Does When You Die Depend on Where You Live? Evidence from Hurricane Katrina*

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Abstract

Hurricane Katrina devastated the Gulf Coast in 2005, displacing over 1 million people. We follow Medicare cohorts over time and space to estimate the hurricane's long-run mortality effects on elderly and disabled victims who were initially living in New Orleans. We estimate that the hurricane *reduced* long-run mortality: inclusive of the initial shock, victims are 1.75 percentage points more likely to be alive eight years after the storm. Two patterns indicate that migration to lower-mortality regions drives this mortality reduction. First, victims in flooded neighborhoods migrated at much higher rates and experienced greater mortality reductions. Second, although migrants who moved to regions with lower mortality look similar at baseline to those who moved to higher-mortality regions, migrants' subsequent mortality is 0.98–1.12 percentage points lower for each percentage-point reduction in local mortality. By contrast, movers' subsequent mortality is unrelated to local Medicare spending. On average, Hurricane Katrina victims relocated to lower-mortality areas, which explains 56–79 percent of the overall mortality reductions we find.

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1 Introduction

Hurricane Katrina, the costliest tropical cyclone ever to strike the United States mainland, devastated the Gulf Coast in 2005. The immediate impact of the storm killed nearly 2,000 individuals and displaced more than 1 million residents, resulting in the largest migration of U.S. residents since the Dust Bowl in the 1930s (Nigg, Barnshaw and Torres, 2006). While prior studies have evaluated how demographic and economic outcomes evolve in the aftermath of environmental catastrophes (e.g., Hornbeck, 2012; Hornbeck and Naidu, 2014; Nakamura, Sigurdsson and Steinsson, 2017), little is known about the effects of such events on long-run health and longevity, which represent considerable economic value (Murphy and Topel, 2006). In particular, when a disaster displaces large segments of the population from their homes, the regions to which people move may play an important role in shaping long-term health outcomes. Thus, understanding how health outcomes evolved in the wake of Hurricane Katrina provides insight into both the economic impact of this historic event and also the ways in which local conditions affect population health (e.g., Fisher et al., 2003*a*,*b*; Chetty et al., 2016).

We study the short- and long-run mortality impacts of Hurricane Katrina on one of the most vulnerable subsets of the population: the elderly and long-term disabled of New Orleans. Roughly half of those killed by the immediate impact of Hurricane Katrina were over the age of 75 (Brunkard, Namulanda and Ratard, 2008), and about one-fifth of the displaced population were elderly individuals on Medicare (Super and Biles, 2005). While the immediate losses and disruption caused by the disaster may have scarred the health of this vulnerable group, widespread migration out of New Orleans to regions with better economic and health outcomes may have generated health benefits. Yet, quantifying the long-run health impacts of events like Hurricane Katrina has proven difficult, due largely to lack of data that capture pre-disaster outcomes and track individuals post-disaster with minimal attrition.

To overcome this challenge, we use administrative Medicare data, which cover the vast majority of U.S. elderly and long-term disabled over the period 1992–2013. Importantly, these data allow us to follow individuals over time and space and provide exact dates of death. We identify cohorts of Medicare beneficiaries living in New Orleans prior to Hurricane Katrina and track their mobility and mortality rates for eight years after the storm (2005–2013). To identify how outcomes would have evolved in the absence of Hurricane Katrina, we examine mobility and mortality for comparable cohorts of Medicare beneficiaries initially residing in 10 cities that were not directly affected by the hurricane (Deryugina, Kawano and Levitt, 2018). To validate this control group choice, we show that mortality trends in the New Orleans and control city cohorts were very similar prior to Hurricane Katrina going back as far as 1992 (the earliest year for which we have data). We then estimate the causal effects of the hurricane by comparing how the New Orleans cohort's post-hurricane outcomes changed relative to those of the comparison cohort.[1]

We find that Hurricane Katrina caused a substantial short-run increase in the mortality rate of the Medicare cohort who resided in New Orleans in early 2005. Among this group, mortality increased by over half a percentage point in 2005, which is over 10 percent of the cohort's mortality that year. Most of these excess deaths occurred within a week of the hurricane's landfall, and this immediate effect quickly dissipates over the next two weeks. The lack of persistently elevated mortality for more than a few weeks after the hurricane is striking because parts of New Orleans remained uninhabitable for months after the storm and all major New Orleans hospitals were closed for at least 28 days, critically reducing access to normal health care options for people who remained in the city.

We then assess the effects of Hurricane Katrina on annual mortality and population migration. In contrast to the short-run mortality increase observed in 2005, we find that Hurricane Katrina led to sustained *reductions* in mortality from 2006 through 2013. This long-run mortality decline is not explained by short-run mortality displacement, or "harvesting": inclusive of the initial increase in mortality, we estimate that Hurricane Katrina

[1]Our central findings are robust to using the rest of the U.S. as the comparison cohort.

increased the probability of surviving eight years past the storm (i.e., through 2013) by 1.75 percentage points, a 2.9 percent increase relative to the overall eight-year survival rate of those residing in New Orleans in early 2005. We also find that the hurricane led to a massive and lasting dislocation of the elderly and long-term disabled, consistent with prior evidence pertaining to the demographic and economic effects of the hurricane (Deryugina, Kawano and Levitt, 2018). Medicare beneficiaries living in New Orleans in early 2005 were about 40 percentage points more likely to leave their city of residence than members of the control group, and over half of those still alive had not returned as of 2013.

We consider two possible (and not mutually exclusive) explanations for the long-run mortality decline: improvements in the New Orleans health care system and relocation of the elderly to areas with better health outcomes. Two empirical patterns suggest that the long-run mortality decline was unrelated to improvements in the New Orleans health care system. First, hospital capacity in New Orleans fell sharply in the aftermath of the hurricane and its recovery growth did not keep pace with the rebound in population. Second, the New Orleans health care infrastructure was rebuilt gradually. However, when we consider the 2006–2013 mortality of those who remain in the city, we see a flat pattern rather than gradual mortality improvements. Thus, any mortality improvements for those who stayed would either have to have occurred in or before 2006 or be exactly offset by stayers' counterfactual trend in mortality, both of which seem unlikely.

Because New Orleans was one of the highest mortality areas in the country prior to Hurricane Katrina, displaced individuals generally relocated to regions with better health outcomes. To the extent that regional health outcomes reflect place-specific factors such as access to quality health care, the decline in mortality among the Hurricane Katrina victims may have been driven by relocation to areas that are more conducive to survival. Two empirical patterns suggest that this is the case. First, we find that hurricane victims living in parts of New Orleans that flooded experienced greater long-run mortality reductions than those not living in flooded areas. This pattern is difficult to explain, except that individuals living in flooded areas were about twice as likely to be displaced from the city.

Second, we examine the mortality patterns among New Orleans residents who moved between early 2005 and early 2006 (i.e., had left New Orleans after the hurricane). We find that hurricane survivors who moved to low-mortality regions subsequently experienced lower mortality than survivors who moved to high-mortality regions. Specifically, each percentage-point increase in the destination region's mortality rate corresponds to a 0.98–1.12 percentage-point change in the movers' mortality rate. This effect emerges as early as 2006–2007, suggesting it does not arise entirely through slow-moving channels such as lifestyle. The relationship between local and migrant mortality describes the causal effect of place on individual mortality under the assumption that baseline mortality risk among those who move is uncorrelated with mortality rates in the destination region. Supporting this assumption, we find little correlation between destination mortality rates and baseline characteristics of movers, including chronic conditions that are strongly predictive of mortality. In addition, the estimates are highly stable even with rich controls, including pre-existing chronic conditions. We estimate that changes in the local mortality rate experienced by hurricane victims explain 56–79 percent of the long-run mortality decline caused by the hurricane.

To the best of our knowledge, we provide the first controlled estimates of the long-run mortality effects of an environmental disaster on adult victims. By contrast, prior research on disasters and health has been limited largely to looking at birth outcomes and infant health (e.g., Torche, 2011; Currie and Rossin-Slater, 2013; Currie and Schwandt, 2016) or conducted by surveying a subset of the victims.[2] These survey approaches, however, generally suffer from non-random sampling, rarely measure pre-existing outcomes, and usually lack a control group. We are able to overcome these limitations in our setting because our data track the mortality and location of every Medicare-eligible individual. Our main finding—that Hurricane Katrina reduced long-run mortality among the elderly and disabled populations by

[2]See, for example, Armenian, Melkonian and Hovanesian (1998); Sastry and VanLandingham (2009); Rhodes et al. (2010); Adams et al. (2011); Adeola and Picou (2012); Pietrzak et al. (2012).

inducing them to relocate—builds on recent evidence that the hurricane indirectly generated other long-run benefits, including higher earnings among the working-age population (Groen, Kutzbach and Polivka, 2016; Deryugina, Kawano and Levitt, 2018) and improved test scores among displaced students (Sacerdote, 2012).

Our findings add to a growing body of literature in economics that uses migration to identify how local conditions affect individual outcomes. For example, Song et al. (2010) and Finkelstein, Gentzkow and Williams (2016) study Medicare patients who move across regions to identify local determinants of diagnosis rates and medical spending. Outside of a health setting, movers have been used to study how local conditions affect education and earnings (Chetty, Hendren and Katz, 2016; Nakamura, Sigurdsson and Steinsson, 2017; Chyn, 2016; Chetty and Hendren, 2018), income reporting in tax filings (Chetty, Friedman and Saez, 2013), and brand preferences (Bronnenberg, Dubé and Gentzkow, 2012). We contribute to this literature by studying how the long-run mortality outcomes of those displaced by Hurricane Katrina depend on the local mortality rates of the destination region. Our finding that a migrant's individual mortality risk corresponds closely to the destination region's mortality rate suggests that local public health conditions are an important determinant of individual health outcomes, at least for the elderly and disabled populations.

A key question in public health is whether higher-spending regions generate better health outcomes than lower-spending regions. Numerous studies have documented widespread geographic variation in health care spending and have shown that higher-spending regions often have little better or even worse health outcomes than lower-spending regions (Fisher et al., 2003*a*,*b*; Baicker and Chandra, 2004; Sirovich et al., 2006; Skinner, 2011). However, regional spending disparities may partly reflect differences in the baseline health of the resident population. Doyle (2011) and Doyle et al. (2015) address this limitation by analyzing quasi-random assignment of patients to hospitals. Both studies find that patients have better outcomes when treated at higher-spending hospitals. While these analyses focus on the returns to being hospitalized in a high-spending region, the returns to *living* in a high-spending region may differ—for example, higher-quality health systems could reduce the need for hospitalization. In our setting, we find no relationship between a mover's subsequent mortality and local health care spending, suggesting that average returns to living in a high-spending region may be low.

Section 2 provides an overview of Hurricane Katrina and its known impacts on economic outcomes and summarizes the literature on natural disasters and health. Section 3 describes our data and estimation sample and presents summary statistics. Section 4 outlines our research design, and Section 5 presents the results. Section 6 concludes.

2 Setting

2.1 Overview of Hurricane Katrina

Hurricane Katrina struck New Orleans on August 29th, 2005 as a Category 3 hurricane with sustained winds of 140 miles per hour (Federal Emergency Management Agency, 2015). Even prior to landfall, officials realized that there was a danger of the hurricane breaching the levees protecting the city. Those fears proved well-founded: there were numerous levee and floodwall failures in the aftermath of Hurricane Katrina, resulting in widespread flooding in New Orleans and the nearby St. Bernard Parish. As a result of both the direct impact of the hurricane and the levee failures, hundreds of thousands of homes were damaged or destroyed. Parts of the city remained uninhabitable for months after the storm; rebuilding in some areas took years. The National Oceanic and Atmospheric Administration (NOAA) estimates that Hurricane Katrina caused $161 billion in direct damages (2017 dollars), the costliest U.S. natural disaster on record (National Hurricane Center, 2018; NOAA, 2018).

Despite a mandatory evacuation order and an estimated evacuation rate of 80–90 percent (Wolshon, 2006), Hurricane Katrina's official death toll was 1,833, making it the deadliest natural disaster in the United States since 1928 (Beven-II et al., 2008). About half of those killed by the immediate impact of the storm were over the age of 75 (Brunkard, Namulanda and Ratard, 2008), and up to 200,000 of those displaced were elderly individuals on Medicare (Super and Biles, 2005).

Figure 1 shows the extent of flooding in New Orleans in the immediate aftermath of Hurricane Katrina. Flood levels of at least 6 feet, indicated by green and blue hues, were not uncommon. Yellow tones correspond to 4–6 feet of water and likewise can be seen in many parts of the city. As the flood waters receded, they left behind uninhabitable homes and in some cases created the risk of harmful mold growth. Officially, individuals in 17 out of 19 New Orleans ZIP codes were prohibited from returning to their homes until at least December 9, 2005 (Federal Emergency Management Agency, 2005). On that date, the Federal Emergency Management Agency (FEMA) allowed residents of 10 New Orleans ZIP codes to return to their homes and stay there ("look-and-stay" ZIP codes); residents in seven other New Orleans ZIP codes could return to their homes during the day but could not spend the night there ("look-and-leave" ZIP codes). Storm victims who could not find suitable living arrangements were given funds to pay for a hotel or apartment or the opportunity to live in specially provided trailers.

The aid response to Hurricane Katrina was considerable. Excluding flood insurance payments and loans, Louisiana received about $50 billion from the federal government (in nominal dollars).[3] The majority of these funds were earmarked for rebuilding infrastructure rather than given directly to victims. Much of the latter type of aid came through FEMA's Individual Assistance program, which paid out about $2.9 billion to New Orleans residents for temporary housing, repairs, rebuilding, and other disaster-related expenses. In 2006–2013, New Orleans homeowners also received about $4.3 billion through the "Road Home" program to rebuild or sell their homes. Finally, FEMA also paid about $320 million in Disaster Unemployment Assistance in the state of Louisiana. Deryugina, Kawano and Levitt (2018) calculate that a reasonable upper bound on the aid spending for the city of New Orleans is $125,000 per capita, of which about $17,000 consisted of direct transfers to individuals.

[3] See Deryugina, Kawano and Levitt (2018) for a detailed description of Hurricane Katrina aid components.

2.2 Health and health care in New Orleans

Hurricane Katrina devastated the health care infrastructure in New Orleans (Rowland, 2007). All nine large hospitals operating there in 2005 were closed in the immediate aftermath of the storm due to damage and/or flooding. One hospital (Touro Infirmary) reopened 28 days later, a second (Tulane Medical Center) reopened in early 2006, and two more (Memorial Medical Center and University Hospital/Interim LSU Hospital) reopened in late 2006. The remaining large hospitals were closed for years or never reopened. In 2015, a new hospital (University Medical Center) was opened, replacing University Hospital and Charity Hospital. Although smaller inpatient facilities and several hospitals in nearby cities continued operating, the closure of so many hospitals reduced health care access for many individuals. Many health care professionals left the city after the storm, likely disrupting access to care across other traditional health care facilities as well.

By 2008, the health care infrastructure in the New Orleans area had begun to recover, although problems persisted (DeSalvo, Sachs and Hamm, 2008). The city had returned to 70 percent of its pre-Katrina population and was continuing to grow, increasing demand for medical services. At the same time, many hospitals faced staffing and financial problems, resulting in long wait times. Moreover, the permanent closure of Charity Hospital, which served a large number of the uninsured in New Orleans, forced many of the uninsured to seek care in emergency rooms, placing further strain on hospital resources.

DeSalvo, Sachs and Hamm (2008) point out that during this time the New Orleans area featured a higher-than-average number of beds per capita prior to Katrina, and that its post-Katrina ratio was close to the national average. Similarly, although the number of physicians dropped significantly post-Katrina, so did the population, and as a result New Orleans had more physicians per capita than the national average. Moreover, community-based primary care clinics funded by various sources sprung up after the hurricane, potentially filling the void left by the closure and shrinkage of hospitals.

To assess the state of the health care system in New Orleans quantitatively, we obtained annual hospital-level data on the total number of hospital beds and the number of hospital employees from Centers for Medicare and Medicaid Services. Hospitals and other inpatient facilities that receive Medicare reimbursements are required to provide this information annually.[4] Figure 2 shows the total number of hospital beds and hospital employees in New Orleans for 1997–2010 (red lines). For comparison, we also show the total number of hospital beds averaged across the 10 comparison cities we use later in the estimation framework (black lines). The annual population of New Orleans, as reported by the Bureau of Economic Analysis, is shown by the dashed blue lines.

Figure 2 shows a large and immediate drop in hospital capacity in New Orleans following Hurricane Katrina. Between 2004 and 2005, the number of reported beds fell by over a thousand, a drop of about 30 percent. Reported bed capacity continued dropping to a low point of slightly more than 1,000 beds in 2007, about 70 percent lower than the number of beds in 2004. The number of beds rose only slightly for 2008–2010, indicating that New Orleans sustained long-run reductions in inpatient care capacity. The number of hospital employees in New Orleans follows a similar trajectory: there is an approximately 30 percent drop between 2004 and 2005, followed by another large drop between 2005 and 2006. In 2006, New Orleans inpatient facilities employed 5,076 people, about 33 percent of the 15,249 who worked there in 2004. Meanwhile, the number of hospital beds and employees in the control cities was very stable, demonstrating that the patterns we see are due largely to Hurricane Katrina rather than any national shocks.

Corresponding to the decline in hospital capacity, the bottom two subfigures of Figure 2 show a precipitous decline in hospital utilization. In 2004–2005, the number of hospital discharges in New Orleans nearly halved, and in 2006 the number of discharges was about two-thirds lower than in 2004.[5] Some of this decline in hospital utilization may reflect

[4]At the end of 2004, there were 22 such facilities in the city of New Orleans.

[5]We observe a similar pattern for the total number of inpatient Medicare days and other hospitalization metrics not shown here. We also examined the hospital data for parishes that border New Orleans (Jefferson, St. Bernard, and St. Tammany) to see if there were any spillovers into their health care systems. The number of hospital beds in the nearby parishes did not increase, suggesting that health care systems in these locations did not increase capacity to offset the loss in New Orleans. The number of hospital employees in neighboring

decreasing demand for health care in New Orleans as the resident population fell sharply following Hurricane Katrina, from 494,000 in July of 2005 to 230,000 in July of 2006. However, with the exception of hospital employees, the rate at which the population recovered exceeds the recovery rate of the hospital metrics shown in Figure 2, suggesting that the health care system in New Orleans may have experienced persistently elevated strain in the post-Katrina years.

Katrina's large-scale destruction of homes, health care capacity, and general infrastructure likely created a very harsh environment for the elderly and long-term disabled, who have, on average, a higher incidence of chronic conditions and less robust physical and mental capabilities. These groups are thought to be more vulnerable to environmental catastrophes than the general population, and emergency managers are often urged to pay special attention to their needs (e.g. Morrow, 1999; Fernandez et al., 2002). Mensah et al. (2005) summarize the many additional challenges that chronic conditions pose during natural disasters, most of which are self-evident. For example, following Hurricane Charley in 2004, the Centers for Disease Control and Prevention (2004) found that many older adults experienced disruptions in treatment for pre-existing conditions, which could have adversely affected their health. In the case of Hurricane Katrina, the evacuees as a whole were not a healthy group: a survey of victims in Houston shelters revealed that 40 percent had at least one chronic condition and a similar fraction reported needing prescription medication (Brodie et al., 2006).

There are several other reasons to expect that Hurricane Katrina led to persistently worse health outcomes among elderly and disabled victims. The elderly are thought to be particularly prone to "relocation stress syndrome," where individuals' physical and mental health suffers as a result of being transferred from one environment to another (Barnhouse, Brugler and Harkulich, 1992). Natural disasters are also thought to lead to a deterioration in mental health (Freedy, Kilpatrick and Resnick, 1993; Norris et al., 2002; Norris, Friedman and Watson, 2002), including increased rates of post-traumatic stress disorder (Galea, Nandi

parishes was also stable.

and Vlahov, 2005; Neria, Nandi and Galea, 2008). Even in the absence of poorer mental health, the disruption and displacement caused by the storm may have made it more difficult for patients to get appropriate health care. While several studies have found deteriorated mental and physical health following Hurricane Katrina, these studies generally lack a control group to account for secular trends, most lack outcomes measured pre-Katrina, and almost all have focused on short-run effects (e.g. Brodie et al., 2006; Kessler et al., 2008; Sastry and VanLandingham, 2009; Sastry and Gregory, 2013).[6]

While there are reasons to expect that Katrina led to persistent health declines, it is also possible that disaster aid and victims' responses may have led to a quick recovery. In particular, the significant population displacement brought about by Hurricane Katrina could have improved long-run survival if victims relocated to areas that are more conducive to good health. After we estimate the aggregate effects of Hurricane Katrina on long-run mortality among the elderly and disabled, we return to consider the role of migration and place in shaping the recovery of the hurricane victims.

3 Data and Estimation Sample

3.1 Data

The primary data for our analysis are Medicare administrative records for the universe of Medicare beneficiaries over the period 1992–2013. As of 2010, over 97 percent of the U.S. population aged 65 and older was enrolled in Medicare, making these data the most comprehensive record of elderly health in the United States. Medicare also covers non-elderly, long-term disabled individuals who have received Social Security Disability benefits for 24 months or have either End-Stage Renal Disease or Amyotropic Lateral Sclerosis.

In addition to their comprehensive coverage of the U.S. elderly and disabled populations,

[6] In the only longer-run study of which we are aware, Paxson et al. (2012) follow 532 low-income mothers who lived in New Orleans during Hurricane Katrina, finding long-lasting increases in post-traumatic stress symptoms and psychological distress.

Medicare data offer two features essential for studying health dynamics in our setting. First, Medicare records the ZIP code of residence for each beneficiary over time, allowing us to identify individuals living in a particular place at a certain time (e.g., New Orleans residents prior to Hurricane Katrina) and to track those individuals over time without attrition even if they move. Second, Medicare records each individual's exact date of death based on Social Security Administration (SSA) records.

Our analysis relies on three sets of annually recorded Medicare variables. The first set of variables comes from Medicare eligibility records and contains beneficiary identifiers and demographic information obtained from the SSA record system, including the 9-digit ZIP code of residence, race, sex, date of birth, date of death, and an end-stage renal disease indicator. The beneficiary ZIP code of residence is based on beneficiary mailing addresses where SSA benefits and official communication are mailed. For 1999 and 2006–2013, ZIP codes correspond to the mailing address on record at the end of the calendar year. In all other years, ZIP codes correspond to the address on record as of March 31 of the following year. Thus, the 2004 ZIP code reflects a beneficiary's address as of March 31, 2005, about five months prior to Hurricane Katrina. The 2005 ZIP code reflects a beneficiary's address as of March 31, 2006, about seven months after the hurricane.

The second set of Medicare variables we use measure health care spending based on fee-for-service claims. For each beneficiary, we calculate total annual spending as the sum of payments due to institutional or non-institutional providers (e.g. physicians), excluding payments for drugs covered under Medicare Part D. Because spending is based on claims, we do not observe spending for individuals enrolled in Medicare Advantage plans (less than 20 percent of our sample). In these cases, Medicare makes fixed payments to private providers who then handle any claims these individuals have.

The third set of Medicare variables we use include 27 indicators for common chronic conditions inferred from medical claim histories. Measured conditions include heart attack, stroke, hypertension, diabetes, cancer, Alzheimer's disease, and depression. We group the 27 individual conditions into eight broad categories: heart disease and stroke; respiratory disease; blood and kidney disease; cancer; diabetes; musculoskeletal diseases; dementia (including Alzheimer's disease); and "other" (cataracts, glaucoma, hypothyrodism, benign prostatic hyperplasia, and depression). Because the chronic condition indicators are based on claims, they are available only for individuals who are continuously enrolled in fee-for-service Medicare over a condition-specific look-back window (usually two years). The Online Appendix provides more detail on how chronic conditions are determined and classified.

Our analysis relies on identifying the region in which a Medicare beneficiary lives, both before and after Hurricane Katrina. Our primary units of geography for this purpose are Hospital Service Areas (HSAs), as defined by the Dartmouth Atlas to partition U.S. ZIP codes into 3,436 local health care markets for hospital care (Wennberg, 1996). In some cases, we aggregate geography even further to Hospital Referral Regions (HRRs), which combine HSAs into 306 regions. We refer to an HSA by the primary city located in the HSA, even though the boundary of the HSA may extend beyond the city's political boundary. For example, the New Orleans HSA is very similar to the city of New Orleans, although it also includes several sparsely populated areas located to the south of the city. We use the terms "city" and "HSA" interchangeably when referring to geographies measured in our data.

Finally, we match Medicare beneficiaries who lived in New Orleans prior to Hurricane Katrina to select neighborhood characteristics based on their 9-digit ZIP code of residence. Specifically, we use Hurricane Katrina flood depth data from FEMA, aggregated to the 9-digit ZIP code level, as well as Census block-group-level income data from the 2000 Census, interpolated to the 9-digit ZIP code.

3.2 Estimation sample and summary statistics

Although Hurricane Katrina generated a credibly exogenous shock to New Orleans residents, identifying the causal effect of the storm on short- and long-run mortality requires estimating counterfactual mortality outcomes among the storm victims. Our primary approach to estimating counterfactual outcomes relies on examining how outcomes evolve among groups of Medicare beneficiaries initially residing in one of the 10 control cities identified by Deryugina, Kawano and Levitt (2018) (see Figure 3). Because individuals may move or die over time, the cohort of individuals who were alive and eligible for Medicare in 2004 (the "2004 cohort") is the most relevant cohort for assessing the impact of the hurricane among Medicare residents of New Orleans. Thus, individuals in the 2004 cohort initially residing in either New Orleans or one of the 10 control cities form the basis for our preferred estimates of the long-run effects of Hurricane Katrina.

Table 1 shows the summary statistics for the 2004 New Orleans/control city cohorts, starting with time-invariant variables (Panel A). The sample contains almost 1.3 million individuals, of whom over 80,000 initially live in New Orleans. About 35 percent of the sample is black, 42 percent is male, and the average age in 2004 is 71. Eighty-two percent of the individuals are 65 and older, while 18 percent qualify for Medicare because of a disability.

On average, 5.2 percent of the whole sample moved between early 2005 and early 2006, as defined by a change in the HSA of residence reported in the 2004 and 2005 Beneficiary Summary Files (the smaller number of observations reflects deaths that happen during this time). However, in the New Orleans sample, over 44 percent of those surviving until early 2006 left the city, reflecting the massive displacement created by Katrina. The 9-digit ZIP code of the average New Orleans beneficiary experienced almost 2.2 feet of flooding during the storm, with a standard deviation of 2.7 feet.

Panel B of Table 1 shows summary statistics for the main panel variables (measured at the individual-year level) we utilize in our analysis. On average over the sample period of 2004–2013, about 5.5 percent of individuals died each year, and 80 percent were enrolled in fee-for-service Medicare (for both calculations, we drop beneficiaries who were not alive at the beginning of that year). Finally, the annual Medicare spending for the average fee-for-service beneficiary was $11,913 with a standard deviation of $25,582.

A limitation of using the 2004 cohort is that it does not enable us to assess annual mortality trends prior to Hurricane Katrina. To do so, we consider cohorts based on Medicare eligibility and residence in an earlier year. Figure 4 plots raw annual death rates for the 1999 Medicare cohort, by initial city of residence. For example, the 2005 mortality rate for New Orleans is calculated as the 2005 mortality rate among Medicare beneficiaries in the 1999 cohort who survived past 2004 and initially lived in New Orleans, regardless of where they lived in 2005. Mortality rates for the New Orleans cohort are plotted in red, and mortality rates for 1999 cohorts from each of the 10 control cities are plotted in blue. To see how New Orleans compares with the rest of the United States, the light gray lines plot mortality rates for the cohorts initially residing in each HRR except the one containing New Orleans.

The raw data plotted in Figure 4 reveal one of the key findings we formally estimate below. Prior to Hurricane Katrina, the New Orleans cohort had one of the highest regional mortality rates in the United States. Cohorts from the 10 control cities also have high mortality rates, falling largely in the top half of the national distribution and trending similarly to the New Orleans cohort. In 2005, the year of Hurricane Katrina, the New Orleans cohort experienced a higher mortality rate than any other regional cohort in the nation. Yet, remarkably, mortality among the New Orleans cohort falls to the middle of the mortality rate distribution in 2006 and remains there through 2013, the latest year for which we have data. This pattern suggests that Hurricane Katrina led to a long-run decline in mortality among the New Orleans cohort. As we estimate formally below, these decreases are so large that they cannot be explained by mortality displacement, or "harvesting," where Hurricane Katrina killed individuals who would have died soon even in the absence of the hurricane, leading to a mechanical decline in future mortality rates.

4 Research Design

4.1 Short-run effects of Hurricane Katrina

We first estimate the short-run effects of Hurricane Katrina on the mortality of the New Orleans Medicare population using a difference-in-differences event study analysis. We begin by identifying the cohort of all individuals who were alive and eligible for Medicare in 2004 and who resided in New Orleans (the New Orleans cohort) or one of the control cities (control city cohorts) as of March 31, 2005. We define event week $t = 0$ as the first 7-day period of 2005 that includes August 29, the day Hurricane Katrina struck New Orleans. We refer to event week $t = 0$ as the week of Hurricane Katrina.[7] We then construct a panel data set for this cohort with observations for each individual i and week t over the 100-week period beginning 35 weeks prior to and ending 64 weeks after Hurricane Katrina. Using these data, we estimate the following difference-in-differences regression:

$$Died_{it} = \sum_{\substack{\tau=-35,\\ \tau\neq-1}}^{64} \beta_t \mathbf{1}(t=\tau) \times NOLA_i + [week\ FE] + [base\ ZIP5\ FE] + \varepsilon_{it}, \tag{1}$$

where the outcome, $Died_{it}$, equals zero if individual i survived through week t, equals one if he or she died that week, and is missing if the individual died prior to week t. We define a "treatment" indicator $NOLA_i$ as equal to one if individual i lived in New Orleans at baseline and equal to zero otherwise. Fixed effects for the 5-digit ZIP code of an individual's residence in the base year capture baseline geographic differences in mortality rates, while event-week fixed effects capture how mortality evolves relative to the reference week ($t = -1$). Standard errors are clustered by baseline ZIP code.

The key parameters of interest in equation (1) are β_t, the coefficients on the interaction of event-week indicators with the New Orleans indicator $NOLA_i$. Thus, β_t nonparametrically captures how changes in the New Orleans cohort's mortality between the reference week

[7] January 1st, 2005 was a Saturday. Thus, the week of Hurricane Katrina begins on Saturday, August 27.

and week t differs from the change in the control city cohorts' mortality rates over the same period. β_t identifies the causal effect of Hurricane Katrina on the New Orleans cohort's mortality rate under the assumption that the mortality rate among the New Orleans cohort would have paralleled the control city cohorts' mortality rates in the absence of the hurricane. The plausibility of this assumption can be assessed by testing for parallel trends in the weeks prior to the storm (i.e. $\beta_t = 0$ for $t < 0$), which motivates the inclusion of the 35 pre-event weeks when estimating equation (1).

4.2 Long-run effects of Hurricane Katrina

Annual Mortality and Mobility We estimate the long-run effects of Hurricane Katrina on mortality and relocation using a cohort approach very similar to our short-run weekly analysis, except that we define the time dimension of the panel data to be annual and extend our period of analysis to cover up to eight years after 2005, the year of Hurricane Katrina. Specifically, we include observations for each individual i and year t starting from the base year used to define the cohort (1992, 1999, or 2004) through 2013, omitting any observations after the year in which the individual dies. We then estimate

$$Y_{it} = \sum_{\substack{\tau = Base\,Year, \\ \tau \neq 2004}}^{2013} \beta_t \mathbf{1}(t = \tau) \times NOLA_i + [year\ FE] + [base\ ZIP5\ FE] + \varepsilon_{it}, \tag{2}$$

where the outcome Y_{it} is a measure of either mortality or residing outside one's baseline city of residence. To capture mortality, we define $Died_{it}$ as equal to zero if individual i survived through year t and equal to one if he or she died that year. To capture relocation, we define $LeftHSA_{it}$ as equal to zero if the individual resided in their baseline HSA in year t and equal to one if he or she was alive and living in another HSA. All other variables are defined as in equation (1) except that the time period t reflects years instead of weeks and we thus include year fixed effects instead of week fixed effects. Standard errors are again clustered by baseline ZIP code. We use 2004, the year prior to Hurricane Katrina, as the reference period so that β_t captures how the change in the New Orleans cohort's mortality between 2004 and year t differs from changes in the control city cohorts' mortality rates over the same period.

As with the weekly analysis, β_t identifies the causal effect of Hurricane Katrina on the New Orleans cohort's mortality rate in a given year under the assumption that the New Orleans cohort's mortality would have paralleled the control city cohorts' mortality rates in the absence of the hurricane. The plausibility of this assumption can be assessed by testing for parallel trends in the years prior to the storm (i.e. $\beta_t = 0$ for $t < 2004$), which can be done when estimating equation (2) for cohorts formed in base years prior to 2004.

We estimate equation (2) separately for the 1992, 1999, and 2004 Medicare cohorts. The 1992 and 1999 cohorts allow us to test for pre-trends over a long time horizon, but these cohorts may not adequately capture the experiences of those affected by Hurricane Katrina, as about two-thirds (one-third) of individuals in the 1992 (1999) cohort move away or die before 2005. Furthermore, the elderly in the 1992 (1999) Medicare cohort were at least 77 (70) by the time Hurricane Katrina struck. While we cannot estimate pre-Katrina trends for the 2004 Medicare cohort, that cohort includes the most relevant group of Medicare individuals exposed to the hurricane, including younger elderly. Thus, we use the 2004 Medicare cohort to calculate our preferred estimates of the magnitude of Hurricane Katrina's mortality effect among elderly and disabled victims.

Cumulative Mortality The annual mortality results obtained from equation (2) can be used to calculate the effect of Hurricane Katrina on changes in cumulative mortality for the New Orleans cohort. Specifically, for each post-Katrina year t between 2005 and 2013, the change in cumulative mortality ΔM_t is given by

$$\Delta M_t = \sum_{\tau=2005}^{t} S_\tau \beta_\tau, \tag{3}$$

where β_τ are the annual mortality effects of Hurricane Katrina and S_τ is the empirical fraction of the New Orleans cohort who are alive at the start of 2005 and survive to the start of year

τ. We estimate ΔM_t and its standard error using the estimates $\widehat{\beta}_t$ from equation (2). The term S_τ in equation (3) is a "discount factor" reflecting the impact of a mortality rate change β_τ at time τ on cumulative mortality of those who are alive in 2005. Note that $S_{2005} = 1$, and thus $\Delta M_{2005} = \beta_{2005}$, i.e., the cumulative mortality effect equals the effect on the mortality rate in the first year. Because survival decreases weakly over time, changes in the mortality rate later in time matter less than earlier changes, holding all else equal. For example, a percentage-point increase in the mortality rate this year followed by a percentage-point decrease in the mortality rate next year results in a cumulative mortality *increase* because individuals are more likely to experience the increase than to experience the decrease.

Concise Difference-in-Differences Event study estimates from equation (2) nonparametrically identify treatment effects over time and can also be used to gauge pre-trends to assess the plausibility of assuming parallel trends in outcomes between the New Orleans and control cohorts. If there are no pre-trends and if the treatment effect is constant over a period of time, a more efficient approach is to partition years into longer periods. To that end, we group years into a pre-treatment reference period (base year–2004), the year of treatment (2005) for capturing short-run effects, and a post-treatment period (2006–2013) for estimating long-run effects. Specifically, we use the following regression specification:

$$\begin{aligned} Y_{it} = \beta_{SR}\mathbf{1}(t = 2005) \times NOLA_i + \beta_{LR}\mathbf{1}(t \geq 2006) \times NOLA_i \\ + [\mathit{year\ FE}] + [\mathit{base\ ZIP5\ FE}] + \theta X_{it} + \varepsilon_{it}. \quad (4) \end{aligned}$$

The indicators $\mathbf{1}(t = 2005)$ and $\mathbf{1}(t \geq 2006)$ denote whether the year of observation is 2005 or falls within the period 2006–2013, respectively. As with equation (2), we include year and baseline ZIP code fixed effects. For robustness, some specifications include additional controls X_{it}, such as differential trends by baseline demographics. The coefficients β_{SR} and β_{LR} thus describe the average short-run (2005) and long-run (2006–2013) causal effects, respectively, of Hurricane Katrina on mortality among the New Orleans cohort under the same identification assumption required for interpreting equation (2) estimates as causal.

Heterogeneous Treatment Effects We estimate heterogeneity in treatment effects with respect to a variety of baseline characteristics, including flooding from Hurricane Katrina in one's 9-digit ZIP code of residence, being 75 or older in 2004, race, residing in a below-median-income 9-digit ZIP code in New Orleans, and the presence of various chronic conditions. We allow estimates of treatment effects to vary arbitrarily by a given characteristic by augmenting the event study or concise difference-in-differences specifications (equations (2) and (4), respectively) to include interactions between the key treatment indicators and the characteristic of interest. Because outcome levels at baseline may differ by the chosen characteristic within New Orleans and between the treatment and control cities, we also control for each characteristic and its interaction with the New Orleans indicator. Furthermore, to allow for differential secular trends, we include interactions between the characteristic and year fixed effects whenever there is variation in the characteristic within the control cohort. Thus, in some cases we do not include such interactions: for example, there was no flooding from Hurricane Katrina in the control cities, so heterogeneity analysis by the flood level of an individual's residence at baseline does not include flood-by-year fixed effects.

4.3 Mechanisms: migration and place

To examine the role of relocation in determining mortality risk following Hurricane Katrina, we estimate how mortality outcomes of individuals displaced by the hurricane depend on characteristics of the region to which they moved. To do so, we restrict our sample to individuals in the 2004 New Orleans cohort who survived through 2005 and moved to another HSA at some point between March 31, 2005, and March 31, 2006. Plausibly, most of these migrants left New Orleans in the aftermath of Hurricane Katrina. To avoid conflating local characteristics with Hurricane Katrina's impact in the vicinity of New Orleans, we further exclude from the migrant sample individuals who moved to an HSA in the same Hospital

Referral Region as the New Orleans HSA.

We estimate the relationship between a New Orleans mover's post-Katrina (2006–2013) mortality rate and the average post-Katrina mortality rate, $MDR_{2006HSA(i)}$, of the HSA in which mover i resided in 2006.[8] To avoid a mechanical relationship between migrant mortality outcomes and our measure of destination mortality, we calculate $MDR_{2006HSA(i)}$ as the empirical 2006–2013 mortality rate of the HSA's 2004 Medicare cohort (i.e., of Medicare beneficiaries who lived in that HSA as of early 2005). We then estimate

$$Died_{it} = \gamma MDR_{2006HSA(i)} + [year\ FE] + [base\ ZIP5\ FE] + \theta X_{it} + \varepsilon_{it}. \quad (5)$$

Because we do not include non-New-Orleans individuals in this empirical exercise, it is not necessary to have New Orleans indicators in equation (5). All remaining control variables are defined as before. The coefficient γ describes the causal effect of place, as captured by local mortality, on migrant mortality under the assumption that migrants do not sort to high- or low-mortality regions based on unobserved mortality risk. When we present the results, we evaluate the plausibility of this assumption by assessing the degree of sorting along observable risk factors, as well as sensitivity of estimates of γ to the inclusion of rich controls, including baseline demographics and chronic conditions.

Finally, we estimate how migrant mortality varies by average medical spending in the destination region by adding average local Medicare spending in each mover's 2006 destination HSA to equation (5). Analogous to how we defined local mortality rates, we define spending in an HSA as the average Medicare spending per fee-for-service beneficiary in 2006–2013, using the HSA's 2004 Medicare cohort. As with local mortality, the estimated relationship between local medical spending and migrants' mortality captures the causal effect of living in a low- or high-spending place under the assumption that migrants are not differentially

[8] In principle, we could let the local mortality rate $MDR_{2006HSA}$ change each year for individuals who continue moving. However, in our setting this is problematic because a non-trivial share of our movers return to New Orleans in the longer run. As a result, we would either have to drop those individuals from our sample in those years—which would likely bias the estimates—or use the New Orleans mortality rate, which was clearly affected by Hurricane Katrina.

selected into low- and high-spending areas based on unobserved mortality risk.

5 Results

5.1 Short-run effects of Hurricane Katrina

Figure 5 reports short-run, weekly effects of Hurricane Katrina on mortality among the 2004 Medicare cohort estimated using equation (1).[9] The gray dashed line 49 weeks after the hurricane indicates the date of FEMA's "look-and-leave"/"look-and-stay" announcement; prior to this date, most New Orleans residents were formally prohibited from returning to their homes. The lack of differential trends in mortality prior to Hurricane Katrina supports interpreting the post-Katrina estimates as causal effects of the hurricane on mortality rather than pre-existing differences between treatment and control individuals.

Perhaps unsurprisingly, the mortality increase is heavily concentrated in the week of Hurricane Katrina, which begins two days before the storm made landfall. That week, the New Orleans cohort's mortality increased by 0.4 percentage points, which accounts for 73 percent of the excess 2005 mortality we identify later in our annual analysis. Relative to average weekly mortality in the sample we use for this analysis, the mortality rate nearly quadrupled during the week of Katrina. We also see statistically significant increases in mortality for two weeks after landfall. While the estimates are about an order of magnitude smaller (0.03 and 0.05 percentage points, respectively), they nonetheless represent large relative mortality increases (a 30 percent and a 47 percent increase, respectively).

In the subsequent 62 weeks, none of the positive point estimates are significant. The combined total of the coefficients in the week of Katrina and the six weeks after *exceeds* the 2005 increase in mortality we see later in the annual analysis, suggesting the presence of short-run mortality displacement (i.e., the deaths of elderly/disabled who would have died

[9]Results are similar if we augment this specification with indicators for all possible combinations of gender, race, and age.

in the near future even absent Katrina). Toward the end of the sample period, there are thirteen weeks in which the mortality rate was significantly lower than it was the week before the hurricane. However, without considering a longer time horizon, we cannot rule out that such patterns are driven by harvesting.

The absence of a more prolonged negative impact on mortality is quite surprising in light of existing literature on elderly health, especially given the scale of Hurricane Katrina's destruction and displacement. On the other hand, about 80 percent of the New Orleans population had evacuated before landfall, and the hurricane prompted a massive private and public response to help the victims. Because we cannot separate the effects of the aid response from the direct effects of the hurricane, it is important to note that counterfactual mortality could have been higher absent the aid.

5.2 Long-run effects of Hurricane Katrina

5.2.1 Annual mortality and mobility

Next, we use annual data to estimate the effect of Hurricane Katrina on elderly and long-term disabled mortality and mobility in the longer run. Figure 6 shows the estimates corresponding to equation (2) (changes in annual mortality and mobility, black lines) as well as equation (3) (changes in cumulative mortality, red lines) for the 2004 Medicare cohort.[10] The top graph shows the estimated effect of Hurricane Katrina on mortality. In the year of Hurricane Katrina, the mortality rate of New Orleans residents increased by over half a percentage point. This increase corresponds to about 10 percent of the average annual mortality rate for this cohort, which is particularly large given that these additional deaths occurred in the last four months of the year.

Remarkably, this mortality increase quickly reversed and became a mortality *reduction*: the death rate for both cohorts fell below pre-Katrina levels in 2006 and remained below them

[10] Exact coefficients and standard errors for this and other figures can be found in the Online Appendix. Our results are similar if we also control for indicators for all possible combinations of gender, race, and age or allow for differential non-linear trends for each of these combinations.

for the rest of the sample period (although not all the estimates are statistically significant at the 5 percent level). In almost every year after 2005, the death rate for New Orleans elderly is at least a quarter of a percentage point lower than that for the controls. The initial decrease in death rates is perhaps unsurprising, as it can potentially be explained by Hurricane Katrina killing particularly sick individuals who would have died relatively soon even in the absence of the storm. However, as the red line plotting changes in cumulative mortality shows, harvesting can at best explain two years of subsequent mortality reductions.

Empirically, we see that changes in cumulative mortality became negative in 2007–2008 after an initial increase in 2005. The change in cumulative mortality became increasingly negative throughout the post-Katrina period, reaching about -1.75 percentage points in 2013 for the 2004 cohort. That is, by the end of our sample period, the victims of Hurricane Katrina were 1.75 percentage points *more* likely to be alive than members of the control group, despite no significant differences in survival probability prior to the hurricane. About 60 percent of the 2004 cohort survived through 2013. Thus, relative to the average survival rate over this time period, a decrease in cumulative mortality of 1.75 percentage points represents a survival improvement of 2.9 percent.

The bottom graph in Figure 6 shows the effect of Hurricane Katrina on elderly mobility. In 2005, Hurricane Katrina displaced about 40 percentage points more individuals than leave their city of residence in a typical year, and most of the displaced stayed away in 2006. They began returning slowly in 2007; however, by 2013, those from the New Orleans cohort who were alive were still about 24 percentage points less likely to be living in their baseline city than were individuals from the control city cohorts. Thus, a large share of New Orleans elderly left the city after Hurricane Katrina and never returned.

Using a value of $100,000 per life year (Cutler, 2005) and a discount rate of 3 percent (Siegel, 1992), we calculate the net present value of the changes in cumulative mortality brought about by Hurricane Katrina over the period 2005–2013. The discounted value of the cumulative mortality effects plotted in Figure 6 is $4,872 per capita ($6,000 per capita without discounting). Because the cumulative mortality reduction likely persisted beyond 2013, this figure plausibly provides a lower bound on the value of the mortality reduction. In our sample of 80,607 New Orleans elderly and disabled victims, the implied aggregate value of the mortality reduction over the period 2005–2013 is about $393 million ($484 million without discounting). Because Hurricane Katrina had many negative consequences that are not captured by mortality outcomes, these estimates do not imply that victims' aggregate welfare increased as a result of the hurricane.

5.2.2 Robustness

Individuals in the 2004 Medicare cohort must have been alive on January 1st, 2004 to be included in our sample. Thus, we focus on earlier Medicare cohorts to assess parallel mortality trends between New Orleans and the control city cohorts. In Figure 7, we re-estimate equation (2) for the mortality rate of the 1992 and 1999 Medicare cohorts.[11] For both cohorts, mortality trends are very similar between the New Orleans and control city cohorts, with no statistically significant differences. The post-Katrina differences in mortality rates are also broadly similar across the cohorts. Remarkably, we even detect a post-Katrina decrease in the mortality rate of the 1992 cohort, of whom almost two-thirds were not alive or were not in New Orleans in 2004. The 2005 increases in the mortality rate for the 1992 and 1999 New Orleans cohorts are even larger than that of the 2004 cohort: 1.05 and 0.78 percentage points, respectively. At first glance, this is perhaps surprising, as quite a few of these individuals were no longer alive by 2005 and others may have left New Orleans. However, the remaining individuals were at least 77 and 70 years old, respectively, at the time of Hurricane Katrina, which may have made them more susceptible to the short-run negative effects of the disaster than younger Medicare beneficiaries.

In the Online Appendix, we replicate the mortality results displayed in Figure 6 using a random 50 percent sample of the entire 1999 and 2004 U.S. cohorts of Medicare beneficiaries

[11] For mobility estimates for the 1999 cohort, see Online Appendix Figure A.2.

as a control for each New Orleans cohort (see Figure A.1 and Table A.4). Each cohort consists of over 170 million individual observations (number of individuals times the number of years in which they were alive during the sample period). As with our smaller control group, we see no differential pre-trends in mortality prior to the hurricane. We obtain qualitatively similar but quantitatively larger and more significant estimates of the post-Katrina reductions in the mortality rate, indicating that the cumulative mortality of New Orleans residents decreased by 2.2–2.7 percentage points by the end of 2013. Because we are more confident in the comparability of New Orleans residents to the residents of the 10 cities in our main control group, we continue to use the more restricted control group. However, it is reassuring that our results do not hinge on this particular choice.[12]

5.2.3 Concise difference-in-differences

Table 2 shows the equation (4) mortality estimates for the 2004 cohort (columns (1)-(3)) and the 1999 cohort (columns (4)-(7)). In addition to our preferred specification (columns (1) and (4), labeled "A" in the table), we also show results we obtained by adding fixed effects for all 5-year-age-bins-by-gender-by-race combinations (labeled "B") and where we additionally allow the year fixed effects to vary by each 5-year-age-bin-by-gender-by-race combination (labeled "C"). Finally, for the 1999 cohort, we also add an indicator for New Orleans interacted with an indicator for the years 1999–2001. This last fixed effect allows us to gauge whether differential pre-trends, if any, are affecting these results.

Overall, we find effects that are very similar to each other and to those obtained in the event study, but more precisely estimated: all estimates in Table 2 are significant at the 1 percent level or better. The immediate (2005) mortality increase for the 2004 cohort ranges from 0.54 to 0.56 percentage points. As in the event study graphs, the increase for the 1999 cohort is 0.74–0.82 percentage points larger. In 2006–2013, the 2004 New Orleans cohort

[12] Our results are also similar if we exclude Detroit—which was hit particularly hard by the Great Recession of 2008—from the control group. We have also estimated equation (2) for the 2000–2003 Medicare cohorts, obtaining similar results.

experiences a significant decline in its mortality rate of 0.28–0.39 percentage points. As we showed in the event study, such sustained decreases cannot be explained by short-run mortality displacement.

The 1999 New Orleans cohort likewise experiences a short-run increase and long-run decline in its mortality rate. In 2005, its mortality rate is 0.74–0.82 percentage points higher than it would have been absent the hurricane. In the next eight years, it is 0.39–0.48 percentage points lower.

5.2.4 Heterogeneous treatment effects

The above analysis shows that, while Hurricane Katrina devastated much of the infrastructure of New Orleans, the Medicare cohorts living in New Orleans were likely to relocate to other cities and to experience long-run reductions in mortality, on average. Next, we estimate how the relocation and mortality effects of the storm varied by the degree to which an individual's baseline 9-digit ZIP code of residence was flooded in the aftermath of the hurricane. To do this, we define a categorical variable indicating either no storm flooding, up to four feet of storm flooding, or over four feet of flooding. We then estimate the controlled event study, allowing treatment effects to vary by the degree of flooding.

We report the results of this exercise in Figure 8. The short-run mortality effects of the hurricane (in 2005) were similar by flood level (top panel). However, the long-run mortality declines were, surprisingly, *larger* in areas that experienced flooding. To try to understand why, we consider heterogeneous relocation effects, reported in the bottom panel of Figure 8. Individuals whose homes were flooded by the hurricane were much more likely to relocate to another city following the storm. Together, these results suggest that responses to the storm such as leaving New Orleans may play a role in long-run survival gains among the cohort exposed to the hurricane.

In Online Appendix Table A.3, we build on equation (4) to estimate a concise version of the controlled event study described above. We find that the short-run mortality impact of the hurricane was similar in flooded and non-flooded parts of New Orleans, but long-run mortality reductions were 0.441 percentage points *greater* in flooded areas. This economically and statistically significant result points to a stronger recovery response among those who were most likely to lose their homes and be displaced.

We also considered heterogeneity along other dimensions, including demographics and pre-existing chronic conditions (Table A.3). The main takeaway from this analysis is that the long-term mortality gains were not concentrated in any particular segment of Hurricane Katrina victims, but appear fairly widespread. In particular, even individuals that seem more vulnerable *ex ante*, such as those with lower incomes or chronic conditions, did not experience increases in long-run mortality.

5.3 Mechanisms

The results we have reported thus far show that Katrina led to significant declines in long-run mortality among the elderly and disabled, with victims living in flooded parts of New Orleans experiencing the largest mortality reductions. These results, in isolation, are counterintuitive, as natural disasters are unlikely to have positive *direct* effects on health. A natural hypothesis, then, is that the mortality improvements following Hurricane Katrina came about indirectly, through other effects of the hurricane. Such indirect benefits have been demonstrated in other contexts. For example, Sacerdote (2012) finds that Katrina and Rita student evacuees experienced long-run improvements in test scores, likely because they transferred to better schools. Relatedly, Deryugina, Kawano and Levitt (2018) find long-run increases in New Orleans victims' earnings brought about because Hurricane Katrina both forced individuals to relocate to stronger labor markets and strengthened the New Orleans labor market. In our context, Hurricane Katrina may have increased long-run survival rates by causing elderly and disabled individuals to move to areas more conducive to better health or by generating health care quality improvements in New Orleans itself (Marsa, 2015).

5.3.1 The importance of rebuilding in New Orleans

We first consider whether improvements in the New Orleans health care system following Hurricane Katrina help explain the aggregate mortality improvements we estimate. There are two key challenges for directly testing how the hurricane affected mortality among individuals who remained in New Orleans. First, because the decision to move is observed only for individuals who survived the initial shock of the hurricane, we cannot estimate stayer-specific difference-in-differences mortality effects using pre-Katrina as a reference period. Second, differences in mortality levels between stayers and movers are also unlikely to be informative of the relative effect of staying in New Orleans since, as we show later, the decision regarding whether to leave or stay was highly correlated with observable predictors of mortality risk.

New Orleans infrastructure was devastated following Hurricane Katrina, however, and therefore it is likely that any health improvements accruing to New Orleans stayers would have developed over time during rebuilding. To empirically test this intuition, we restrict the sample to individuals from the 2004 cohort who survived until at least the beginning of 2006. We then estimate equation (2) with only the control individuals and New Orleans "stayers" (defined by individuals' location as of March 31, 2006). Because survival until 2006 is necessary for inclusion, the reference category is 2006. Figure 10 plots the results, which show that stayers' mortality did not improve over time relative to 2006. This finding suggests it is unlikely that the cohort-level mortality declines among hurricane victims reflect health improvements from remaining in New Orleans.

5.3.2 The importance of place: improving survival through migration

Next, we consider whether migration to other regions contributed to the long-run mortality declines among New Orleans hurricane victims. The elderly and disabled mortality rate in New Orleans was among the highest in the country prior to Hurricane Katrina, so individuals displaced by the storm generally relocated to places with better health outcomes. To the extent that regional mortality differences reflect causal effects of place, migrant health may have improved as a result of the move. The results reported in Section 5.2.4—that individuals whose homes were flooded by the storm relocated to new cities at much higher rates and also experienced larger mortality reductions—further indicate an important role for migration in shaping long-run health outcomes.

To examine the role of place on mortality outcomes more directly, we focus on individuals who were displaced by the hurricane and relate their subsequent mortality outcomes to characteristics of the region to which they moved, as outlined in Section 5.2.4. Specifically, movers are defined as individuals from the 2004 Medicare cohort who left New Orleans following Hurricane Katrina and survived past 2005. We define the destination city (HSA) for each mover based on place of residency as of March 2006, regardless of whether they subsequently moved. Because we focus on New Orleans victims displaced by the storm, New Orleans itself is never a destination region.

We focus on two characteristics of destination regions: the local mortality rate and local average Medicare spending. We define each HSA's characteristics based on its own cohort, defined as individuals from the 2004 Medicare cohort who initially resided in that HSA and, like the New Orleans mover sample, survived past 2005. Thus, there is no overlap between the mover sample and the destination cohorts, which avoids creating a mechanical relationship between destination characteristics and movers' own outcomes. Regional mortality rates are calculated as the average annual mortality rate among the 2004 destination cohort over the period 2006–2013. Similarly, regional spending is calculated as the average annual Medicare spending over 2006–2013 among the destination cohort enrolled in Medicare fee-for-service.

We estimate the relationship between destination characteristics and movers' mortality outcomes using equation (5). This relationship describes the causal effect of place, as captured by mortality rates and local spending, on individual mortality under the assumption that baseline mortality risk among those who move is uncorrelated with mortality rates and local spending in the destination region. A primary threat to this identification assumption is that migrants with lower latent mortality risk may sort to destination regions with low mortality rates or high local spending.

We assess the scope for migrant sorting to destination regions based on latent mortality risk in two ways. As a first test of differential sorting, we directly compare how migrants' baseline observable risk factors—demographics and chronic conditions—vary with the characteristics of the region into which these individuals move. As shown in columns (1)-(2) of Table 3, individuals who move out of New Orleans differ substantially from those who stay along many of the observable risk factors we consider: female, black, poorer, younger, and flooded Medicare individuals as well as those with respiratory disease are all more likely to move, holding all else equal, while individuals with Alzheimer's/dementia, end-stage renal disease, and cancer are less likely to leave the city. However, because this test focuses only on the decision to leave New Orleans and not on sorting among those who do move, it neither validates nor invalidates the identification assumption of our movers exercise.

Columns (3)-(4) of Table 3 provide a direct test of sorting to regions with relatively higher or lower mortality. Column (3) contains predictors that are available for all New Orleans movers, while column (4) contains additional chronic condition variables that are available only for a subset of the individuals. In contrast to the strong selection observed for the decision to move out of New Orleans, we observe few differences in observable characteristics between those who move to regions with higher or lower mortality, with only two variables significant at the 5 percent level. In column (3), where we do not control for chronic conditions, the estimates indicate that being male is associated with moving to a higher-mortality area. When we add chronic conditions in column (4), we see that individuals with Alzheimer's disease or dementia moved to places with slightly higher mortality levels. The p-value of the F-statistic for all the variables in our most comprehensive specification displayed in column (4) is 0.08, indicating little overall correlation between destination mortality rates and baseline characteristics of movers. Notably, while flooding is highly predictive of *whether* one moves, it is not predictive of the destination region's mortality rate.

Similarly, columns (5)-(6) of Table 3 show that none of the baseline demographic or chronic condition variables we examine for migrants are significant predictors of local spending in the area to which they move, suggesting that sorting appears not to be an important confounder in this setting.

Local Mortality and Movers' Mortality As shown in column (1) of Table 4, Panel A, destination mortality rates are strongly associated with movers' own mortality rates for 2006–2013. Specifically, each percentage-point reduction in the destination region's mortality rate corresponds to a 1.04 percentage-point reduction in the mortality rate of individuals from New Orleans who move to that region.

As a second test for whether selection may be driving the relationship between mover mortality and destination region mortality rates, we re-estimate equation (5) using increasingly comprehensive controls. As reported in columns (2)-(4) of Table 4, Panel A, the estimated coefficient on destination mortality changes little, ranging from 0.98–1.12 across these specifications. The smallest estimate of 0.98 reported in column (4)—obtained by controlling for baseline ZIP code fixed effects, baseline Medicare spending, the eight groups of all available chronic conditions, and separate year fixed effects for all combinations of 5-year age bins, gender, and race—is very similar to the estimate of 1.04 reported in column (1) with only year and baseline ZIP code fixed effects. The stability of this estimate across the various sets of controls further suggests that significant migrant sorting on latent mortality risk is unlikely in this context.

In Table 5, we extend these results by separating the post-Katrina years into two periods: 2006–2007 and 2008–2013. We find a strong relationship between local mortality and movers' mortality as early as 2006–2007, suggesting that migrant mortality rates are not shaped solely by slow-moving channels such as lifestyle changes. More generally, the speed with which individuals' mortality rates converge to the local rate makes it very unlikely that this convergence is primarily due to individuals' becoming more or less likely to develop chronic conditions. Rather, faster-moving channels such as the quality of the local health care system or other environmental factors appear to be driving both local mortality rates and the mortality rates of new arrivals.

In the Online Appendix, we present several robustness tests. In Table A.5, we show the results of estimating the relationship between movers' own mortality and the mortality in their destination HSA using individuals' locations from the 2006 Beneficiary Summary Files (i.e., locations as of December 31, 2006). This allows us to exclude any short-term moves as well as moves that may have not been reported by the beneficiaries until later in 2006. The coefficients on local mortality are slightly lower than, but remain qualitatively similar to, the baseline estimates. In Panel A of Table A.6, we include data for 2004–2005 in the calculation of each HSA's mortality, while in Panel B we exclude the HSAs corresponding to the cities of Houston and Baton Rouge (the two most common destinations for New Orleans movers). These alternative specifications generate similar results to the baseline estimates.

Finally, we perform a back-of-the-envelope evaluation of the extent to which migration to lower-mortality regions can account for the average mortality decline of -0.28 to -0.39 percentage points among the New Orleans cohort over the period 2006–2013 (Table 2). For these individuals (i.e., those in the New Orleans cohort surviving past 2005), we first identify their HSA of residence as of March 31, 2016. To measure the changes in mortality exposure following Hurricane Katrina, we then calculate the difference in mortality between each individual's 2006 HSA and the New Orleans HSA, using the 2004 mortality rate of each area's 2004 cohort.[13] Calculated in this way, the local mortality change experienced by Hurricane Katrina victims averages -0.22 percentage points (including individuals who remained in New Orleans, for whom the difference is zero). Given an approximately one-for-one relationship between local mortality rates and Katrina victims' own subsequent mortality (Table 4), these changes in local mortality explain 56–79 percent of the average long-run mortality decline caused by the hurricane.

[13] Calculating mortality rate differences over the period 2006–2013 instead of 2004 would adhere most closely to our movers' regression framework, but that figure for New Orleans would be confounded by the effects of the hurricane. If counterfactual cohort mortality rates trend in parallel across regions, differences in 2004 mortality rates provide an unbiased, although perhaps less precise, estimate of longer-run differences.

There are a number of factors that may explain the remaining 21–44 percent of the long-run mortality decline. First, some portion of the decline may reflect mortality displacement, although our cumulative mortality results show that harvesting cannot explain the persistent mortality reduction. Second, the aggregate mortality decline may be due in part to effects that were uncorrelated with whether or where victims moved. For example, the disaster may have increased resilience among the elderly (Adams et al., 2011). Finally, some of the long-run mortality decline following Hurricane Katrina may be driven by where people move, but based on local factors that are uncorrelated with a region's mortality rate. In this case, our estimate of the share of the mortality decline that can be attributed to moving is a lower bound on the effect of place on mortality. For example, regional variations in medical spending have been found not to be highly correlated with mortality. Likewise, in our setting there is a wide distribution of local mortality rates and local spending in the movers' destination regions (see Figure 10), but no significant association between the two. In the next section, we consider whether moving to a high medical spending region may lower one's mortality risk.

Local Spending and Movers' Mortality We estimate how migrants' mortality varies jointly with local mortality and local average medical spending in destination HSAs. Numerous studies have found that regional spending levels are not associated with better health outcomes (e.g., Fisher et al., 2003*a*,*b*; Baicker and Chandra, 2004; Sirovich et al., 2006), suggesting that the returns to additional medical spending may be low (e.g., Fisher, Bynum and Skinner, 2009; Cutler, 2010; Skinner and Fisher, 2010). However, worse population health may lead to higher spending, which could result in a net correlation close to zero even though the returns to living in a higher spending region may be positive. The mass migration caused by Hurricane Katrina provides a novel opportunity to estimate the returns to living in a higher- or a lower-spending region, using measures of regional spending that are separate from the migrants' health and spending.

We perform this test by augmenting equation (5) to include both the local mortality rate and local average spending in the destination region. As reported in Panel B of Table 4, we estimate small effects: a $1,000 increase in an area's average medical spending is associated with a (statistically insignificant) 0.04 to 0.09 percentage-point reduction in movers' mortality.[14] The relationship between local mortality and movers' subsequent mortality remains highly significant and similar to that of Panel A.

6 Conclusion

Hurricane Katrina devastated the City of New Orleans and other parts of the Gulf Coast, causing billions of dollars' worth of direct damage and displacing over one million individuals from their homes. However, the hurricane appears to have come with a silver lining: the elderly and long-term disabled living in New Orleans at the time of the hurricane experienced non-trivial reductions in long-run mortality. While we do not find evidence of long-run improvements in the New Orleans health care system, our analysis suggests that relocation to areas with better mortality outcomes can explain 56–79 percent of the post-Katrina mortality decline among the elderly and disabled. By contrast, we find that regional differences in health care spending largely fail to explain the observed mortality reductions.

While we find that Hurricane Katrina reduced long-run mortality rates, these effects do not necessarily imply that individuals' *welfare* increased, as the destruction of physical assets and lost utility due to displacement may have more than offset any indirect benefits of the hurricane. We estimate that changes in mortality due to the hurricane—inclusive of the initial mortality shock—are worth almost $4,900 per capita. Given that moving costs have been estimated to be as high as $300,000 for some populations (Kennan and Walker, 2010), it is reasonable to expect that individuals would not voluntarily relocate for these mortality benefits alone. Taken together, our findings demonstrate the importance of place in shaping health outcomes even later in life.

[14] Considering local spending alone, rather than jointly with local mortality, yields very similar results.

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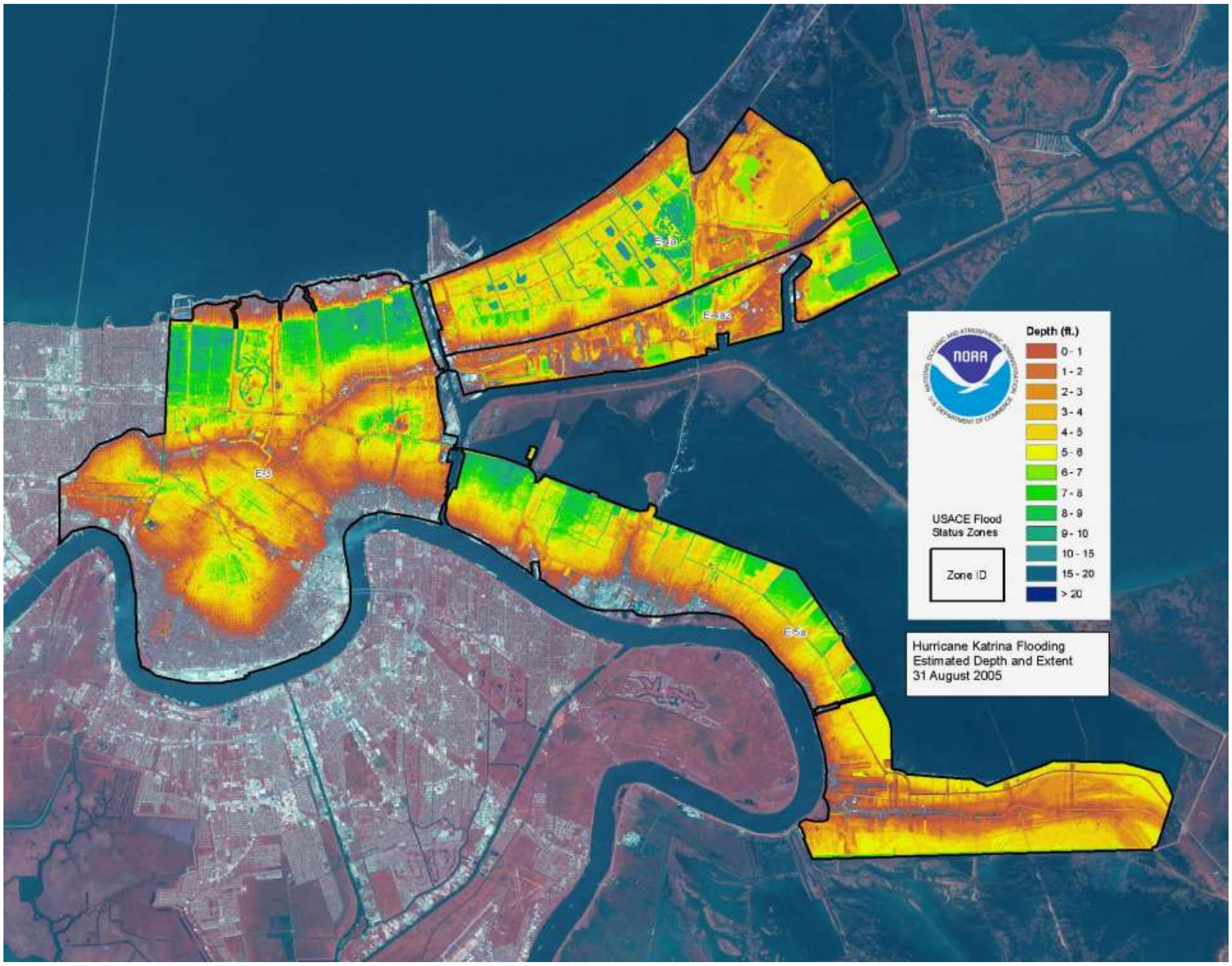
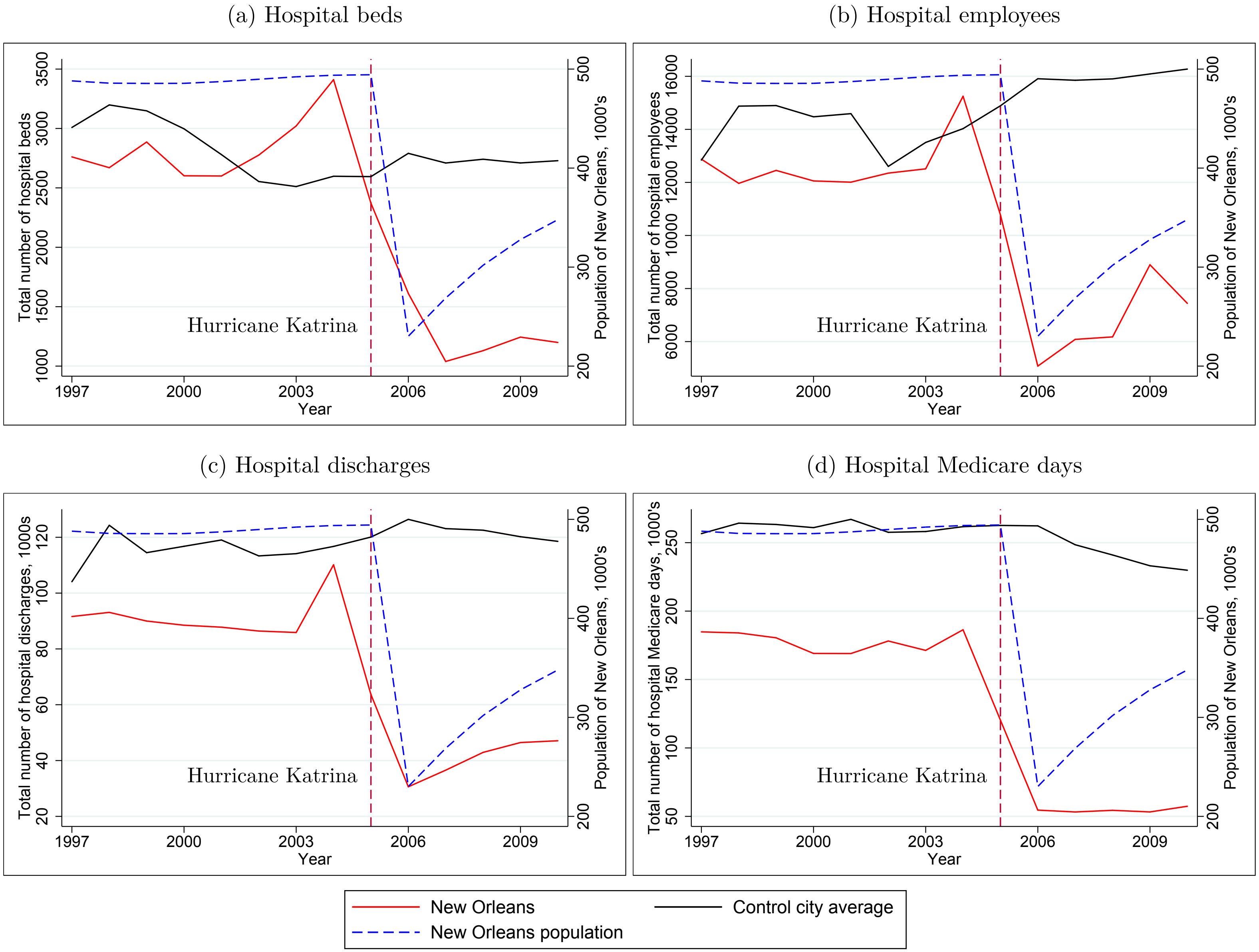
Figures

Figure 1: Hurricane Katrina flood map



Source: National Oceanic and Atmospheric Administration (NOAA).

Figure 2: Capacity and utilization of the New Orleans health care system following Hurricane Katrina

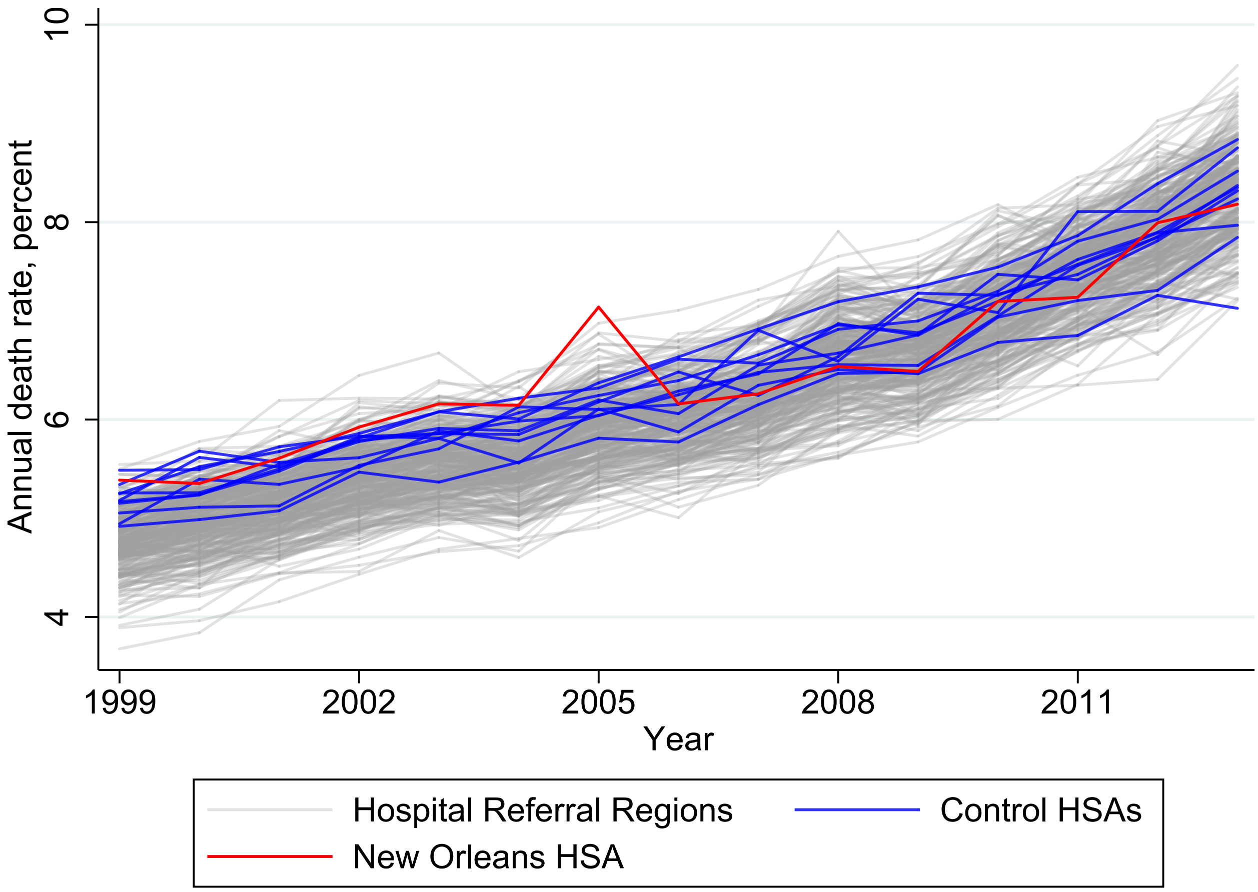


Notes: The figure shows the number of hospital beds (panel (a)), the number of hospital employees (panel (b)), the number of hospital discharges (panel (c)), and the number of hospital Medicare days (panel (d)) in New Orleans and the 10 control cities we utilize for our individual-level analysis. Also plotted in each panel is the New Orleans population (right axis). The vertical dashed red lines indicate the year of Hurricane Katrina (2005). Sources: Centers for Medicare and Medicaid Services Hospital 2552-96 Cost Report Data file; Bureau of Economic Analysis.

Figure 3: New Orleans and control cities

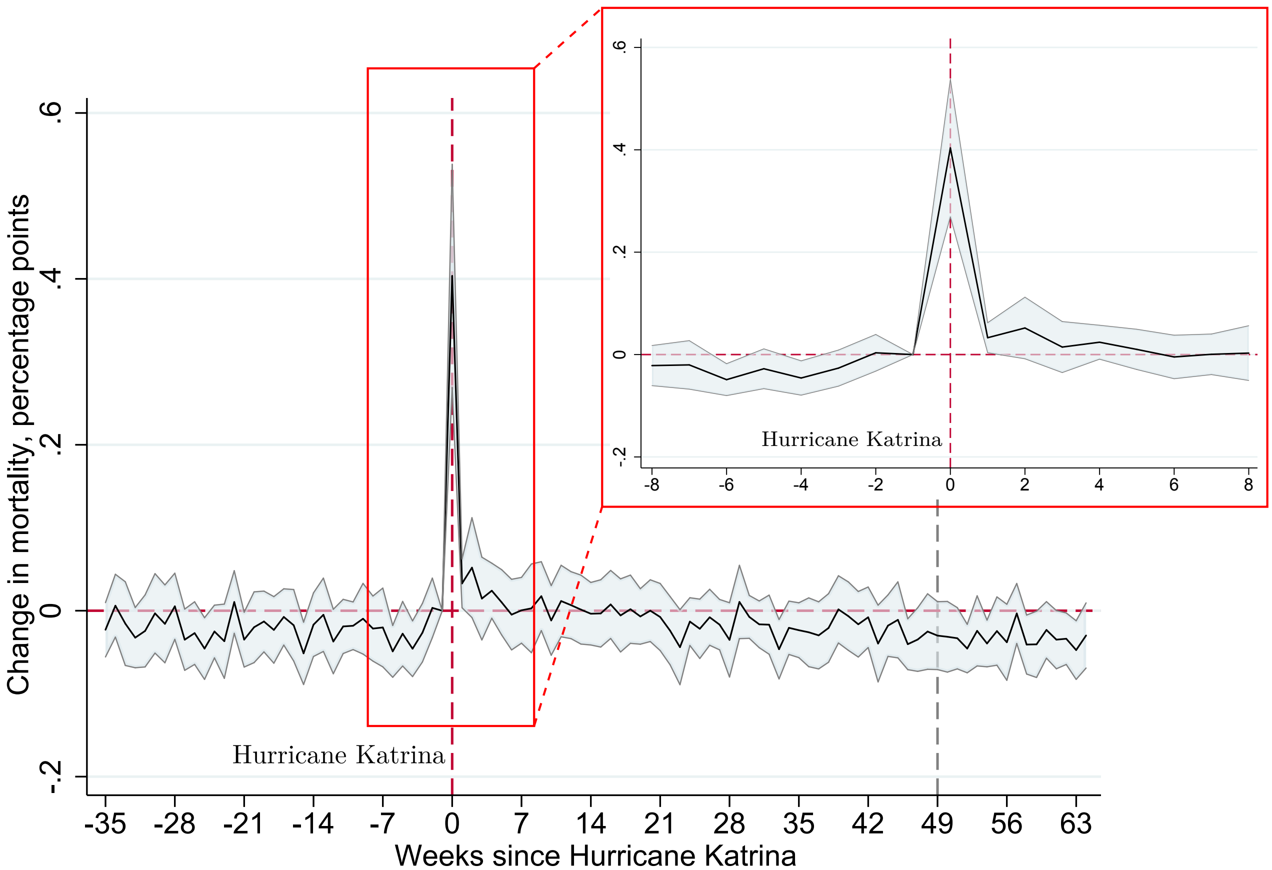
Notes: The figure shows the location of New Orleans and each of the 10 control cities used to construct comparison cohorts for identifying the effects of Hurricane Katrina on Medicare beneficiaries initially residing in New Orleans.

Figure 4: Mortality rates in New Orleans versus other areas (1999 Medicare cohort)



Notes: The figure shows raw annual death rates of 1999 Medicare cohorts by initial region of residence. Mortality rates for the New Orleans cohort ("New Orleans HSA") are plotted in red, and mortality rates for 1999 cohorts from each of the 10 control cities ("Control HSAs") are plotted in blue. The light gray lines plot mortality rates for the cohorts initially residing in each U.S. Hospital Referral Region except the one containing New Orleans.

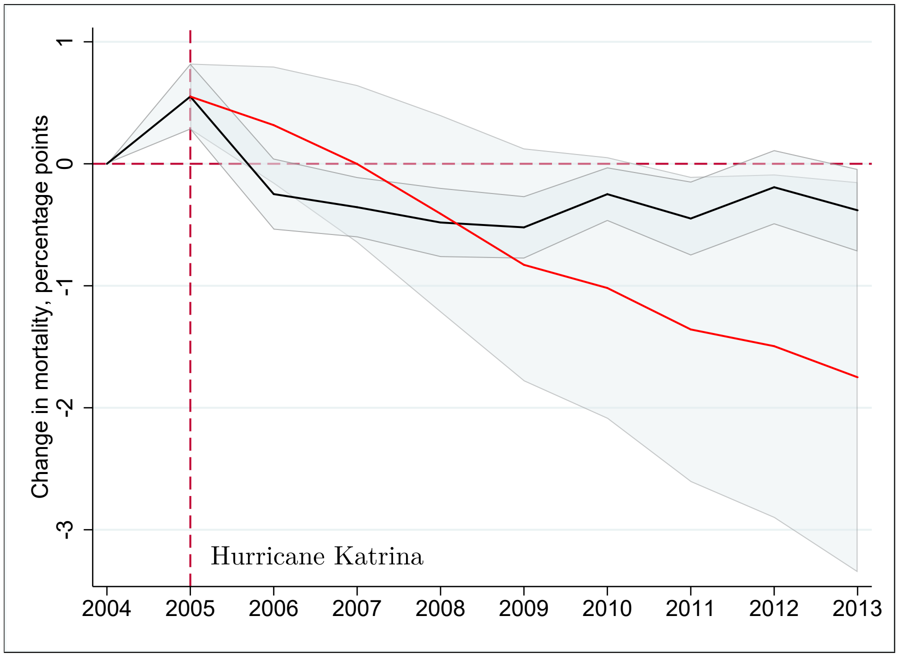
Figure 5: Short-run mortality effects of Hurricane Katrina (2004 Medicare cohort)



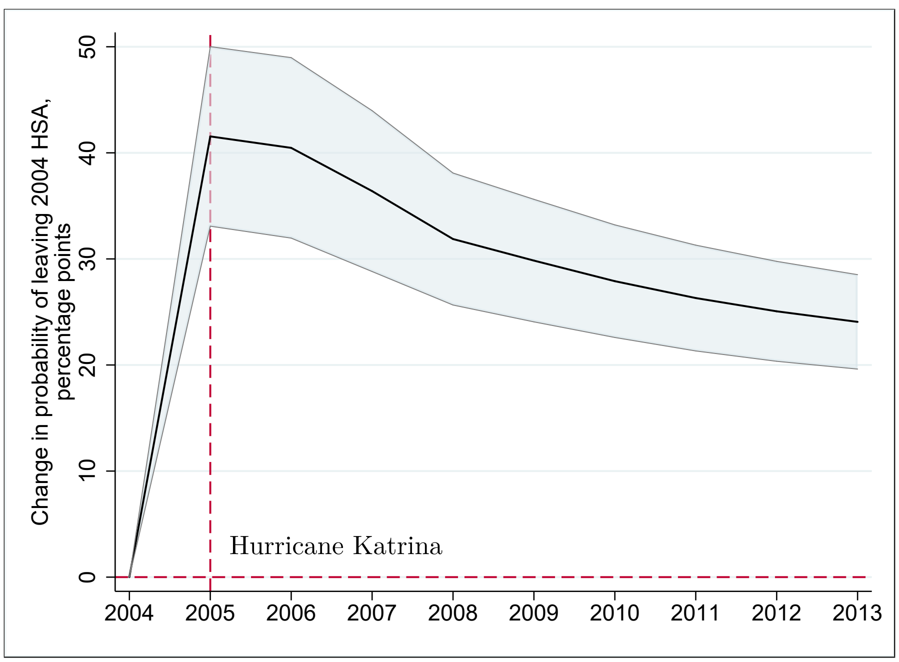
Notes: The figure shows estimates and corresponding 95 percent confidence intervals from equation (1), estimated over the 35 weeks preceding Hurricane Katrina and the 64 weeks following. The inset at top right zooms in on estimates from the eight weeks before Hurricane Katrina through the eight weeks after. The dependent variable is an indicator equal to 0 if a beneficiary was alive during the entire week and equal to 1 if the beneficiary died in a given week. The week in which Hurricane Katrina struck New Orleans is labeled "0" on the horizontal axis (this week begins on Saturday, August 27, 2005). The gray dashed line indicates FEMA's "look-and-leave"/"look-and-stay" announcement date (December 5, 2005). Standard errors are clustered by beneficiary baseline ZIP codes. Coefficients and confidence intervals have been scaled by 100 to reflect changes in percentage points.

Figure 6: Long-run effects of Hurricane Katrina (2004 Medicare cohort)

(a) Annual and cumulative mortality



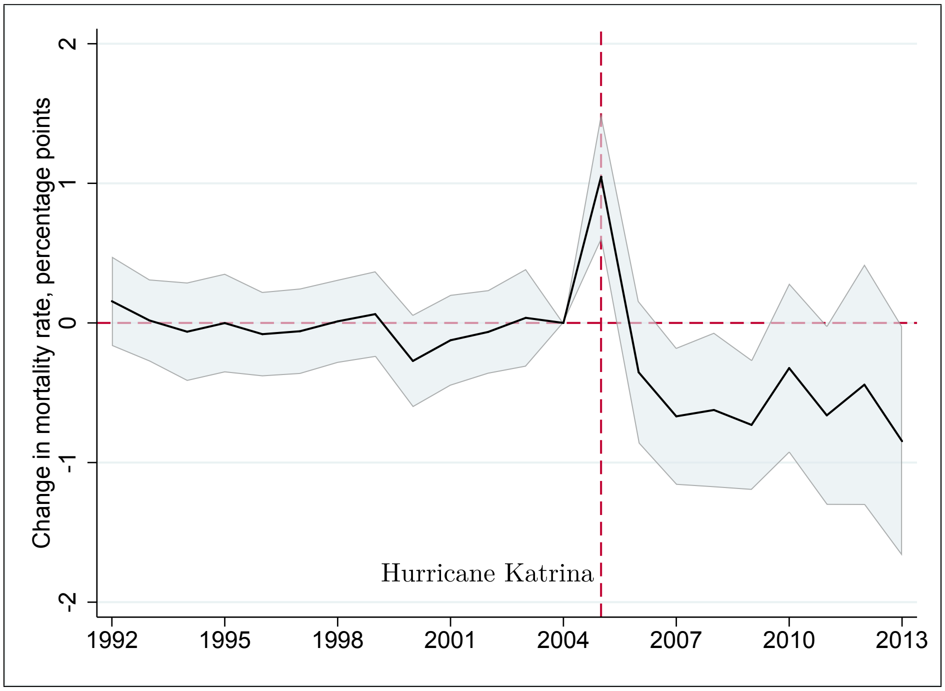
(b) Relocation



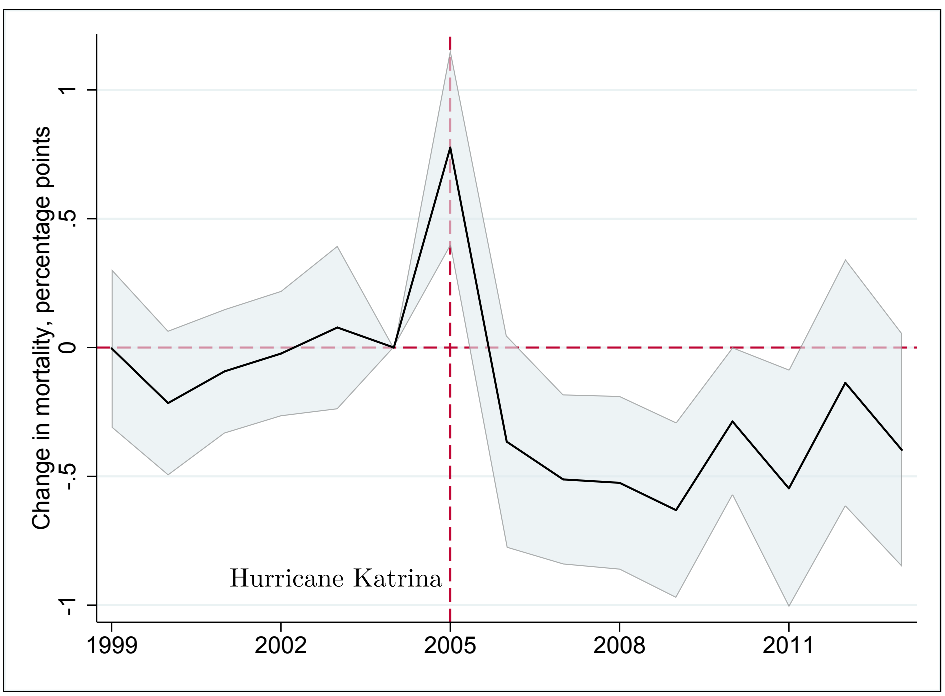
Notes: The figure shows estimates of changes in the probability that an individual dies (panel (a)) or is living in a city other than the city of residence in 2004 (panel (b)). The black lines track estimates from equation (2). The red line in panel (a) tracks the implied changes in cumulative mortality probability (equation (3)). The gray shaded areas represent 95 percent confidence intervals based on standard errors that are clustered by beneficiary baseline ZIP codes. See Section 4 for definitions of the dependent variables. Coefficients and confidence intervals have been scaled by 100 to reflect changes in percentage points.

Figure 7: Long-run mortality effects of Hurricane Katrina (earlier Medicare cohorts)

(a) 1992 Medicare cohort



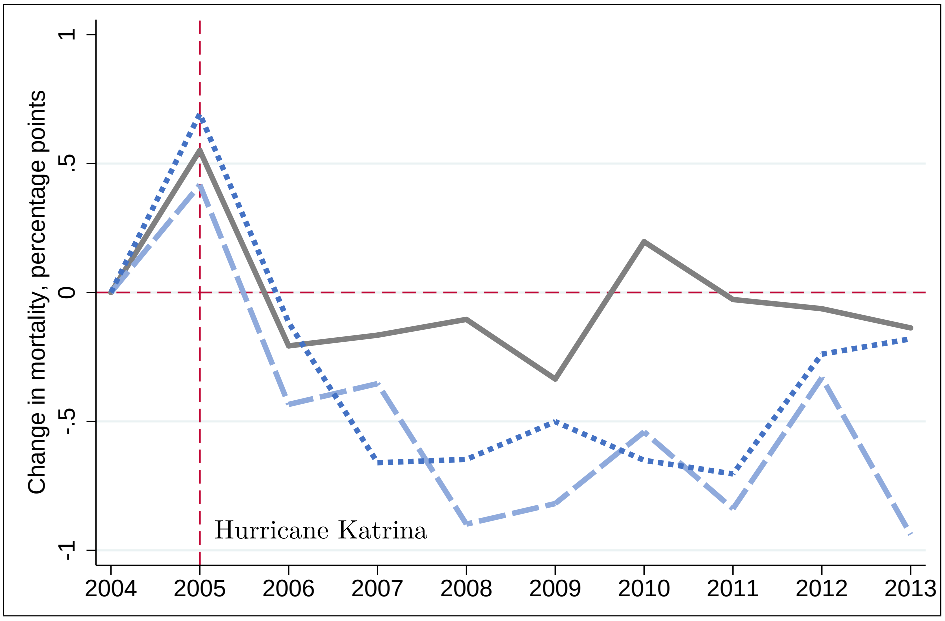
(b) 1999 Medicare cohort



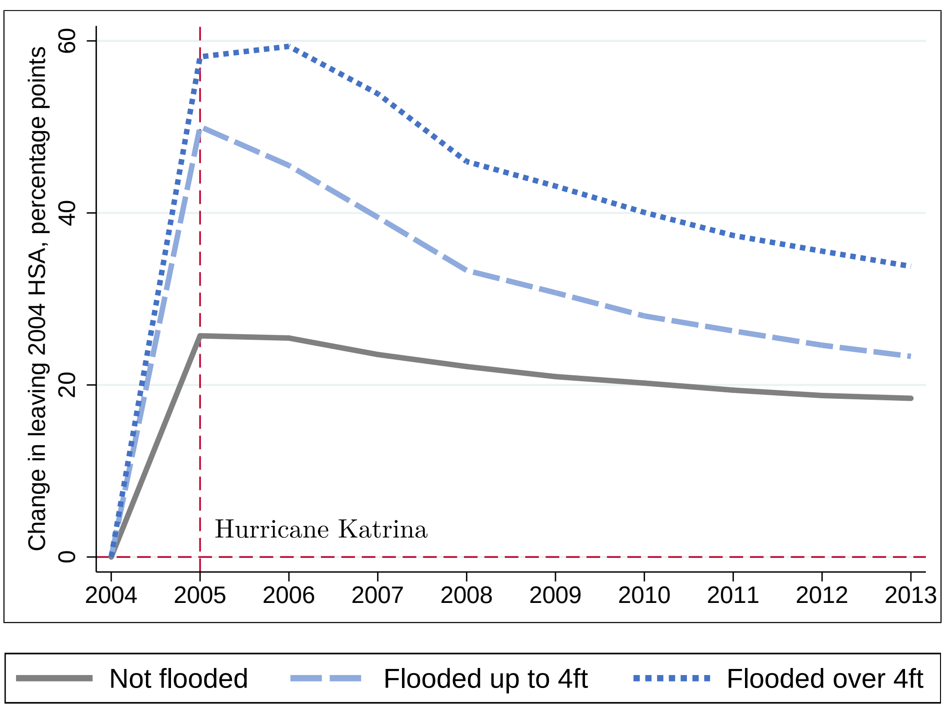
Notes: The figure shows estimates and 95 percent confidence intervals from equation (2) for the Medicare cohort indicated above each subplot. The dependent variable is an indicator equal to 0 if a beneficiary was alive during the entire year and equal to 1 if the beneficiary died in a given year. Standard errors are clustered by beneficiary baseline ZIP codes. Coefficients and confidence intervals have been scaled by 100 to reflect changes in percentage points.

Figure 8: Long-run effects of Hurricane Katrina, by flood level (2004 Medicare cohort)

(a) Annual and cumulative mortality

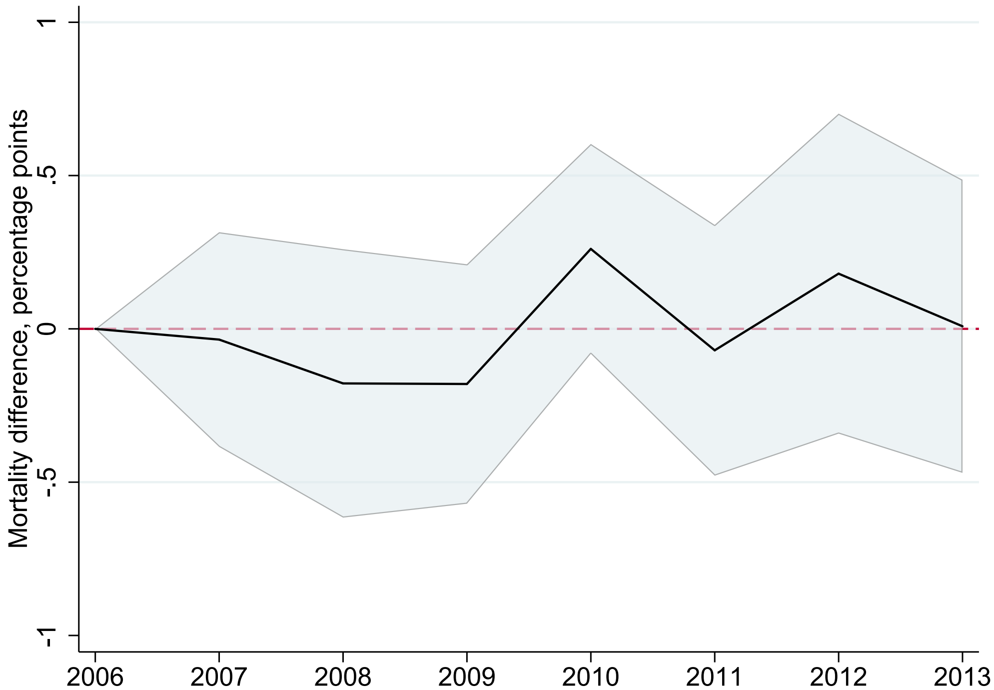


(b) Relocation



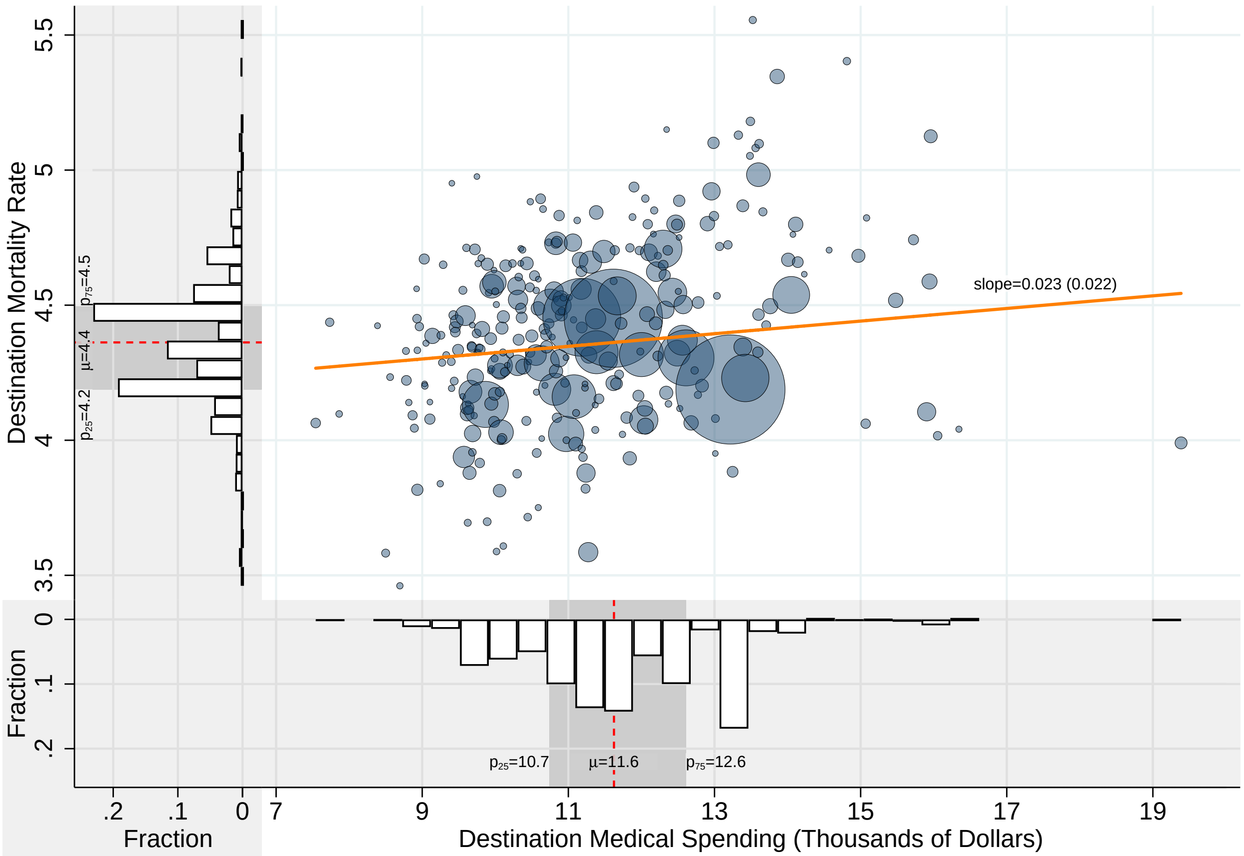
Notes: The figure shows estimates of changes in the probability that an individual dies (panel (a)) or is living in a city other than the city of residence in 2004 (panel (b)), by level of flooding from Hurricane Katrina. Estimates are from an augmented version of equation (2) where the interactions between calendar years and living in New Orleans at baseline (2004) are fully interacted with a categorical variable indicating whether an individual's baseline 9-digit ZIP code was (a) not flooded by the hurricane, (b) flooded >0–4 feet, or (c) flooded more than 4 feet. See Section 4 for definitions of the dependent variables. Coefficients have been scaled by 100 to reflect changes in percentage points.

Figure 9: Changes in stayers' mortality rates over time



Notes: The figure shows estimates and 95 percent confidence intervals from an augmented version of equation (2) for individuals who remained in New Orleans in 2006. The dependent variable is an indicator equal to 0 if a beneficiary is alive during the entire calendar year and equal to 1 if the beneficiary died in a given year. Standard errors are clustered by beneficiary baseline ZIP codes. Coefficients and confidence intervals have been scaled by 100 to reflect changes in percentage points.

Figure 10: Local mortality and Medicare spending in migrants' destination cities (HSAs)



Notes: The figure shows the annual Medicare spending per fee-for-service beneficiary and annual mortality rates in the cities (HSAs) to which people displaced from New Orleans after Hurricane Katrina moved in 2006. Local annual Medicare spending and local annual mortality rates are calculated based on the cohort of individuals living in each city in 2004, averaged over the post-Katrina period 2006–2013. Each observation in the scatter plot corresponds to a destination city and the size of each circle is proportional to the number of migrants to that city. Only destinations with 11 or more migrants, which cover over 90 percent of all migrants, are shown. The orange trendline is from regressing local mortality on local spending over all destination cities, weighting by the number of migrants to each city. The histograms show the migrant-weighted distribution of local spending and mortality among destination cities shown in the scatter plot. The dashed red lines and darkly shaded regions behind the histograms show, respectively, the migrant-weighted mean (μ) and interquartile range ($p_{25} - p_{75}$) for the corresponding characteristic across all destination cities (including those with fewer than 11 migrants).

Tables

Table 1: Summary statistics for the 2004 cohort

	(1) Mean	(2) Std. dev.	(3) Obs.
Panel A: Cross-sectional variables			
Race = black indicator	0.353	0.478	1,279,559
Male indicator	0.422	0.494	1,279,559
Age at baseline	71.106	12.686	1,279,559
Above 64 indicator	0.820	0.385	1,279,559
Moved in 2005-2006	0.052	0.222	1,217,833
Moved in 2005-2006, New Orleans only	0.441	0.497	76,524
Flood depth during Katrina, feet	2.238	2.747	80,607
Panel B: Panel-sectional variables			
Died during the year	0.055	0.228	10,174,633
Enrolled in fee-for-service Medicare	0.802	0.399	10,174,633
Annual Medicare spending (fee-for-service only)	11,913	25,582	8,157,505

Table 2: Concise difference-in-differences mortality estimates

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
		2004 Cohort				1999 Cohort	
2005 x New Orleans	0.55***	0.54***	0.56***	0.82***	0.80***	0.76***	0.74***
	(0.14)	(0.14)	(0.13)	(0.17)	(0.18)	(0.15)	(0.15)
(2006-2013) x New Orleans	-0.36***	-0.39***	-0.28***	-0.39***	-0.42***	-0.45***	-0.48***
	(0.11)	(0.13)	(0.10)	(0.12)	(0.15)	(0.11)	(0.12)
Control for 1999-2001 N.O.	No	No	No	No	No	Yes	Yes
Included controls	A	B	C	A	B	A	B
Dep. var. mean	5.48	5.48	5.48	6.27	6.27	6.27	6.27
Observations	10,174,387	10,174,387	10,174,380	12,843,079	12,843,079	12,843,079	12,843,079

Significance levels: * 10 percent, ** 5 percent, *** 1 percent. The table reports difference-in-differences estimates of equation (2) based on the 2004 cohort (columns (1)-(3)) and the 1999 cohort (columns (4)-(7)). Standard errors (in parentheses) are clustered by beneficiary baseline ZIP codes. Dependent variable is an indicator equal to 0 if a beneficiary was alive during the entire calendar year and equal to 1 if the beneficiary died in a given year. Coefficients and standard errors have been scaled by 100. Controls are as follows: A includes baseline ZIP code and year fixed effects; B also includes fixed effects for each 5-year-age-bin, race, and gender combination. C additionally allows the year fixed to differ by each 5-year-age-bin, race, and gender combination. "Control for 1999-2001 N.O." row indicates whether a fixed effect for New Orleans in 1999–2001 is included (1999 cohort only).

Table 3: Predictors of leaving New Orleans, movers' local mortality rates, and movers' local spending

	(1)	(2)	(3)	(4)	(5)	(6)
	Whether moved		Local mortality rate		Local average spending	
Black	0.139***	0.152***	-0.007	-0.009	170.6	141.3
	(0.041)	(0.039)	(0.022)	(0.022)	(187.4)	(193.0)
Male	-0.036***	-0.037***	0.009***	0.003	-25.7	-27.9
	(0.004)	(0.004)	(0.003)	(0.004)	(20.4)	(23.2)
75 and older	-0.047***	-0.060***	-0.002	-0.009	-0.7	-9.4
	(0.006)	(0.007)	(0.006)	(0.007)	(40.6)	(45.6)
Below median income	0.041***	0.039***	0.001	0.003	25.7	24.9
	(0.006)	(0.008)	(0.005)	(0.007)	(25.5)	(41.4)
Katrina flood level, feet	0.011***	0.010***	0.001	0.000	-2.8	1.7
	(0.002)	(0.002)	(0.001)	(0.001)	(4.9)	(6.3)
Alzheimer's/dementia		-0.050***		0.041***		53.5
		(0.009)		(0.013)		(55.7)
End-stage renal disease		-0.051***		-0.002		63.7
		(0.016)		(0.015)		(84.9)
Heart disease and stroke		0.005		0.010*		36.2
		(0.005)		(0.005)		(27.3)
Blood and kidney disease		0.002		-0.007		-26.3
		(0.006)		(0.006)		(31.4)
Musculoskeletal		-0.001		-0.005		12.1
		(0.004)		(0.006)		(26.1)
Respiratory disease		0.024***		-0.003		-72.6*
		(0.006)		(0.007)		(40.1)
Cancer		-0.068***		-0.006		-33.3
		(0.018)		(0.008)		(41.9)
Diabetes		0.001		0.009*		53.5
		(0.005)		(0.005)		(33.0)
Other		0.007*		-0.005		13.9
		(0.004)		(0.005)		(30.5)
Dep. var. mean	0.441	0.451	4.362	4.361	11624.7	11642.2
Observations	76,524	34,989	32,699	15,345	32,699	15,345
R-squared	0.171	0.175	0.010	0.015	0.0	0.0

Significance levels: * 10 percent, ** 5 percent, *** 1 percent. Standard errors (in parentheses) are clustered by beneficiary 2006 HSAs. The dependent variable is specified at the top of each column. All regressions include baseline ZIP code fixed effects.

Table 4: Migrant mortality, by destination mortality and spending (New Orleans movers)

	(1)	(2)	(3)	(4)
Panel A: Local mortality only				
Mean death rate in 2006 HSA	1.04***	1.10***	1.12***	0.98***
	(0.31)	(0.27)	(0.28)	(0.36)
Set of controls	A	B	C	D
Dep. var. mean	5.63	5.63	5.63	6.22
Observations	213,971	213,971	213,893	97,982
R-squared	0.00	0.04	0.04	0.07
Panel B: Local mortality and local spending				
Mean death rate in 2006 HSA	1.10***	1.12***	1.15***	1.03***
	(0.30)	(0.27)	(0.28)	(0.37)
Mean spending in 2006 HSA, thousands	-0.09*	-0.04	-0.04	-0.06
	(0.05)	(0.03)	(0.04)	(0.05)
Set of controls	A	B	C	D
Dep. var. mean	5.63	5.63	5.63	6.22
Observations	213,971	213,971	213,893	97,982
R-squared	0.00	0.04	0.04	0.07

Significance levels: * 10 percent, ** 5 percent, *** 1 percent. The table reports estimates of equation (5). Standard errors (in parentheses) are clustered by a beneficiary's 2006 HSA. Dependent variable is an indicator equal to 0 if a beneficiary was alive during the entire calendar year and equal to 1 if the beneficiary died in a given year. Coefficients and standard errors have been scaled by 100. Controls are as follows: A includes year and baseline ZIP code fixed effects. B adds 5-year-age-bins-by-gender-by-race fixed effects to the controls in A. C controls for 1-year-age-bins-by-gender-by-race fixed effects, and allows year fixed effects to vary by all unique 5-year-age-bins-gender-race combinations as well as by baseline ZIP code. D includes all controls in C, as well as controls for 2004 Medicare spending and chronic conditions.

Table 5: Migrant mortality over time, by destination mortality (New Orleans movers)

	(1)	(2)	(3)	(4)
Mean death rate in 2006 HSA x (2006-2007)	1.42***	1.40***	1.43***	1.13*
	(0.46)	(0.48)	(0.46)	(0.64)
Mean death rate in 2006 HSA x (2008-2013)	0.87**	0.97***	0.99***	0.92**
	(0.34)	(0.28)	(0.29)	(0.41)
Controls	A	B	C	D
Dep. var. mean	5.63	5.63	5.63	6.22
Observations	213,971	213,971	213,893	97,982
R-squared	0.00	0.04	0.04	0.07

Significance levels: * 10 percent, ** 5 percent, *** 1 percent. The table reports estimates of equation (5). Standard errors (in parentheses) are clustered by a beneficiary's 2006 HSA. The dependent variable is an indicator equal to 0 if a beneficiary was alive during the entire calendar year and equal to 1 if the beneficiary died in a given year. Coefficients and standard errors have been scaled by 100. Controls are as follows: A includes year and baseline ZIP code fixed effects. B adds 5-year-age-bins-by-gender-by-race fixed effects to the controls in A. C controls for 1-year-age-bins-by-gender-by-race fixed effects, and and allows year fixed effects to vary by all unique 5-year-age-bins-gender-race combinations as well as by baseline ZIP code. D includes all controls in C, as well as controls for 2004 Medicare spending and chronic conditions.

A Online Appendix

Definition of chronic conditions

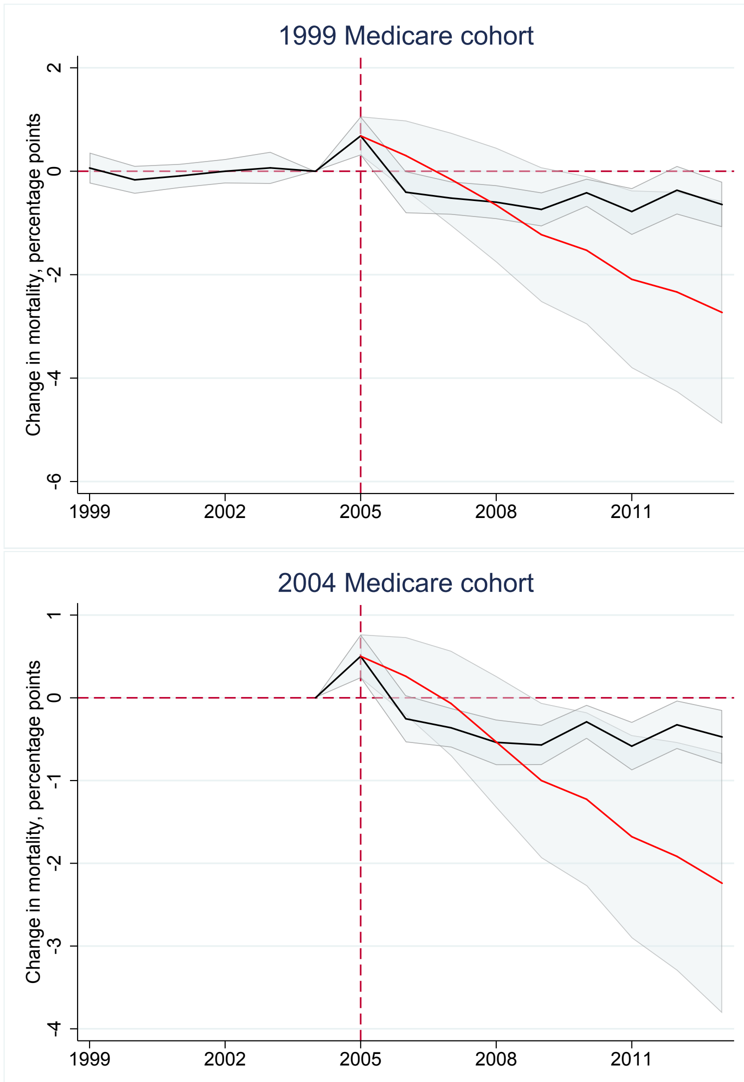
1. Heart disease and stroke: acute myocardial infarction, atrial fibrillation, heart failure, ischemic heart disease, hypertension, stroke/transient ischemic attack
2. Respiratory disease: chronic obstructive pulmonary disease, asthma
3. Blood and kidney disease: chronic kidney disease, anemia, hyperlipidemia
4. Cancer: breast cancer, colorectal cancer, prostate cancer, lunch cancer, endometrial cancer.
5. Diabetes: own category
6. Musculoskeletal: hip fracture, osteoporosis, rheumatoid arthritis/osteoarthritis
7. Dementia: own category, includes Alzheimer's
8. Other: cataracts, glaucoma, hypothyrodism, benign prostatic hyperplasia, and depression

Throughout, we use the end-of-year flags from 2004 to determine whether an individual has a particular condition. For more details on how the chronic conditions flags are defined, see the CMS Chronic Conditions Data Flags Data Dictionary [15]

[15] Available from https://healthcaredelivery.cancer.gov/seermedicare/medicare/chronic-conditions-flags.pdf.

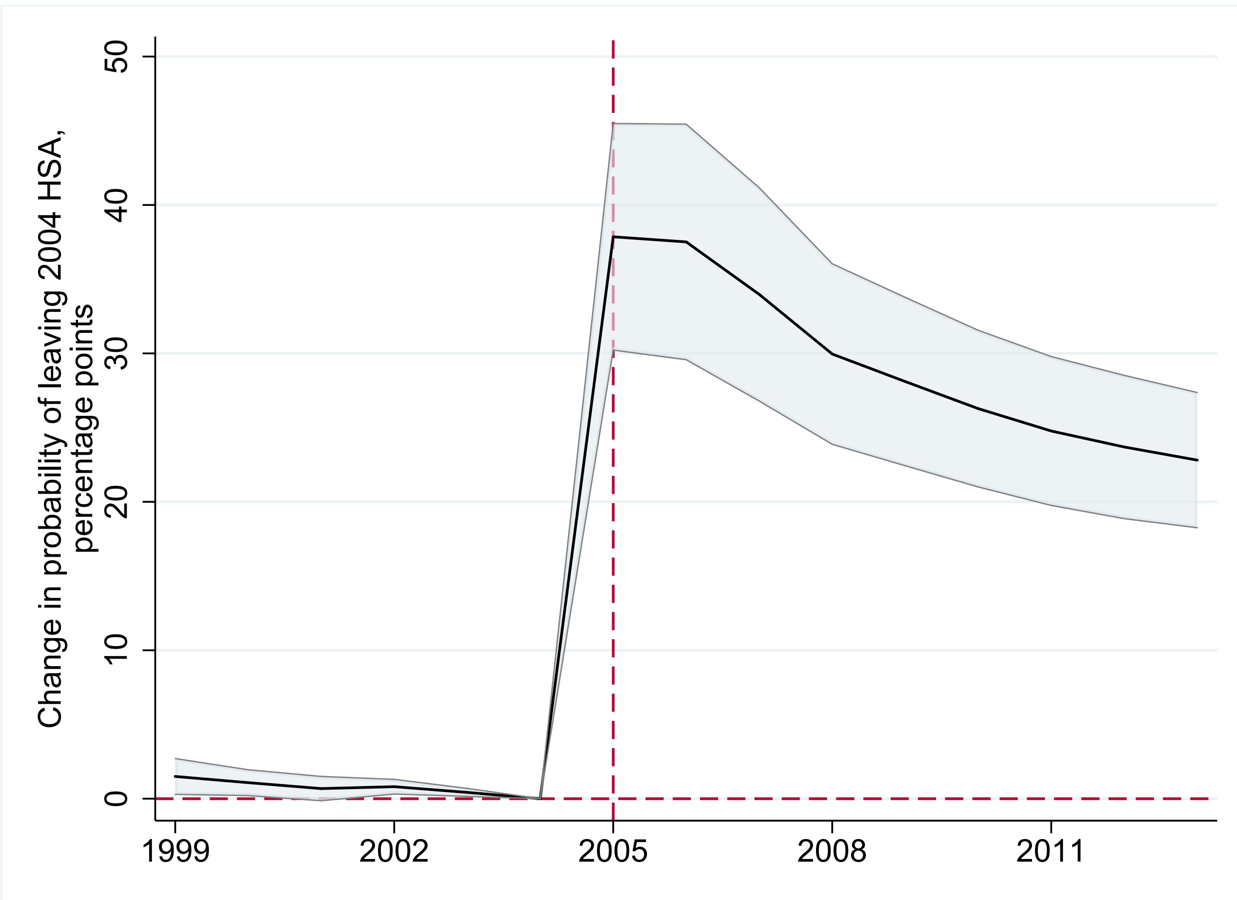
Appendix Figures and Tables

Figure A.1: Long-run mortality effects of Hurricane Katrina (2004 and 1999 Medicare cohorts), using a 50 percent U.S. sample as a control



Notes: The black line plots estimates from equation (2) for the Medicare cohort indicated above each subplot. The red line tracks the implied changes in cumulative mortality probability (equation (3)). The gray shaded areas represent 95 percent confidence intervals based on standard errors that are clustered by beneficiary's baseline ZIP code. The dependent variable is an indicator equal to 0 if a beneficiary was alive during the entire calendar year and equal to 1 if the beneficiary died in a given year. Coefficients and confidence intervals have been scaled by 100 to reflect changes in percentage points.

Figure A.2: Long-run mobility effects of Hurricane Katrina (1999 Medicare cohort)



Notes: The figure shows estimates and 95 percent confidence intervals from equation (2) for the 1999 Medicare cohort. Standard errors are clustered by beneficiary baseline ZIP codes. The dependent variable is an indicator equal to 0 if a beneficiary was living in his or her 2004 HSA of residence in that year and equal to 1 if the beneficiary was living in a different HSA. Coefficients and confidence intervals have been scaled by 100 to reflect changes in percentage points.

Table A.1: Point estimates for Figure 6

(4)	(1) Mortality rate	(2) Cumulative mortality	(3) Leaving 2004 HSA
2005	0.55***	0.55***	41.6***
	(0.14)	(0.14)	(4.3)
2006	-0.25*	0.32	40.5***
	(0.15)	(0.24)	(4.3)
2007	-0.36***	-0.00	36.4***
	(0.13)	(0.33)	(3.9)
2008	-0.48***	-0.41	31.9***
	(0.14)	(0.41)	(3.2)
2009	-0.52***	-0.83*	29.8***
	(0.13)	(0.49)	(2.9)
2010	-0.25**	-1.02*	27.9***
	(0.11)	(0.55)	(2.7)
2011	-0.45***	-1.36**	26.3***
	(0.15)	(0.64)	(2.5)
2012	-0.19	-1.50**	25.1***
	(0.15)	(0.72)	(2.4)
2013	-0.38**	-1.75**	24.1***
	(0.17)	(0.82)	(2.3)
Dep. var. mean	5.48	5.48	8.6
Observations	10,174,387	10,174,387	10,168,746

Significance levels: * 10 percent, ** 5 percent, *** 1 percent. The table reports estimates of equations (2) and (3) from the main text. Standard errors (in parentheses) are clustered by beneficiary baseline ZIP codes. Outcome variables are indicated at top of each column. All regressions include baseline ZIP code and year fixed effects.

Table A.2: Point estimates for Figure 7

	(1) 1992 cohort	(2) 1999 cohort
1992	0.16	
	(0.16)	
1993	0.02	
	(0.15)	
1994	-0.06	
	(0.18)	
1995	-0.00	
	(0.18)	
1996	-0.08	
	(0.15)	
1997	-0.06	
	(0.16)	
1998	0.01	
	(0.15)	
1999	0.06	-0.00
	(0.16)	(0.16)
2000	-0.27	-0.22
	(0.17)	(0.14)
2001	-0.12	-0.09
	(0.17)	(0.12)
2002	-0.06	-0.02
	(0.15)	(0.12)
2003	0.04	0.08
	(0.18)	(0.16)
2005	1.05***	0.78***
	(0.23)	(0.20)
2006	-0.35	-0.37*
	(0.26)	(0.21)
2007	-0.67***	-0.51***
	(0.25)	(0.17)
2008	-0.62**	-0.53***
	(0.28)	(0.17)
2009	-0.73***	-0.63***
	(0.24)	(0.17)
2010	-0.32	-0.29*
	(0.31)	(0.15)
2011	-0.66**	-0.55**
	(0.33)	(0.24)
2012	-0.44	-0.14
	(0.44)	(0.24)
2013	-0.85**	-0.40*
	(0.42)	(0.23)
Dep. var. mean	7.04	6.27
Observations	14,473,864	12,843,079

Significance levels: * 10 percent, ** 5 percent, *** 1 percent. The table reports estimates of equation (2) from the main text. Standard errors (in parentheses) are clustered by beneficiary baseline ZIP codes. The dependent variable is an indicator equal to 0 if a beneficiary was alive during the entire calendar year and equal to 1 if the beneficiary died in a given year. All regressions include ZIP code and year fixed effects.

Table A.3: Heterogeneous mortality effects of Hurricane Katrina (2004 Medicare cohort)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
			Difference-in-differences estimates				
			Short-run (2005)		Long-run (2006-2013)		
Baseline *var*	Percent $var = 1$ in NOLA, 2004	Mean mortality if $var = 1$ in NOLA, 2004	NOLA × 2005	NOLA × 2005 × *var*	NOLA × (2006-2013)	NOLA × (2006-2013) × *var*	Observations
1	100.0	5.0	0.551***		-0.360***		10,174,388
			(0.138)		(0.113)		
Flooded	56.1	5.2	0.551***	0.000	-0.112	-0.441**	10,174,388
			(0.182)	(0.256)	(0.178)	(0.212)	
Below median income	24.3	5.3	0.639***	-0.361	-0.233*	-0.523**	10,174,388
			(0.154)	(0.269)	(0.121)	(0.220)	
Age 75+	40.7	8.1	0.034	1.303***	-0.384***	0.070	10,174,388
			(0.125)	(0.307)	(0.091)	(0.234)	
Black	51.6	5.0	0.807***	-0.489	-0.104	-0.356	10,174,388
			(0.248)	(0.351)	(0.145)	(0.218)	
Male	43.3	5.4	0.462***	0.210	-0.313**	-0.109	10,174,388
			(0.156)	(0.185)	(0.141)	(0.192)	
End-stage renal disease	1.9	19.9	0.567***	0.170	-0.287**	-1.936	10,174,388
			(0.145)	(1.322)	(0.115)	(1.346)	
Heart disease or stroke	64.8	7.7	0.523**	0.207	-0.695***	-0.373	7,140,694
			(0.251)	(0.345)	(0.161)	(0.331)	
Respiratory disease	12.7	12.0	0.368**	1.274**	-1.021***	-0.055	7,774,624
			(0.164)	(0.529)	(0.169)	(0.512)	
Blood or kidney disease	47.2	8.4	0.999***	-0.737***	-0.536***	-0.913***	7,140,694
			(0.184)	(0.259)	(0.129)	(0.296)	
Cancer	6.9	12.8	0.516***	0.152	-1.005***	-0.272	7,774,624
			(0.165)	(1.037)	(0.167)	(0.653)	
Diabetes	26.8	8.7	0.605***	0.226	-0.796***	-0.420	7,140,694
			(0.186)	(0.291)	(0.142)	(0.261)	
Musculoskeletal disease	28.7	6.3	0.310	1.234**	-1.154***	0.827***	7,140,694
			(0.226)	(0.487)	(0.164)	(0.309)	
Alzheimer's/dementia	12.5	19.9	0.456***	3.137***	-0.785***	-1.491*	6,511,643
			(0.174)	(0.928)	(0.160)	(0.888)	
Other chronic condition	40.4	4.5	0.445**	0.377	-1.212***	0.739***	7,774,624
			(0.217)	(0.287)	(0.182)	(0.216)	

Each row reports summary statistics along with short-run (2005) and long-run (2006-2013) mortality effects estimated from a difference-in-differences model where the effect may vary by the individual, baseline characteristic, *var*, specified by the row. Observations are at the individual-year level, and include all Medicare beneficiaries living in New Orleans or one of the 10 control cities in 2004 and who were alive at the beginning of the year of observation. The outcome in each regression is an indicator for whether an individual died that year. All regressions control for baseline ZIP code and calendar year fixed effects. For characteristics that vary within the control cities, regressions further include interactions between the characteristic and calendar-year fixed effects. Standard errors clustered by baseline ZIP code are reported in parentheses. A */**/*** indicates significance at the 10%/5%/1% levels, respectively.

Table A.4: Point estimates for Figure A1

	(1)	(2)	(3)	(4)
	Mortality rate		Cumulative mortality	
	1999 cohort	2004 cohort	1999 cohort	2004 cohort
1999	0.06			
	(0.15)			
2000	-0.17			
	(0.14)			
2001	-0.09			
	(0.12)			
2002	0.00			
	(0.12)			
2003	0.06			
	(0.16)			
2005	0.68***	0.50***	0.68***	0.50***
	(0.19)	(0.13)	(0.19)	(0.13)
2006	-0.41**	-0.25*	0.30	0.26
	(0.21)	(0.14)	(0.35)	(0.24)
2007	-0.52***	-0.36***	-0.16	-0.07
	(0.16)	(0.12)	(0.46)	(0.32)
2008	-0.60***	-0.54***	-0.65	-0.53
	(0.17)	(0.14)	(0.56)	(0.41)
2009	-0.74***	-0.57***	-1.23*	-1.00**
	(0.17)	(0.12)	(0.66)	(0.48)
2010	-0.42***	-0.29***	-1.53**	-1.23**
	(0.14)	(0.10)	(0.73)	(0.54)
2011	-0.78***	-0.58***	-2.09**	-1.68***
	(0.23)	(0.15)	(0.88)	(0.63)
2012	-0.37	-0.33**	-2.33**	-1.92***
	(0.24)	(0.15)	(0.99)	(0.70)
2013	-0.64***	-0.47***	-2.73**	-2.24***
	(0.22)	(0.17)	(1.10)	(0.80)
Dep. var. mean	5.95	5.16	5.95	5.16
Observations	206,069,664	171,138,064	206,069,664	171,138,064

Significance levels: * 10 percent, ** 5 percent, *** 1 percent. The table reports estimates of equations (2) and (3) from the main text. Standard errors (in parentheses) are clustered by beneficiary baseline ZIP codes. Dependent variables are indicated at top of each column. All regressions include baseline ZIP code and year fixed effects.

Table A.5: Migrant mortality, by destination mortality and spending (later New Orleans movers)

	(1)	(2)	(3)	(4)
	Panel A: Local mortality only			
Mean death rate in 2006 HSA	0.87***	0.86***	0.88***	0.72*
	(0.30)	(0.29)	(0.30)	(0.39)
Set of controls	A	B	C	D
Dep. var. mean	5.95	5.95	5.95	6.50
Observations	201,863	201,863	201,810	94,384
R-squared	0.00	0.04	0.05	0.07
	Panel B: Local mortality and local spending			
Mean death rate in 2006 HSA	0.92***	0.90***	0.91***	0.76*
	(0.30)	(0.31)	(0.31)	(0.40)
Mean spending in 2006 HSA, thousands	-0.07	-0.05	-0.05	-0.05
	(0.05)	(0.05)	(0.05)	(0.06)
Set of controls	A	B	C	D
Dep. var. mean	5.95	5.95	5.95	6.50
Observations	201,863	201,863	201,810	94,384
R-squared	0.00	0.04	0.05	0.07

Significance levels: * 10 percent, ** 5 percent, *** 1 percent. Standard errors (in parentheses) are clustered by a beneficiary's 2006 HSA. The dependent variable is an indicator equal to 0 if a beneficiary was alive during the entire calendar year and equal to 1 if the beneficiary died in a given year. Coefficients and standard errors have been scaled by 100. Controls are as follows: A includes year and baseline ZIP code fixed effects. B adds 5-year-age-bins-by-gender-by-race fixed effects to the controls in A. C controls for 1-year-age-bins-by-gender-by-race fixed effects, and allows year fixed effects to vary by all unique 5-year-age-bins-gender-race combinations as well as by baseline ZIP code. D includes all controls in C, and also controls for 2004 Medicare spending and chronic conditions.

Table A.6: Robustness of relationship between New Orleans movers' own mortality and local mortality

	(1)	(2)	(3)	(4)
Panel A: Including 2004 cohorts' 2004-2005 mortality experience				
Mean death rate in 2006 HSA	0.89***	0.91***	0.93***	0.81***
	(0.25)	(0.23)	(0.23)	(0.30)
Set of controls	A	B	C	D
Dep. var. mean	5.63	5.63	5.63	6.22
Observations	213,971	213,971	213,893	97,982
R-squared	0.00	0.04	0.04	0.07
Panel B: Excluding Houston and Baton Rouge				
Mean death rate in 2006 HSA	0.85***	1.12***	1.12***	0.92**
	(0.30)	(0.30)	(0.31)	(0.42)
Set of controls	A	B	C	D
Dep. var. mean	5.78	5.78	5.77	6.40
Observations	153,173	153,173	153,107	70,282
R-squared	0.00	0.04	0.05	0.07

Significance levels: * 10 percent, ** 5 percent, *** 1 percent. Standard errors (in parentheses) are clustered by a beneficiary's 2006 HSA. The dependent variable is an indicator equal to 0 if a beneficiary was alive during the entire calendar year and equal to 1 if the beneficiary died in a given year. Coefficients and standard errors have been scaled by 100. Controls are as follows: A includes year and baseline ZIP code fixed effects. B adds 5-year-age-bins-by-gender-by-race fixed effects to the controls in A. C controls for 1-year-age-bins-by-gender-by-race fixed effects, and and allows year fixed effects to vary by all unique 5-year-age-bins-gender-race combinations as well as by baseline ZIP code. D includes all controls in C, and also controls for 2004 Medicare spending and chronic conditions.