortality and Costs by Sex of Patients (IV 2^{nd} Stage)

	Female		Male	
	(1) Mean	(2) Estimate	(3) Mean	(4) Estimate
Mortality				
1 day	0.036	-0.021**	0.031	-0.020*
		(0.010)		(0.011)
7 days	0.139	-0.056***	0.095	-0.048***
		(0.020)		(0.017)
30 days	0.211	-0.096***	0.143	-0.082***
		(0.023)		(0.020)
90 days	0.252	-0.118***	0.171	-0.096***
		(0.024)		(0.020)
182 days	0.281	-0.106***	0.191	-0.089***
		(0.025)		(0.021)
1 year	0.317	-0.107***	0.219	-0.093***
		(0.025)		(0.022)
1.5 years	0.346	-0.101***	0.238	-0.090***
		(0.025)		(0.022)
2 years	0.370	-0.102***	0.255	-0.091***
		(0.025)		(0.022)
3 years	0.411	-0.116***	0.288	-0.080***
		(0.025)		(0.023)
Inpatient costs				
7 days	5,521.6	549.1***	7,182.9	342.1
		(203.3)		(241.9)
30 days	8,829.4	-222.6	10,350.2	-597.8
		(367.1)		(434.3)
90 days	10,164.9	-693.8	11,983.9	-951.2
		(451.5)		(586.5)
182 days	11,376.5	-625.0	13,268.3	-708.7
		(532.8)		(684.8)
1 year	13,374.2	-542.2	15,572.0	-46.8
		(675.9)		(817.4)
1.5 years	15,157.7	-88.5	17,171.5	484.7
		(789.9)		(921.2)
2 years	16,933.6	316.9	18,774.5	531.6
		(908.5)		(1,025.3)
Outpatient costs				
90 days	653.4	7.9	682.1	-49.9
		(34.8)		(41.4)
182 days	1,137.6	79.3	1,221.2	-16.4
		(56.7)		(78.3)
1 year	2,019.8	253.6**	2,157.4	47.7
		(112.2)		(129.8)
1.5 years	2,784.2	445.5***	2,946.9	124.9
		(163.3)		(172.7)
2 years	3,488.7	600.0***	3,690.9	252.9
		(209.2)		(219.8)
N		2,051		2,869

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 and 3, columns 2 and 4 show the 2SLS estimates. Each cell represents the results from a separate regression. All regressions include controls for age, 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, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 7: Effects on Mortality and Costs by Medical History (IV 2^{nd} Stage)

	Symptom-free		Previous heart diseases	
	(1) Mean	(2) Estimate	(3) Mean	(4) Estimate
Mortality				
1 day	0.027	-0.014*	0.046	-0.034**
		(0.008)		(0.016)
7 days	0.091	-0.037***	0.170	-0.089***
		(0.014)		(0.028)
30 days	0.136	-0.067***	0.259	-0.142***
		(0.017)		(0.031)
90 days	0.163	-0.088***	0.310	-0.153***
		(0.017)		(0.033)
182 days	0.183	-0.078***	0.342	-0.146***
		(0.018)		(0.033)
1 year	0.206	-0.077***	0.393	-0.153***
		(0.018)		(0.034)
1.5 years	0.226	-0.079***	0.424	-0.132***
		(0.019)		(0.034)
2 years	0.242	-0.079***	0.456	-0.135***
		(0.019)		(0.034)
3 years	0.271	-0.089***	0.509	-0.114***
		(0.019)		(0.034)
Inpatient costs				
7 days	6,982.2	459.3**	5,263.7	392.9
		(195.8)		(278.2)
30 days	10,170.8	-551.6	8,582.2	-46.3
		(345.6)		(521.0)
90 days	11,566.6	-1,115.6**	10,375.0	-89.0
		(454.1)		(688.2)
182 days	12,665.1	-1,119.8**	12,017.2	492.7
		(523.1)		(837.1)
1 year	14,497.5	-844.9	15,050.9	1,082.9
		(611.7)		(1,094.5)
1.5 years	15,912.1	-612.4	17,379.2	2,208.1*
		(681.8)		(1,307.1)
2 years	17,332.6	-705.3	19,689.5	3,030.6**
		(758.9)		(1,497.7)
Outpatient costs				
90 days	659.6	-77.5***	696.4	119.5**
		(29.9)		(59.7)
182 days	1,156.2	-66.6	1,261.6	283.4**
		(51.3)		(118.2)
1 year	2,051.7	-48.3	2,220.5	633.0***
		(90.7)		(200.5)
1.5 years	2,802.9	5.1	3,069.0	934.2***
		(124.8)		(271.2)
2 years	3,509.7	67.4	3,848.3	1,256.0***
		(162.2)		(338.1)
N		3,512		1,408

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 and 3, 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, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 8: 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***	438.3	425.9***
	(0.0169)	(695.8)	(152.5)
Non-movers *(N=4,093)*	-0.0950***	981.5	542.8***
	(0.0186)	(769.2)	(168.9)
Symptom-free patients *(N=3,512)*	-0.0885***	-705.3	67.45
	(0.0193)	(758.9)	(162.2)
Urban patients *(N=1,350)*	-0.146***	-620.5	748.4***
	(0.0345)	(1,624.2)	(264.8)
PCI hospital within 7 days *(N=4,920)*	-0.166***	775.3	745.0***
	(0.0283)	(1,186.1)	(258.8)
PCI hospital within 30 days *(N=4,920)*	-0.206***	779.2	941.2***
	(0.0345)	(1,472.2)	(320.7)
PCI hospital within 90 days *(N=4,920)*	-0.210***	866.1	951.9***
	(0.0351)	(1,499.4)	(326.2)

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. Robust standard errors are provided in parentheses, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 9: Effects on Days in Hospital (IV 2^{nd} Stage)

	Any Diagnosis		**Diagnosis I**	
	(1) Mean	(2) Estimate	(3) Mean	(4) Estimate
7 days	6.096	0.157**	6.004	0.362***
		(0.067)		(0.070)
30 days	11.122	-1.971***	10.389	-1.295***
		(0.295)		(0.281)
90 days	13.795	-2.294***	11.772	-1.824***
		(0.490)		(0.404)
182 days	16.146	-1.809***	12.777	-1.552***
		(0.635)		(0.470)
365 days	20.217	-1.034	14.388	-1.218**
		(0.866)		(0.575)

Notes: This Table summarizes the effects of patients' admission to PCI hospitals on the number of days spent in hospitals within different points in time after the infarction. Column 1 show average number of days spent in hospitals, column 3 the days spent because of diseases of the circulatory system (ICD-10 codes I00-I99). Columns 2 and 4 show the 2SLS estimates, where 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, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.