**Technical Appendix: Methodology**

Our model seeks to allocate the national costs in each cost category (fatality, health, criminal justice, and productivity) to each state in the state-level analysis. Then, we distribute the state costs in each cost category among the counties in the county-level analysis. We restrict our county-level analysis to those with population over 2,500.

***Overall Cost Estimates***

The overall cost of the opioid crisis is defined as the sum of fatality costs and non-mortality costs (health, criminal justice, and productivity).

*Fatality Costs*

Fatality costs are calculated by applying an age-dependent Value of a Statistical Life (VSL) to the number of opioid deaths in a year.

Aldy and Viscusi (2008) indicate that the VSL varies by age. Using guidance from the US Department of Transportation (2016b), we update Aldy and Viscusi’s estimates for each year from 2009 to 2018.

Opioid deaths from the CDC’s WONDER database are associated with the following ICD-10 codes: T40.0 (Opium), T40.1 (Heroin), T40.2 (Other opioids), T40.3 (Methadone), T40.4 (Other synthetic narcotics), and T40.6 (Other and unspecified narcotics). We follow Ruhm (2017) and assume that the proportion of unspecified drug-related deaths caused by opioids is the same as the proportion of drug deaths with an identified cause within an age group and year. The models estimated in Ruhm (2017) indicate that the proportion of unidentified deaths that are attributable to opioids is uncorrelated with geography, so we use the public Mortality Multiple Cause files to derive national estimates of underreporting rates and then apply the estimated rate uniformly across counties and states.

Finally, to calculate fatality costs, we multiply the adjusted number of opioid-related fatalities for an age group by the associated VSL for that year, and then sum across age groups.

*Non-mortality Costs*

Consistent with Florence (2016), we calculate non-fatal costs by applying a cost per-user to the number of cases of opioid dependence or abuse in a given year. Florence (2016) estimates health, criminal justice, and lost productivity costs per opioid abuser in 2013. To obtain a per-user cost in other years, we index the 2013 health cost to the Medical Care Services CPI from the BLS, the criminal justice cost to the Bureau of Prison’s average cost of incarceration for Federal inmates, and the productivity cost to the BLS non-farm labor productivity index.

This per-user cost is then applied to the number of those with opioid abuse/dependence in the Substance Abuse and Mental Health Data Archive (SAMHDA)’s National Survey on Drug Use and Health (NSDUH). As in Florence (2016), we define opioid abuse/dependence as the number of either pain reliever abuse/dependence and/or heroin abuse/dependence.

***State/County Level Mortality Costs***

We determine the weights to distribute the mortality costs using estimates of opioid-related deaths derived from the CDC Wide-ranging Online Data for Epidemiologic Research (WONDER) database.

For state, *s*, mortality-related costs, , are calculated using the following methodology. Let indicate the number of opioid-related deaths in state, *s*.

We use the same methodology to allocate mortality-related costs among counties within states. However, CDC WONDER does not report deaths for every U.S. County. We therefore model the number of opioid-related deaths where the data is missing using one of two models. For counties with data on overall drug-related deaths (ICD-10: Drug poisonings (overdose) Unintentional (X40-X44), Drug poisonings (overdose) Suicide (X60-X64), Drug poisonings (overdose) Homicide (X85), Drug poisonings (overdose) Undetermined (Y10-Y14)), we predict the number of opioid-related deaths using a mixed-effects negative binomial model. In the model, we use the following dependent variables: the log of the count of drug-related deaths, the log of the estimated number of people who use pain relievers for nonmedical use, the log of the population, the log of the median household income in the county, the proportion of the population who live in rural areas, the proportion of the population who are Black, the proportion of the population who are Hispanic, and the proportion of the population who have not graduated high-school. The model also includes a state-level random effect. For the counties without any death data, we use the same model, excluding the count of drug-related deaths as a covariate.

We allocate mortality-related costs among the counties within a state using the following methodology. Let indicate the estimated number of deaths in county, *c*, in state, *s*; and represent the predicted mortality-related costs within each county.

***State/County Level Healthcare-related Costs***

We determine the weights associated with healthcare-related costs using opioid-related hospitalization cost estimates from the Agency from Healthcare Research and Quality’s Healthcare Cost and Utilization project (HCUP). In 2015 HCUP reported the total number of discharges and total costs associated with opioid-related conditions for 32 states (Arkansas, Arizona, California, Florida, Hawaii, Iowa, Illinois, Indiana, Kentucky, Louisiana, Massachusetts, Maryland, Maine, Michigan, Minnesota, North Carolina, North Dakota, New Jersey, New Mexico, Nevada, Oklahoma, Oregon, Pennsylvania, Rhode Island, South Carolina, Tennessee, Texas, Utah, Washington, Wisconsin, West Virginia, and Wyoming).

We estimate hospitalization costs in the remaining states and D.C. with a linear regression model. We predict the log of opioid-related hospitalization costs using the log of total population, the log of state-wide opioid deaths, Medicare’s physician fee schedule associated with critical care (CPT code 99291), and log median per capita income. We then exponentiate this prediction and correct for potential non-normality of the residuals to arrive at a state-level hospitalization cost estimate.

For state, *s*, healthcare-related costs, , are estimated as follows. Let indicate either the HCUP estimate of state-level opioid-related hospitalization costs or the prediction derived from our model.

For the county-level estimates, we allocate the state-level costs among the counties with each state. However, HCUP only reports county-level opioid-related hospitalization costs for 1,330 counties. For the remaining counties, we estimate hospitalization costs in the following manner. For counties for which we have estimates of opioid-related deaths, we estimate a mixed-effects linear regression in which we predict the log of total hospitalization costs using the log of opioid deaths, local physician fee schedule for critical care, log of population, log of overall drug deaths, and log of the number of people who use pain relievers for nonmedical use, along with a state-level random effect. We use this model to predict the total hospitalization costs for each county. For counties for which we have data on overall drug related deaths, we estimate the same model, excluding opioid-related deaths. For the remainder, we estimate the same model excluding both opioid and drug-related deaths as covariates.

We allocate healthcare-related costs among the counties within a state using the following methodology. Let indicate the estimated opioid-related hospitalization costs in county, *c*, in state, *s*; and represent the predicted healthcare-related costs within each county.

***State/County Level Productivity-related Costs***

We determine the weights associated with opioid-related productivity loss using household median income, state-level working age population, the proportion of people in the state who use pain relievers for nonmedical use, and the overall loss of productivity due to opioid abuse or dependence. The proportion of individuals who use pain relievers for nonmedical use is collected from the Substance Abuse and Mental Health Services Administration National Surveys on Drug Use and Health from 2012 – 2014. In addition, Florence (2016) estimates that drug abuse/dependence contributes to a 17 to 18 percent decrease in productivity.

We first estimate county-level productivity related costs, and then aggregate to the state level.

For county*, c*, in state*, s*, productivity-related costs, , are estimated as follows. Let represent median household income in the state; let represent the population between 25 and 64 years of age; let indicate represent the proportion of people who use pain relievers from nonmedical use.

We then aggregate county-level costs to the state-level in order to derive state-level estimates of productivity costs, .

***State/County Level Criminal Justice Costs***

Unlike with the prior categories, we lack local estimates of criminal costs. As such, we utilize state-level estimates of per capita criminal costs and then weight them among counties proportionally according to the number of individuals who use pain relievers for nonmedical use.

For county*, c*, in state*, s*, criminal justice-related costs, , are estimated as follows. Let represent per capital criminal justice expenditures, as reported by the Bureau of Justice Statistics (2015, 2016); let represent the overall county population; let indicate represent the proportion of people who use pain relievers from nonmedical use.

We then aggregate county-level costs to the state-level in order to derive state-level estimates of productivity costs, .

***Local Diffusion***

To examine the dynamics of the spatial diffusion of the crisis, we estimate a series of time-space recursive spatial models (see Anselin et al. (2008) for details) in which we predict the mortality rate in a focal county and year based on the prior year’s mortality rate for the focal county and the prior year’s mortality rate for all other counties within 100 miles. All models rely on data from 2008 to -2018, include state and year fixed effects, and controls for the unemployment rate and urbanization level. Robust standard errors are clustered by the county level. See “Code/diffusion.R” and “Code/diffusion/diffusion.do” for detailed implementation.

In calculating mortality rates for counties within 100 miles of a focal county (“nearby counties”), we divide the sum of the opioid-related mortality count by the total population (for all counties with data) and then multiply by 100,000. Counties within 100 miles are identified using the National Bureau of Economic Research Census County Distance Database, which calculates great-circle distances to Census-designated centers of counties.

Illegal opioid–-related deaths are defined as those with MCD codes that include opium (T40.0), heroin (T40.1), or other synthetic narcotics (T40.4). Opium and heroin can only be obtained illegally, and according to the CDC, most deaths caused by synthetic narcotics are due to illegally made fentanyl. We define prescription- opioids deaths as those with MCD codes containing either methadone (T40.3) or other opioids (T40.2). We exclude deaths whose only relevant MCD code is other and unspecified narcotics (T40.6), as we cannot determine whether these deaths were caused by legal or illegal drugs.

**Data Sources**

*Criminal Justice Costs*: BJS Justice Expenditure and Employment Extracts, Bureau of Justice Statistics. <https://www.bjs.gov/index.cfm?ty=pbse&sid=33> [2015-16]

*Consumer Price Index:*  Bureau of Labor Statistics. <https://fred.stlouisfed.org/series/CPIAUCSL> [2007-18]

*Cost of Incarceration for Federal Inmates:* Bureau of Prisons Cost of Incarceration Fee, Department of Justice. <https://www.federalregister.gov/documents/2019/11/19/2019-24942/annual-determination-of-average-cost-of-incarceration-fee-coif> (link is to cost for 2018, similar reports exist for 2007-17) [2007-18]

*County Distances*: County Distance Database, National Bureau of Economic Research. <https://data.nber.org/data/county-distance-database.html>

*Educational Attainment*: American Community Survey. United States Census Bureau. https://www.census.gov/programs-surveys/acs/data.html. [2015-2018; 5-year estimates]

*Hospitalization costs*: HCUPnet, Healthcare Cost and Utilization Project. Agency for Healthcare Research and Quality. <https://hcupnet.ahrq.gov> [2014-15]

*Median Income*: Small Area Income and Poverty Estimates Program. United States Census Bureau. <https://www.census.gov/data/datasets/2016/demo/saipe/2016-state-and-county.html> (link is for 2016 data but data for 2015, 17-18 are also available) [2015-18 estimates].

*Medical Care Services Consumer Price Index:* Consumer Price Index for All Urban Consumers: Medical Care Services in U.S. City Average, Bureau of Labor Statistics. <https://fred.stlouisfed.org/series/CUUR0000SAM2> [2007-2018]

*Nonmedical Use of Pain Relievers, Substate/Metro*: National Surveys on Drug Use and Health. Substance Abuse and Mental Health Services Administration. <https://pdas.samhsa.gov/saes/substate>. [Substate/Metro; 2012-2014]

*Opioid-related and Drug-related deaths*: CDC WONDER Multiple Cause of Death database. <https://wonder.cdc.gov/mcd-icd10.html>. [2014-18]

*Pain-killer abuse/misuse and Heroin abuse/misuse:* National Surveys on Drug Use and Health. Substance Abuse and Mental Health Services Administration. <https://pdas.samhsa.gov/#/survey/NSDUH-2018-DS0001> (link is for 2018 but 2015-17 data are also available). [2015-18]

*Physician Fee Schedule*: Medicare Physician Fee Schedule. Centers for Medicare and Medicaid Services. <https://www.cms.gov/apps/physician-fee-schedule/overview.aspx> [2015-18]

*Productivity (non-farm businesses)*: Division of Major Sector Productivity, Bureau of Labor Statistics. <https://www.bls.gov/news.release/prod2.nr0.htm> [2007-18]

*Population (total and working age)*: American Community Survey. United States Census Bureau. <https://www.census.gov/programs-surveys/acs/data.html> [2015-2018; 5-year estimates]

*Racial composition*: American Community Survey. United States Census Bureau. <https://www.census.gov/programs-surveys/acs/data.html> [2015-2018; 5-year estimates]