The Opioid Crisis and the Location of Work: Evidence from Online Job Profile Data

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Abstract

While growing evidence indicates that the opioid crisis has led to a reduction in local labor supply, whether this decline can be attributable to worker flow in and out of the local area remains unclear. Using over 130 million online job profiles of workers in the US, this paper investigates the effect of the opioid crisis on workers' location choices. Our job profile data capture worker-level job transitions from 2007 to 2019, allowing us to measure the inflow and outflow of workers for every county pair. We use a difference-in-differences design that leverages geographic variation in exposure to the 2010 reformulation of OxyContin, which led to a large transition from prescription opioids to illicit opioids. We find strong evidence that this transition toward illicit opioids resulted in an increased net outflow of workers away from counties more affected by the reformulation relative to those less affected. Moreover, we show that the increase in net outflow is more pronounced among higher-skilled workers, leading to a substantial decrease in the average skill level of the workers in highly exposed areas. Finally, we investigate the economic consequences of the net outflow among high-skilled workers and demonstrate that the reformulation is associated with a decline in local innovation in terms of patent filings and startup formation. Overall, our findings suggest that the opioid crisis adversely affects both the quantity and quality of local labor supply by influencing workers' location choices, eventually leading to a deterioration in the economic prospects of affected areas.

JEL classification: I12, I18, J61, O31
Keywords: Opioid crisis, OxyContin reformulation, Skilled migration, Innovation

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1 Introduction

With the deepening of the opioid crisis, its impact on the labor market has been increasingly receiving attention from researchers and policymakers in the United States.[1] Recent studies have documented that the opioid epidemic has lowered local labor supply in terms of labor force participation rate, employment rate, hours worked, and earnings in the areas highly exposed to the crisis (Krueger, 2017; Harris et al., 2020a; Park and Powell, 2021; Alpert et al., 2022; Beheshti, 2022; Aliprantis et al., 2023). Despite theses findings, the mechanisms driving these changes remain largely unexplored. One possible explanation is that increased opioid use among workers leads to a decline in individual labor supply. Alternatively, the decline may be attributed to workers relocating from areas heavily impacted by the opioid crisis. While these explanations are not mutually exclusive, understanding each mechanism is crucial for inform policies aimed at mitigating the adverse labor market outcomes of the opioid crisis.

In this paper, we explore the second explanation: are workers moving away from areas heavily impacted by the opioid crisis? Using individual-level data on online job profiles of workers in the US, we find that the opioid crisis has indeed increased the net outflow of workers away from the counties more affected by the crisis. Furthermore, by analyzing detailed data regarding workers' skill levels, we demonstrate that this effect on outflow is concentrated among higher-skilled workers. As a result, we find a significant decline in the average skill level in more severely affected areas. Finally, to understand economic implications of this worker relocation effect, we examine the impact of the opioid crisis on local innovation activities. We find that greater exposure to the crisis is associated with reduced innovation in terms of patent filings and startup formation. Our results highlight the opioid crisis's long-term economic implications through the outflow of higher-skilled workers.

Despite its importance, estimating the causal effect of the opioid crisis on workers' inflow and outflow is empirically challenging for two reasons. First, there are concerns around common causes and reverse causality. For instance, worsening economic conditions could both contribute to an increase in opioid usage and also affect location choices among workers. Furthermore, the relocation decisions of workers might reversely affect local opioid consumption patterns by altering the demographic composition of opioid users and non-users within the area. To address these concerns, we need exogenous variation in exposure to the opioid crisis to identify the causal effects. Second, to measure inflow and outflow of workers, we need comprehensive data on job

[1] The opioid crisis is a major public health concern in the United States. Over a million people have died since 1999 from a drug overdose, majority of which involved opioids. From 1999 to 2021, the number of fatal opioid overdoses increased more than tenfold (Ahmad et al., 2024).

transitions for a representative sample, yet such data are often lacking or available for only a small subset of the US workforce.

To overcome concerns around endogeneity, we exploit plausibly-exogenous variation generated by the reformulation of OxyContin, an intervention that inadvertently shifted users from prescription opioids toward riskier and unregulated illicitly-manufactured opioids. Prior to the reformulation, OxyContin had been widely used for nonmedical purposes (Cicero et al., 2005). In response to increasing OxyContin abuse, Purdue Pharma introduced an abuse-deterrent version of OxyContin in August 2010, substituting the original formulation. The reformulation marks one of the most substantial reductions in abusable prescription opioids. Prior research suggests that while the reformulation reduced OxyContin misuse, it induced drug users to switch from abusable prescription opioids to illicit opioids (Cicero and Ellis, 2015; Cicero et al., 2015). Moreover, previous studies have shown that areas with higher use of OxyContin in the pre-reformulation period experienced disproportionate growth in illicit drug markets, increased rates of heroin-related crime, heroin-involved overdose deaths, and hepatitis B and C infections (Buchmueller and Carey, 2018; Alpert et al., 2018; Evans et al., 2019; Powell et al., 2019; Beheshti, 2019; Powell and Pacula, 2021). Building on this literature, we investigate how this sharp transition toward illicit drugs affects choices of work location.

To identify a worker's job transition across areas, we use the Lightcast Job Profile Database, which contains the longitudinal job history of more than 130 million workers in the US. These data allow us to capture job switchers' origin, destination, and transition date. The data also include detailed information on each worker's educational background and skills as well as information on each job, such as employer name, industry, and occupation. This information is crucial for understanding the characteristics of relocating workers and the context of their relocation. Most importantly, information on skill sets allow us to investigate the heterogeneous migration patterns across different skill levels among various skill categories such as cognitive, software, and social skills. To our best knowledge, this is the only data source providing such detailed information on worker transfers at granular geographic levels like counties.[2] We also use several complementary data sets on the housing market and innovation to understand the mechanisms and the long-term economic consequences in local communities.

The shift toward illicit opioids can influence workers' location choices in many different ways. First, rising concerns about opioid-related crime and safety, as documented in the literature, may

[2]For instance, relocation information in the American Community Surveys (ACS) does not cover all counties. The Current Population Survey (CPS) has a limited sample size, preventing accurate county-level estimates, and data for many counties are not available due to confidentiality concerns. Although the IRS Statistics of Income (IRS SOI) data provide the aggregate number of migrants between counties and the average income level at the county level, they lack additional details on worker education or skill levels.

decrease the value of local amenities, thereby making highly exposed areas less attractive to live and work in. Second, if the decreased amenity value leads to lower housing prices, it may attract workers who are more sensitive to housing costs. Third, the expansion of illicit drug markets may attract certain types of workers seeking an accessible and stable source of opioids. Workers consider various factors in their location decisions, so the transition towards illicit opioid use might impact them differently depending on their unique needs and priorities. Our worker-level job transition data allow us to explore the heterogeneous effect on the decision of location among workers of various job skill levels and demographic characteristics.

We use a difference-in-differences event study design that compares counties with higher initial rates of prescription opioid use and those with lower initial rates of prescription opioid use, following the approach suggested by prior research (Alpert et al., 2018; Evans et al., 2022). The idea is that counties with higher initial prescription opioid use prior to the reformulation are likely more affected by the shift towards illegal substances resulting from reformulation. Using this approach, we investigate whether areas with higher exposure to reformulation experience a greater inflow or outflow of workers compared to less exposed areas. One concern with our analysis is the presence of a potential confounder, such as the Great Recession around 2008, which could have disproportionately affected areas that were highly exposed to the reformulation. To account for potential confounding effects, we explicitly control for county-level exposure to the 2008 Great Recession interacted with time fixed effects as well as state-by-time fixed effects in our econometric model.

We find that the shift toward illicit opioids resulted in a rise in both inflow and outflow of workers. Nevertheless, the increase in outflow is substantially more pronounced, resulting in a net outflow of workers away from highly exposed counties. Our results indicate that a one standard deviation increase in pre-intervention opioid prescriptions per capita (0.852 opioid prescriptions per capita) results in a 10 percent increase in outflow workers and a 5.3 percent increase in inflow workers during the first ten years following the reformulation. As a result, this leads to a 4 percent increase in the relative outflow (ratio of outflow workers to inflow workers) during the same period.

Our analysis reveals important heterogeneity in relocation responses across worker skill levels: the increase in the inflow of workers is entirely driven by less-skilled workers, while there is not much heterogeneity in the outflow of workers across skill levels. This implies that the net outflow among less-skilled workers remains largely unchanged due to these balancing effects, while there is a significant rise in net outflow away from highly exposed areas among higher-skilled workers. Importantly, we find that this outflow of higher-skilled workers has led to a reduction in the average skill level of workers in these counties. A one standard deviation increase in exposure to

the reformulation leads to an average decline in cognitive and software skills by 2.2 percent and 3.7 percent, respectively. Our event study estimates indicate that the impact on worker relocation decisions and the average skill levels in local areas persists over the decade following the reformulation.

To understand the economic implications of the degradation in local skill levels, we explore the impact of reformulation on local innovation activities. We find that the number of patents and startups and their quality significantly decreased in highly exposed counties during the decade following reformulation. In addition, we explore a possible explanation for the increased inflow of less-skilled workers into high-exposure areas and provide suggestive evidence that counties more severely affected by reformulation experience the decline in housing costs. In summary, our findings underscore the prolonged negative economic consequences of the net outflow of high-skilled workers, triggered by the trend towards illicit drug use.

This paper contributes to three strands of literature. First, we contribute to the growing literature on the labor market impact of the opioid crisis. Previous research documents that a higher local prescription rate reduces local labor supply in terms of labor force participation, employment rate, and labor productivity (Krueger, 2017; Harris et al., 2020a; Park and Powell, 2021; Alpert et al., 2022; Aliprantis et al., 2023). For instance, Park and Powell (2021) use state-level variation in exposure to the reformulation of OxyContin and find that one standard deviation increase in exposure to reformulation predicts an additional 1.2 percent reduction in employment. However, despite the increasing evidence, the exact mechanisms driving such a large labor supply impact of the opioid crisis has remained largely unknown. Our study contributes to the literature by suggesting that worker relocation may be a crucial channel through which the opioid crisis influences local labor supply. It is noteworthy that the opioid crisis could influence relocation decisions among workers, regardless of whether they have a history of opioid use. Consequently, the overall impact on the local labor market could be significantly greater than in a scenario where only opioid users are affected. To the best of our knowledge, our paper is the fist to report that the opioid epidemic lowers the average skill level in highly exposed local labor markets through workers' migration patterns.

Second, we contribute to the extensive literature studying the consequences of the opioid crisis. Prior research has documented its wide-ranging effects on outcomes such as crime (Deiana and Giua, 2021; Mallatt, 2022), children's well-being (Ziedan and Kaestner, 2020; Evans et al., 2022), and the housing market (Custodio et al., 2023), highlighting the profound implications of the opioid crisis on various aspects of life. Moreover, recent studies have investigated the economic consequences of the opioid crisis and documented the adverse impact on firm value (Ouimet et al.,

2020), the financing costs of local governments (Li and Zhu, 2019), municipal finance (Cornaggia et al., 2022), and corporate innovation (Chen et al., 2021). Our study adds to this literature by demonstrating that the opioid crisis affects workers' relocation decisions, ultimately reducing innovation activities of regions through the net outflow of higher-skilled workers.

Finally, We contribute to the literature studying the impact of public health shocks on migration decisions. Recent work by Chen et al. (2022) shows that air pollution is responsible for large changes in inflows and outflows of migration in Chinese counties. They also find that these migration responses are largely driven by well-educated individuals at the early stages of their professional careers. Trinh et al. (2021) find that more severe natural disasters directly increase the likelihood of migration in Vietnam, with this effect being consistent across both economically disadvantaged and advantaged households. Our work shows that increasing use of illicit opioids—a major public concern in the US—has had a significant impact on worker location choices, and these relocation responses differ across worker skill levels.

Overall, we conclude that the transition from prescription opioids to illicit opioids has detrimentally affected both the quantity and quality of the local labor supply through worker relocation. Our findings are highly policy-relevant in several aspects. First, our study highlights the need for diverse policy interventions that extend beyond providing access to opioid use treatment. For instance, implementing strategies to retain more-skilled workers within the community or to attract them from other communities could play a pivotal role in alleviating the adverse labor market and economic consequences. Second, our findings of worker relocation and reduced innovation suggest that the opioid crisis may have enduring implications for local economy. If the decline in innovation over the short to medium term accelerates the outflow of higher-skilled workers, it may induce a harmful cycle that negatively impacts both the labor market and economic health.[3] This underscores the importance of early interventions to counteract the worker outflow to address the negative consequences of the opioid crisis on local economies and labor markets.

The remainder of the paper proceeds as follows. Section 2 provides background on OxyContin reformulation and its potential impacts on migration. Section 3 provides details on the data, and Section 4 outlines our empirical strategies. Section 5 provides the main results, mechanisms, and robustness exercises. Section 6 discusses policy implications and concludes.

[3]There is a well-documented causal link between migration and innovation (Hunt and Gauthier-Loiselle, 2010; Bosetti et al., 2015; Peri et al., 2015; Kerr et al., 2017; Azoulay et al., 2022; Bernstein et al., 2022; Glennon, 2024; Lissoni and Miguelez, 2024).

2 Background

OxyContin, introduced by Purdue Pharma in 1996, is a brand-name version of the extended-release form of oxycodone that acts for 12 hours. Purdue Pharma aggressively marketed OxyContin, targeting primary care providers for the treatment of non-cancer chronic pain, pushing for more lenient prescribing standards (Van Zee, 2009). This marketing strategy led to OxyContin being prescribed to a broader population. As a result, OxyContin's sales skyrocketed from $48 million in 1996 to nearly $1.1 billion by 2000 (Van Zee, 2009). The widespread availability of OxyContin was associated with a rise in its misuse, diversion, and addiction rates, making it one of the most abused drugs in the United States by 2004 (Cicero et al., 2005). Recent studies have indicated that its introduction and promotional targeting significantly account for the increases in the supply of prescription opioids and overdose incidents since 1996 (Alpert et al., 2022; Arteaga and Barone, 2022).

In April 2010, Purdue Pharma unveiled a reformulated version of OxyContin with the primary objective of rendering the drug less susceptible to abuse. By August 2010, Purdue Pharma had ceased the distribution of the original OxyContin formulation to pharmacies. This newly designed variant marked the FDA's inaugural "abuse-deterrent" designation for any pharmaceutical product. This abuse-deterrent version deployed physical and chemical obstacles to render the pill-resistant to breaking, crushing, or dissolution, thereby discouraging the most harmful forms of misuse. Critically, it retained its pain-relief properties for legitimate medical users who ingested the medication orally.[4]

To show how much the reformulation affected the distribution of OxyContin and oxycodone in general, we present the national trend in the prescription of OxyContin and oxycodone from January 2008 to December 2012, around the time of reformulation, in Appendix Figure A1. We use the database on all legal opioid dosages from the Automated Reports and Consolidated Ordering System (ARCOS) published by the Washington Post.[5] Panel (a) reports the trends of the per capita Morphine Equivalent Dose (MED) of total oxycodone (blue hollow circles) and high-dosage OxyContin (red diamonds), which is more susceptible to abuse (Janssen and Zhang, 2023). The figure clearly shows that the high-dosage OxyContin sharply dropped immediately following the release of the new formula in August 2010, ceasing the increasing trend of overall oxycodone distribution. As shown in panel (b), the sudden drop was also noticeable in the per

[4]However, it is imperative to acknowledge that while the reformulation made abuse more difficult, it did not render it entirely "abuse-proof." Oral misuse, involving the consumption of more pills or higher doses than prescribed, remained a possibility, and some individuals found methods to circumvent the abuse-deterrent features of the new version.

[5]The database managed by the Drug Enforcement Administration (DEA) traces every single pain pill sold in the United States from manufacturers and distributors to pharmacies. Refer to the website of the Washington Post for more information.

capita MED of total OxyContin, which accounts for about a third of the per capita MED of total oxycodone.

As reported by the growing number of papers in the literature, the reformulation of OxyContin had unintended consequences, leading to a significant shift from prescription opioids to illicit opioids. It also contributed to the expansion of the illegal drug market and introduced a new population to potent illicit opioids. Cicero et al. (2015) surveyed 153 recreational OxyContin users, finding that 33% of them switched to other substances due to the reformulation, with 70% of this group moving to heroin. Consistent with these survey results, subsequent research finds that while the reformulation reduced OxyContin abuse, the areas with more pre-reformulation opioid prescriptions per capita experienced a more significant increase in fatal overdoses involving heroin and other illicit drugs and more crimes related to illegal opioids (Alpert et al., 2018; Evans et al., 2019; Powell and Pacula, 2021; Mallatt, 2022). Figure 1 displays geographic variation in pre-intervention opioid prescriptions across counties, indicating that the Far West and Southeast could be most affected.

3 Conceptual Framework

The transition toward illicit drug use induced by the OxyContin reformulation may have unintended consequences on worker flow as it affects the characteristics of neighborhoods. First, the induced fatal overdoses and opioid-related crimes in a local community would give an incentive to residents and workers to transfer to other communities where such problems are not prevalent. Second, there is a possibility that the unfavorable changes in a local community may absorb some types of workers having specific purposes. For instance, illicit drug markets stimulated by the reformulation (Powell and Pacula, 2021) may attract drug users who need reliable sources of drugs. It is also possible that the decline in housing costs, which reflects the quality of a local community, could attract workers who search for a lower housing rent but do not care much about illegal opioid use in the neighborhood. Testing these hypotheses requires a separate analysis of the outflow and inflow of workers.

Figure 2 shows the trend in the share of worker outflow among total worker flow (outflow + inflow) for the top 5% counties with the highest pre-reformulation opioid prescriptions and the other 95% of counties. While there is a slightly decreasing national trend in the share of worker outflow in our data, the share for the high-exposed counties strays from the national trend and starts exceeding the share of the other counties after 2010 when Purdue Pharma conducted the drug reformulation. This descriptive result implies that the increase in illegal opioid use in the

high-exposed counties after the reformulation may result in either an increase in outflow or a decrease in inflow.

It is also essential to capture heterogeneous relocation patterns across different types of workers because a change in workforce composition driven by the heterogeneous effects on relocation could have additional policy implications. While the difference in geographic mobility across skill levels could make workers move differently, the incidence of a local shock itself could differ across workers by the context of the shock (Notowidigdo, 2020). Suppose the incidence of the unintended consequences of the reformulation is the same across low-skilled and high-skill workers. In that case, high-skill workers are more likely to move out of neighborhoods with high opioid prescriptions because they are more mobile than low-skilled workers. Similarly, high-skill workers are less likely to move into neighborhoods with high opioid prescriptions.

On the other hand, the incidence of the opioid crisis may differ across skill levels. For instance, the prevalence of illegal opioid use and its aftermath could have disproportionate effects on the community of low-skilled workers because they have a higher rate of opioid overdoses than high-skilled workers (Altekruse et al., 2020; Maclean et al., 2020). Then, the low-skilled workers could have more incentive to transfer to other counties with fewer problems with illegal opioid use than high-skilled workers. On the other hand, if the opioid crisis lowers the quality of the neighborhood and housing rent, it may induce more low-skilled workers to move into the community because they are more sensitive to housing costs than high-skill workers. To tackle these issues, we analyze the effects of OxyContin reformulation on relocation patterns across skill levels.

If the opioid epidemic has heterogeneous effects on local workers with different skill levels, it could also change the overall labor force composition of the local community. This change in skill composition may subsequently affect local innovation activities because a core contributor to knowledge production and the formation of innovative startups is high-skilled workers (Stuen et al., 2012; Bosetti et al., 2015; Kerr et al., 2017; Bernstein et al., 2022). Furthermore, endogenous growth theory and empirical evidence indicate that these innovation activities have considerable repercussions on economic growth (Romer, 1990; Aghion and Howitt, 1992; Jones, 2009; Kogan et al., 2017). Thus, the opioid crisis would degrade the innovative capability and economic growth of the local community in the long run if it raises the probability of high-skilled workers moving out of the affected community or lowers the probability of them moving into the affected community.

4 Data

Understanding the impacts of the opioid crisis on worker flow and regional skill composition requires detailed information on the job transition and the characteristics of workers. Lightcast Job Profile Database ("Lightcast" henceforth) contains the longitudinal job history of more than 130 million workers,[6] collected from online professional profiles and resumes where individuals share information about their employment, skills, and education. Lightcast provides not only worker-level characteristics, such as gender, education level, experience year, and skill sets, but also the detailed characteristics of the job, including job title, employer name, occupation, industry, start and end dates, and location. The dataset contains the workers who are currently in the United States or worked in the United States for their most recent jobs. We observe all job histories for each worker profile, even from other countries.

To measure an individual's skill level, we utilize skill set information. The skill set contains more than 10,000 unique skill keywords, standardized by Lighstcast's algorithm. The list of skills includes general skills (such as communication skills, teamwork, critical thinking, quality control, etc.), specific skills (such as foreign languages, legal compliance, computer numerical control, revenue projections, etc.), and specific software names (such as SAP, Python, Java, SQL, Tensor Flow, ND4J, etc.). We follow Deming and Kahn (2018) who create categories of skill requirements in the Lightcast Job Posting Database because Lightcast constructs unified skill keywords for those two databases. Appendix Table A1 lists the ten skill categories and the corresponding keywords or phrases that belong to each category.[7]

Using Lightcast, we identify a worker's relocation as follows. First, we order each worker's jobs according to their start dates. If the start date of the next job is later than the end date of the previous job, we view that as a job transition. We define a job transition as a relocation if the county codes of the previous job and the next job differ from each other. There could be a time difference between the previous job's end and the next job's start. However, we capture the end date of the previous job as the time of moving to make the outflow and inflow numbers comparable. So, our definition of relocation also includes temporary worker flows to unemployment or out-of-labor force. However, we would like to include these cases because they could also reflect the intention to move out of the local community. We provide robustness checks with different relocation definitions in Section 6.4.

A complication occurs when a worker has multiple jobs at the same time. Even though we

[6] Lightcast employs various machine-learning processes to unify duplicate profiles to create one unique master profile corresponding to one person.

[7] Deming and Kahn (2018) also confirm that the skills in each skill category are prevalent in the job ads of relevant occupations.

identify a relocation following the previous definition, we do not count it as relocation in this case: Suppose a worker changed from Job 1 to Job 2, and the county codes of these jobs differ. The worker had another job (Job 3) during the work period of the following job (Job 2), and the county code of Job 3 is the same as that of Job 1. We do not view the job transition from Job 1 to Job 2 as relocation because it is hard to say that the worker intended to move out of the community of Job 1 to that of Job 2. The counties of Job 1 and Job 2 are also adjacent or border each other in most of these cases.

Note that our definition of relocation does not rule out the case where a worker changes her workplace to another county while staying at her current residence. Though this case is not a relocation per se, we would like to include it in our analysis because this type of job transition could also indicate a worker's location choice in response to the opioid crisis in the area of her workplace. We also check the robustness of our results just with out-of-state relocation, which should incur a residence relocation in most cases.

Since the Lighcast Job Profile Database is new in the literature, we conduct some exercises to check Lighcast's representativeness. First, we compare the geographic variations in our data with those from the county migration flows provided by the Internal Revenue Service Statistics of Income (IRS SOI). The IRS SOI provides the aggregated number of individuals who moved into or out of a county based on the tax records, showing accurate geographic patterns of internal migrants in the US. Note that there are two major distinctions between Lighcast and IRS SOI. First, the IRS only covers US taxpayers and misses foreign workers working in the US, which are covered in Lightcast. Second, the IRS is based on a taxpayer's home address, while Lighcast captures the workplace address. Thus, we compare the patterns of cross-state worker flow from the two data sources, considering that it is likely to cause changes in residence and workplace.

Figure 3 reports the state shares in cross-state worker flow constructed from Lighcast and IRS SOI. The Y-axis of panel (a) plots the state shares in the outflow of workers to other states calculated from Lightcast for 2007, the base year, while the X-axis plots the same statistics calculated from the IRS. We also plot the 45-degree line as a benchmark. All markers should line up on the 45-degree line if the geographical representativeness of Lightcast is the same as that of IRS. In panel (b), we plot the parallel statistics for the inflow of workers from other states. The graphs show that most markers are close to the 45-degree line, and the slopes are around one, indicating that the geographic variation in Lightcast is close to that in the IRS. In Appendix Figure A2, we also report that this geographical representativeness is stable over the period of interest.[8]

[8] Appendix Figure A2 describes the change in the representativeness across states in Lightcast and IRS SOI among out-migrants to other states (panel a) and in-migrants from other states (panel b). The Y-axis in each panel plots the change in the state share from Lightcast from 2007 to 2013, and the X-axis plots the change in the state share from IRS SOI

Second, we compare the occupation and education composition of workers from Lightcast and American Community Surveys (ACS) to see if Lighcast over- or under-represent a subgroup of workers in the US labor market. Figure 4 presents the share of workers with a college degree by 2-digit SOC occupation from Lightcast and ACS. Note that the online job profiles may not report their education information, so about 45% of workers in our sample from Lighcast do not have a college degree, which is higher than in ACS. However, the correlation of the cross-occupation college shares between Lighcast and ACS is 0.965. So, it is unlikely that Lighcast overrepresents a particular skill group of workers within each occupation group. This result is crucial because the effect of the opioid crisis on worker flow considerably differs across occupations, as we show in Subsection 6.1.

Our data on county-level prescription opioid use are from the Centers for Disease Control (CDC). This dataset comprises an 85 percent sample of retail pharmacy providers. Within our dataset, a compelling pattern emerges: median per capita opioid prescriptions show a steady increase until they reach a peak in the year 2012, after which they undergo a noticeable decline. It is worth noting that other researchers, such as Alpert et al. (2018) and Evans et al. (2019) have explored national trends in OxyContin abuse using distinct measures. Their findings reveal a peak in 2010, a peak that coincides with the drug's reformulation, occurring approximately two years earlier than the peak observed in the median opioid prescriptions within our dataset.

Our measure of local innovations comprises patents and startups. County-level patent information is collected from PatentsView, a data platform sponsored by the United States Patent and Trademark Office (USPTO). To be consistent with our analysis focusing on workers, not firms, we match each patent with a county based on the inventor's location rather than the assignee's location. We use the number of patents and patent citations at the county level. We collect information on local startups from the Startup Cartography Project, a project by the MIT Innovation Initiative, as an alternative measure of local innovation. The project leverages population-level business registration records to construct the measures of quality and quantity of startups at the local level in the United States. From the database, we employ the number of newly registered startups within a county and the number of startups within a county expected to achieve a significant growth outcome later, the latter of which is predicted by their algorithm.[9] To capture how the neighborhood quality changes in response to the opioid crisis, we also use the S&P CoreLogic Case-Shiller U.S. National Home Price NSA Index.

We use the data for 2007-2019, around 2010, the year of the reformulation of OxyContin,

during the same period. All markers should line up on the 45-degree line if the change in geographical representativeness is consistent in the two datasets.

[9] Refer to the website of the Startup Cartography Project for more information.

except for the startup data, which is reported until 2016. Table 1 reports the summary statistics of our county-level data. Panel A reports the population-weighted average per capita opioid prescriptions from 2006 to 2009, before the reformulation of OxyContin. On average, each individual received 0.852 Schedule II opioid prescriptions during this period, with a standard deviation of 0.457. Panel B presents yearly means for the outcomes over the time window. The numbers of out-migrants and in-migrants are 14.3% and 10.1% of the total job profiles, which are similar to the overall national migration rate of 12-13% from the Census.[10] The skill data shows that the average number of skills is 14.5, 9.9 (68.3%) of which are specialized skills. Other skills besides specialized skills are general skills that can be required for any job. Among the specialized skills, cognitive and software skills account for 38%.

5 Empirical Strategy

To explore the causal impact of the OxyContin reformulation on worker flow and its consequences, we employ difference-in-differences, and event study designs that exploit pre-reformulation exposure to prescription opioids. This section explains how we construct the measure of exposure to the OxyContin reformulation and our empirical models.

To quantify the causal impact of the OxyContin reformulation on worker flow, we leverage geographic variations in pre-intervention exposure to prescription opioids following Alpert et al. (2018) and Evans et al. (2019). This approach has widely been adopted in the literature. Alpert et al. (2018) use state-level variation by constructing a pre-intervention exposure metric based on the population-weighted rate of OxyContin misuse at the state level from 2004 to 2009. This measure is only available at the state level, and to construct a measure at the county level, we follow Evans et al. (2019) and construct a pre-intervention exposure measure using the population-weighted mean number of all Schedule II opioid prescriptions per capita in each county for the years 2006 to 2009, obtained from CDC data.

While Alpert et al. (2018) focuses exclusively on OxyContin misuse, our county-level measure of pre-intervention exposure covers both prescribed and misuse of all Schedule II prescription opioids, extending beyond just OxyContin. This broadness offers a more precise representation of local variations in pre-intervention opioid exposure (Evans et al., 2019), even though it includes a broader range of prescription opioids than the specific target of the intervention, OxyContin. Evans et al. (2019) highlights the validity of this pre-intervention exposure measure by showing that the states where pre-reformulation opioid use was most prevalent experienced the most

[10]The gap between the numbers of out-migrants and in-migrants is driven by the out-migrants from the US to the other countries. Our data does not capture the immigrants from other countries to the US.

substantial reduction in OxyContin misuse and the most considerable growth in heroin deaths by adverse substitution.

To validate our county-level pre-reformulation opioid prescription per capita, we aggregate the measure at the state level and check the relationship with available state-level indicators of opioid misuse.[11] Appendix Figure A3 shows that our measure has a strong positive correlation with state-level OxyContin misuse rate during 2004-2009, which is used in Alpert et al. (2018). More importantly, Appendix Figure A4 presents that a higher pre-reformulation opioid prescription per capita is strongly associated with a greater reduction in OxyContin misuse rates during 2008–2012 and a more significant growth in heroin mortality rate during 2008–2016. These patterns are consistent with the results of Alpert et al. (2018) and confirm that our county-level exposure measure also well represents the patterns in local opioid misuse.

The main specification of county-level event study takes the form of:

$$y_{it} = \sum_{k=2007, k\neq 2009}^{2019} \delta_k Exposure_i \cdot 1[t = k] + \alpha_i + \gamma_t + X_{it}'\beta + \varepsilon_{it}, \tag{1}$$

where y_{it} is an outcome including logs of inflow and outflow of workers. α_i are county fixed effects, δ_t are year fixed effects. $Exposure_i$ is the county-level pre-intervention exposure measure from the previous subsection, and $1[t = k]$ is the indicator of each period k relative to 2010 when the OxyContin reformulation was enacted. X_{ft} is a time-varying set of controls that vary across specifications. Specifically, we control for county-level recession shock interaction with year-specific dummy variables to eliminate the confounding effects of the Great Recession, which occurred around the reformulation. Following Hershbein and Kahn (2018) and Yagan (2019), we use the 2007-2009 county-level unemployment rate as a proxy of the recession shock. The observations are weighted by the number of relocating workers in 2009, the year before the intervention, and are clustered at the county level. We also use the corresponding difference-in-differences specification to summarize the average effect in the post-period.

The assumption to interpret δ_k as the average treatment effect (ATE) is that the potential outcomes without the OxyContin reformulation must be parallel for more-affected and less-affected counties by the enaction of the reformulation. In other words, the pre-intervention opioid exposure must be orthogonal to the other unobservable shocks after controlling for the fixed effects and the covariates, and there must be no anticipatory effects. The assumption of parallel trends is likely to hold for several reasons. First, the effects of the OxyContin reformulation were unintended and unpredictable for workers. As Purdue Pharma announced, the

[11] We aggregate our measure at the state level because no other county-level measures of opioid misuse are available.

firm reformulated the medicine to prevent its abusive use, but the reformulation unintentionally stimulated the use of other illicit alternatives such as cocaine and heroin. Second, we could not find any pre-existing differential of the outcome variables in our event study results.

6 Results

6.1 Effects on Worker Flow

We begin by exploring the effect of the reformulation of OxyContin on the number of relocating workers at the county level. Specifically, we analyze how one standard deviation increase in pre-intervention opioid prescriptions per capita affects the logs of outflow and inflow of workers after the reformulation, employing Equation (1). Panel (a) in Figure 5 presents the dynamic effects of OxyContin reformulation on the log of outflow at the county level. We observe no evidence of a pre-existing trend, followed by a sharp increase beginning in 2011. This sharp growth rate is persistent until the end of the period of interest. The scale of the effects is also economically significant. The effect of one standard deviation higher rate of exposure to reformulation has been stable at around 10% since four years after the reformulation. This long-term effect supports the hypothesis that the reformulation of OxyContin and the subsequent rise in illegal opioid overdoses would result in a persistent increase in the outflow of workers.

On the other hand, panel (b) of Figure 5 reports the parallel effects on the log of inflow of workers. The counties more exposed to the reformulation have experienced higher inflow rates since 2012 without any pre-trend. Like the outflow, the inflow of workers also shows persistent effects, though the point estimates are about half of those for the outflow. This result is not a prediction that would arise from a simple location choice model unless the unintended consequences of the reformulation induced certain individuals to sort systematically into the more exposed counties. The higher inflow to the higher exposed counties could arise if unintended consequences of the reformulation, such as lowered housing costs and the rise of illicit drug markets, attracted certain types of workers who think these changes are preferable and care for them more than the other unfavorable changes. This result also suggests the analysis of the heterogeneity in the inflow of workers because these certain workers systematically sorting into the more exposed counties might have real effects on local labor force composition.

To quantify the impact on worker flow, we also present the results of a difference-in-difference version of Equation (1) in Table 2. Columns (1) and (3) show the baseline results, and columns (2) and (4) report the parallel results with state-by-time fixed effects controlled to eliminate any state-level time-varying confounding effects. The baseline results indicate that one standard deviation

higher rate of pre-intervention opioid prescriptions per capita raises the outflow and inflow of workers by 10% and 6%, respectively. Controlling for state-specific year fixed effects mitigates the point estimates to 8.3% and 4.1%, respectively. From now on, we report the estimation results with state-specific year fixed effects for brevity, but the results are robust to excluding these fixed effects.

To better understand the relative size of these two effects, we report the difference-in-difference effect of the reformulation on the log of relative outflow (outflow divided by inflow) in columns (5) and (6). The results indicate that the number of out-migrants increased more than the number of in-migrants in the counties that were more exposed to opioid overdoses after the reformulation. One standard deviation higher rate of pre-intervention opioid prescriptions per capita results in about a three-point percentage point larger number of out-migrants compared to the number of in-migrants. This result has a couple of takeaways. First, it suggests that the negative impact of the opioid crisis on local neighborhood quality could outweigh the sorting effects attracting some types of workers. Second, considering that the outflow and inflow of workers account for about 15% of local workers in our data, respectively, a back-of-the-envelope calculation suggests that the flow of workers lowered the local employment by 0.42% in the counties with one standard deviation higher exposure to the opioid crisis.

To see if the relocation patterns are consistent with the context of the opioid crisis, we investigate the heterogeneous effects on the outflow of workers by destination location, industry, and occupation in Table 3. We classify relocation as moving out to a higher-exposure county if the pre-intervention opioid prescriptions per capita are higher in the destination county than in the origination county. Otherwise, we classify relocation as moving out to a lower-exposure county. Columns (1) and (2) show that the outflow of workers to lower-exposure counties increased by 9%, which is much higher than the 4.6% increase of the outflow to higher-exposure counties. Note that there was not much difference between the number of out-migrants in higher-exposure counties and lower-exposure counties before the reformulation, as shown in the row of untransformed mean in the table. These results are consistent with the location choice model in the sense that migrants would choose a destination with a lower level of opioid overdoses if they move out of the current county because of the unfavorable effects of the opioid epidemic.

Columns (3) and (4) present the effects on inter-state and intra-state outflow. Note that we define relocation in terms of the workplace, so a change in the workplace to a neighborhood county does not necessarily involve a change in residence, which is generally regarded as relocation. If this type of "migrants," who change their workplace but stay in the same residence, majorly drives our results, we would observe a significant effect on intra-state outflow while seeing a statistically insignificant or less effect on inter-state outflow. Even if this is the case, it does not refute our

idea because, in our context of focusing on workforce composition, a change in the workplace matters more than a change in the residence. However, such a result would have different policy implications. The results show that both inter-state and intra-state outflow significantly increased in response to the reformulation of OxyContin, indicating that changing workplace to nearby areas without changing residence does not fully drive our results.

The location choice model also implies that if workers move out to avoid any unfavorable effects of illegal opioid use in the local area, they may sacrifice other welfare losses that occur from the move. This move would happen when the welfare loss from moving is smaller than the welfare loss from staying in the current community with high illegal opioid use. Such a loss from moving may be realized in terms of job transition. Suppose a worker changes her industry or occupation when moving to a county with lower exposure to the opioid crisis. In that case, she may lose the compensation for industry-specific (Neal, 1995; Parent, 2000) or occupation-specific skills (Kambourov and Manovskii, 2009; Gathmann and Schonberg, 2010). To investigate this issue, we split the outflow of workers into within-industry (or within-occupation) moves and out-of-industry (or out-of-occupation) moves based on a 2-digit NAICS code (or 2-digit O*NET code).

Columns (5) and (6) report the effects on within-industry and out-of-industry outflow, indicating that the reformulation of OxyContin similarly affects the two types of outflow. Note that we split them based on a broad classification of industry, so transitioning to a different industry means changing careers very sharply, such as from a manufacturing firm to an IT firm. Similarly, columns (7) and (8) indicate that out-of-occupation outflow increased at a similar rate to within-occupation outflow in response to the opioid crisis. These results imply that a significant portion of out-migrants sacrifice the compensation for industry-specific or occupation-specific skills when changing location to avoid adverse effects of the spread of illicit opioid use.

As another heterogeneity analysis, we investigated the worker flow patterns by demographics (gender and experience years). Since the job profile data does not report the workers' age, we use experience year instead. To be specific, we classify workers into low-experienced (less than 4 years), middle-experienced (4-9 years), and high-experienced (more than 9 years) groups based on the accumulated years of experience in the job profile data. In Panel A of Table 4, columns (1) and (2) present that the OxyContin reformulation accelerated the inflow of female and male workers at similar rates. Columns (1) and (2) in Panel B also report that the effect on the inflow is similar across genders. Considering that men account for the majority of drug users,[12] these results indicate that the effects on the worker flow and local labor supply are not solely driven by opioid

[12] According to the National Institutes of Health (NIH), men are more likely than women to use almost all types of illicit drugs, and illicit drug use is more likely to result in emergency department visits or overdose deaths for men than for women. Seven out of 10 opioid overdose death victims were men in 2022. For more information, refer to this website.

drug takers.

Columns (3) through (5) in Table 4 report significant heterogeneity in the effects across experience years. Panel A presents that one standard deviation higher level of pre-intervention opioid prescriptions results in 4.7% and 3.7% increase in the outflow of low-experienced and middle-experienced groups, respectively. On the contrary, there is no statistically significant effect on the outflow of highly experienced workers. Panel B shows a similar heterogeneity in the outflow of workers across experience groups. These results are consistent with our hypothesis for a couple of reasons. First, the more significant effect on the inflow of less experienced workers may reflect their prominent preference for lower housing costs and easier access to illegal drug markets. Young workers are more sensitive to housing costs than older ones, so lowered housing prices in highly exposed local areas could attract more young workers. Young adults also have a higher rate of opioid overdose than older ones, so workers relocating to highly exposed local communities to seek easier access to illegal drug markets are more likely to be young workers. Second, the more prominent effect on the outflow of less experienced workers also makes sense because, within the same local area, young workers could be more exposed to opioid-related incidents than older workers, considering the higher rate of opioid overdose of young workers.

We also check how the effect of the OxyContin reformulation on worker flow differs by occupation. Specifically, we split worker flow by 2-digit O*NET occupations excluding farming and military jobs and run the difference-in-difference version of Equation (1) separately for each occupation group. Figure 6 reports the effect of the opioid crisis on the worker flow ratio (outflow/inflow) and indicates that cleaning and maintenance occupations (Code 37) and personal care and service occupation (Code 39) experienced a particularly large net outflow of workers in response to the reformulation. These results are consistent with the context of the opioid crisis in the sense that these occupations, including street cleaners, lobby attendants, and travel guides, are more likely exposed to drug-related violence and crimes in the neighborhoods than the others. Appendix Figure A5 confirms that these disproportionate effects are driven by the lower inflow of workers in these occupations.

We next consider whether the OxyContin reformulation affected the composition of relocating workers in terms of skill level. Illicit opioid overdoses in the local community might attract individuals who used OxyContin for non-medical purposes but switched to cocaine or heroin post-reformulation. If these individuals concentrate in some skill group, the OxyContin reformulation could change the skill composition of in-migrants. Alternatively, a decrease in housing costs caused by the spread of opioid overdoses might also attract low-income workers who are more sensitive to living costs. The effect on out-migrants could also differ across skill

levels, considering the high geographic mobility of high-skilled workers. Alternatively, the welfare loss by spreading cocaine and heroin might differ across skill levels.

To measure the skill level of each mover, we use the number of skills in each skill category classified by Deming and Kahn (2018). We focus on cognitive, computer, and software skills[13] because the literature primarily considers them the major skill categories. An individual's skill set may evolve over time, but we fixed the skill set in 2009, right before the OxyContin reformulation, to focus on the change in workforce composition. For each skill category, we classify a worker as high-skilled if the number of her skills is higher than the median in 2009 and as low-skilled otherwise.

Panel A of Table 5 presents the heterogeneous effects on the inflow of workers across the skill groups. The OxyContin reformulation sharply raises the inflow of low-skilled workers in any skill category while having statistically insignificant effects on the corresponding high-skilled inflow. Column (1) shows that, in a county with one standard deviation higher level of pre-intervention opioid prescriptions, the inflow of workers having a less-than-median number of any skills increases by 5.5% than in a county with the average level of pre-intervention opioid prescriptions. On the contrary, the inflow of high-skilled workers in terms of the number of any skills does not show any disproportionate change in such a place, as shown in column (2). We can observe similar disparities across cognitive, computer, and software skills.

In Panel B of Table 5, we study the parallel effects on the outflow of workers. Contrary to the effects on the inflow, the outflow of both low-skilled and high-skilled workers sharply increased in response to the OxyContin reformulation. Though the effects on low-skilled workers are generally more prominent than the high-skilled ones, the gaps in the point estimates are much smaller than those of inflow. As shown for the overall outflow and inflow of workers, the reformulation affects outflow significantly more than inflow within the skill group.

These results consistently show that the OxyContin reformulation and subsequent changes in local communities have heterogeneous impacts on relocation patterns across skill groups. The sharp increase in the inflow of low-skilled workers, along with the muted effects on the inflow of high-skill migrants, clearly indicates that the opioid crisis disproportionately attracted certain types of workers with relatively fewer skills. Considering that heroin overdoses increased immediately in the counties with a high level of pre-intervention opioid prescriptions after reformulation (Powell and Pacula, 2021), easier access to illicit opioids may attract low-skilled workers who are more likely to take the drugs (Altekruse et al., 2020; Maclean et al., 2020). A decrease in housing costs

[13] Software skills include names of specialized software, such as Python, Java, TensorFlow, and Unity, while computer skills are commonly-used software, such as Microsoft Excel and PowerPoint.

driven by the spread of the illicit opioid market could also result in the inflow of more low-skilled workers who search for lower housing costs (Broxterman and Yezer, 2015).

At the same time, the OxyContin reformulation induces both low- and high-skilled workers to move out of highly exposed counties, which means that the prevalence of illegal opioid overdoses in the local community results in the welfare loss of workers regardless of skill levels. However, it does not necessarily mean that the incidence of the opioid epidemic is similar across skill groups because the realized relocation is affected by both the incidence of shock and mobility. Considering that high-skilled workers are usually more mobile than low-skilled workers, the similar outflow responses imply that the incidence of the opioid crisis could be more significant for low-skilled workers, which is consistent with the fact that low-skilled workers are more exposed to opioid overdoses.

6.2 Effects on Skill Composition and Innovation

So far, we have shown that the reformulation of OxyContin accelerated the relocation of workers around the counties that are highly exposed to illegal opioid use, inducing more outflow of workers than inflow. Workers with relatively fewer skills especially drove the rising inflow. We next consider whether these relocation patterns affected the characteristics of the highly exposed local communities. Suppose the worker flow has no impact on the counties' outcomes. In that case, the relocation results mean that the worker flow equilibrated local labor markets in response to the spread of illegal opioids based on workers' optimal location choice, and our analysis is not policy-relevant. We specifically focus on the composition of the local workforce and innovation activities, which could be directly affected by the composition change in worker flow.

To see if relocation driven by the OxyContin reformulation affected the overall skills of local workers, we freeze their skill set pre-reformulation and construct the average skill level of local workers at the county-by-year level. So, a change in our skill measure can only occur by the change in the workforce composition. Figure 7 reports the dynamic effects of the reformulation on these county-level skill levels. Panel (a) indicates that the counties that are highly exposed to illegal opioid use experienced a gradual decline in the average number of any skills without any pre-trend. The effect to a county with one standard deviation higher level of pre-intervention opioid prescriptions reached about -5% nine years after the reformulation.

The effects on specific skills, including cognitive, computer, and software, are even larger, as shown in panels (a), (b), and (c). A county with one standard deviation higher level of pre-intervention opioid prescriptions experienced about 7%, 5%, and 11% decreases in cognitive, computer, and software skills, respectively, nine years after the reformulation. Appendix Table A2

reports the consistent results after controlling for the state-specific year fixed effects. Appendix Figure A6 also confirms that the drop is not just for cognitive, computer, and software skills, showing similar but relatively weak decreasing patterns for social, administrative, and service skills.

Again, these results are solely driven by the composition change of the local workforce. Though the share of movers in the local labor force is small, the persistent effects of the OxyContin reformulation on the flow of workers by skill level result in gradual and significant declines in the overall skill levels in the local communities. A substantial effect on software skill level may occur due to the high job mobility of IT workers, who can efficiently work from home. It is known that the opioid epidemic undermined the labor supply and productivity of individual workers (Harris et al., 2020b; Park and Powell, 2021; Alpert et al., 2022). Our results add to that by showing that the opioid crisis also degraded the quality of the local workforce through the composition change, which would give different policy implications.

The skill level of migrants and workers, in general, is crucial to innovative activities in local communities (Hunt and Gauthier-Loiselle, 2010; Bosetti et al., 2015; Peri et al., 2015; Kerr et al., 2017; Azoulay et al., 2022). If the opioid crisis slows down local innovation through the change in workforce composition, then it could have long-run scarring effects on the productivity and income level of local communities. So, local governments should have an incentive to mitigate such relocation of workers via policy tools.

In Table 6, we report the effects of the OxyContin reformulation on county-level patents and startup formation. Specifically, we link a patent to the county of the inventor's residence and use the sum of total patents and total citations on the patents as the outcomes. We also use the quantity and quality indices on local startups collected from the Startup Cartography Project. We use the startup data until 2016 because the startup project ended in 2017. In column (1), we observe that, given one standard deviation higher level of pre-intervention opioid prescriptions, the OxyContin reformulation led to a 5.2% decrease in the number of patents produced by the inventors in the local community. At the same time, the significant effect (10.4%) on the patent citations, shown in column (2), indicates that the quality of patents might also have decreased. These results are consistent with the concurrent decline in local cognitive skills, which includes research and analytic skills.

In columns (3) and (4), we estimate that one standard deviation larger OxyContin prescriptions predicts 6.5% and 9.0% reductions in startup formation and quality, respectively. These results are consistent with the sharp decline in the local computer and software skill levels in the highly exposed counties, considering that startup formulation and venture capital investment concentrate

in the IT sector. These results also confirm that the effects on local innovation are not just for patenting, which could indirectly affect the local economy in the long run, but for the business ecosystem, directly affecting the local economy.

6.3 Mechanism

We have shown that the opioid epidemic changed the composition of worker flow, lowering the average skill levels and innovation activities in the highly exposed local communities. This change was mainly driven by the change in the composition of inflow rather than that of outflow: low-skilled in-migrants filled the jobs where both low-skilled and high-skilled workers left. In this subsection, we present suggestive mechanisms of the heterogenous patterns between low-skilled and high-skilled workers.

We consider two possible mechanisms for the sharp increase in the inflow of low-skilled workers and the lack of change in high-skilled inflow in response to the reformulation of OxyContin. First, if the opioid crisis lowers housing costs in highly exposed counties via the increased outflow of workers and the fall in neighborhood quality, it may attract low-skilled workers from other areas, who are more sensitive to housing costs than high-skilled workers (Broxterman and Yezer, 2015). Table 7 presents the effect of the OxyContin reformulation on the county-level house price index. Though the point estimate is statistically insignificant with the baseline model (column (1)), controlling for state-specific year fixed effects results in a 1.9% decrease of the house price index in the counties with one standard deviation higher exposure than the average after the reformulation (column (2)). To alleviate the concern of any confounding effects from the housing supply side, we additionally control for the number of permits for residential buildings from the local government in the last year in column (3) and find that the point estimate is robust. Adding the number of permits in the current year in column (4) also does not change the effect much. These results indicate the possibility that the lowered housing cost may drive the increased inflow of low-skilled workers to the highly exposed counties while resulting in the muted effect of the opioid epidemic on the inflow of high-skilled workers.

Second, the rise of the black market for illegal opioids in highly exposed communities may attract drug addicts from other neighborhoods, who are more likely low-skilled workers. Though we cannot directly investigate this channel because of the lack of data on the illicit markets, the literature collectively implies that this may be the case. Powell and Pacula (2021) reports that more exposed areas experienced disproportionate increases in fatal overdoses of synthetic opioids (fentanyl) and non-opioid substances (cocaine and heroin) after the reformulation. Alpert et al. (2018) also find that areas with the highest initial rates of OxyContin experienced the most

significant increases in heroin deaths. So, these studies imply that the reformulation could stimulate illicit drug markets to grow. Some studies also point out that at-risk socioeconomic groups for fatal opioid use include people in lower-income strata (Altekruse et al., 2020; Maclean et al., 2020). Overall, the literature suggests that highly exposed counties may absorb some low-skilled workers from other local communities who search for more accessible illicit drug markets.

6.4 Robustness Checks

In this subsection, we meticulously provide several robustness checks on these baseline patterns, leaving no potential concerns regarding our identification unaddressed.

To alleviate the concern about confounding factors, we control for the county-level recession shock interaction with year-specific dummy variables in our baseline specification and show the lack of pre-trends of our primary outcome variables. On top of that, we try to add other controls that are potentially correlated to local opioid use and worker flow. First, we partially control for the quality of local health care by including county-level medical workforce such as doctors, nurses, other health practitioners, and technicians. Second, we control for the effect of the US-China trade war on the local labor market because it started in 2015 and may partially drive our results for the overlapping periods. Specifically, we add the county-level tariff rates to the Chinese exports to the US (set by the US government) and to the US exports to China (set by the Chinese government), which are constructed by Waugh (2019).[14] Table 8 presents that the effects of the opioid crisis on local worker flow are robust to including these controls.

Another potential compounding factor is the decline of the coal mining industry in the Appalachian area during the same period. In the area stretching from the western Catskill Mountains of New York state to northern Georgia, Alabama, and Mississippi states, coal production fell by more than 65% overall between 2005 and 2020, which could generate the net outflow of workers. Figure 1 also confirms that the Appalachian area experienced considerable opioid prescription rates before the reformulation. To mitigate the concern that this shock might result in the spurious effect of the reformulation of OxyContin on the net outflow of workers, we estimate the baseline model after excluding the 423 counties in the Appalachian region. Appendix Table A3 reports similar estimates as our baseline results, assuring this concern is invalid.

Another robustness check concerns our sample construction and variable selection. First, our particular way of defining a worker's relocation may spuriously generate the significant effects of

[14] Waugh (2019) constructs average tariff rates at the county level based on the industry-level tariff rates and the industry composition of a county.

the opioid crisis on worker flow. As explained in Chapter 4, the end year of a worker's previous job could differ from the start year of the next job, while we set the previous job's end year as the time for outflow and inflow in our baseline model. As a robustness check, we try to set the start year of the next job separately, as reported in the data. As Panel A of Table 9 shows, the results are robust to timing switching.

Second, our observations include the flow of workers between the US and foreign countries, which may drive the whole effect of the opioid crisis. Even if this is the case, it does not directly rebut our arguments in the sense that workers could move to foreign countries where illegal drug use is less prevalent. Otherwise, workers from foreign countries would like to get jobs in counties with less opioid exposure. However, it would be less plausible if most of the worker flow induced by the opioid crisis headed to or from foreign countries. In Panel B of Table 9, the estimation results, excluding the flow of workers between the US and foreign countries, are similar to the baseline results, indicating that immigration is not the main driver.

Third, the skill level measured from the skill set in online job platforms may not be representative. To assume this is not the case, we conduct the parallel analysis using education level. Specifically, we identify the highest degree of a worker among non-college, college (associate or bachelor's), master's, and doctorate degrees at a given time and investigate how worker flow by education level responds to the OxyContin reformulation. Table 10 reports that the inflow of workers with higher degrees increased less than those with lower degrees, while the effects on the outflow are indistinguishable across education groups. These results are consistent with the results using our baseline skill measures in Table 5.

7 Conclusion

Prior evidence identifies the immediate negative impacts of the ongoing opioid crisis on local labor supply in the U.S. These studies help understand the broad economic impacts of such a health crisis and how supply-side interventions such as the reformulation of OxyContin could have unintended consequences on the local economy. However, effective policy interventions to mitigate the economic ramifications require a more detailed understanding of how the composition of local labor supply changes and how such a workforce change affects the local economy. By utilizing universal online job profile data, we identify the causal impacts of the OxyContin reformulation on the composition of worker flow and the subsequent impacts on local skill levels and innovation activities.

Our analysis identifies the sharp and immediate increase in the outflow and inflow of workers

in response to the reformulation. Still, the effect on the outflow dominated that on the inflow. Counties more exposed to the reformulation experienced a persistent increase in the outflow of workers relative to the inflow of workers. Moreover, we find that low-skilled workers solely drove the increase in the worker inflow, while the outflow of both low-skilled and high-skilled workers increased in response to the reformulation. We suggest evidence that the lowered housing costs and the growth of illicit drug markets in the highly affected areas may result in heterogeneous patterns in worker inflow by skill level.

We also report evidence that the composition change in relocating workers itself, excluding the change in an individual's skill level, drove a considerable decline in the skill level of local workers in the highly affected areas. In addition, our analysis finds the corresponding reduction in local innovation activities, such as the number and quality of patents, startup formulation, and startup quality. Thus, our study points out that the ongoing opioid epidemic changes the composition of the local labor supply via the relocation of workers in a way that lowers the overall skill level and innovation activities, undermining the economic potential of the local community.

Our findings have important policy implications. First, our results indicate that the opioid crisis lowers the local labor force through the relocation of workers. While prior evidence emphasizes the negative impact on local labor supply from the health consequences of opioid users, our results point out that a big chunk of labor supply reductions come from the outflow of workers who want to stay away from the unfavorable consequences of local illicit opioid overdoses. So, our results emphasize the importance of policy interventions to attract workers to the local communities along with the healthcare to illegal opioid users.

Second, our study highlights the long-run effect of the opioid crisis on the local skill level, which undermines the economic potential of the local communities. Our findings reveal that the heterogeneous relocation patterns across low-skilled and high-skilled workers persistently lower the skill level in most skill categories. The decrease in skill levels, in turn, weakens local innovation and economic activities, potentially leading to a vicious cycle of the lack of high-skilled workers. The cases of once-bustling cities, such as Cleveland, Detroit, and Rochester, show us how hard it is to break out of such a vicious circle of declining cities. Our results imply that the local communities that are highly exposed to the opioid epidemic may follow suit unless governments implement policy interventions to counteract this flow of workers.

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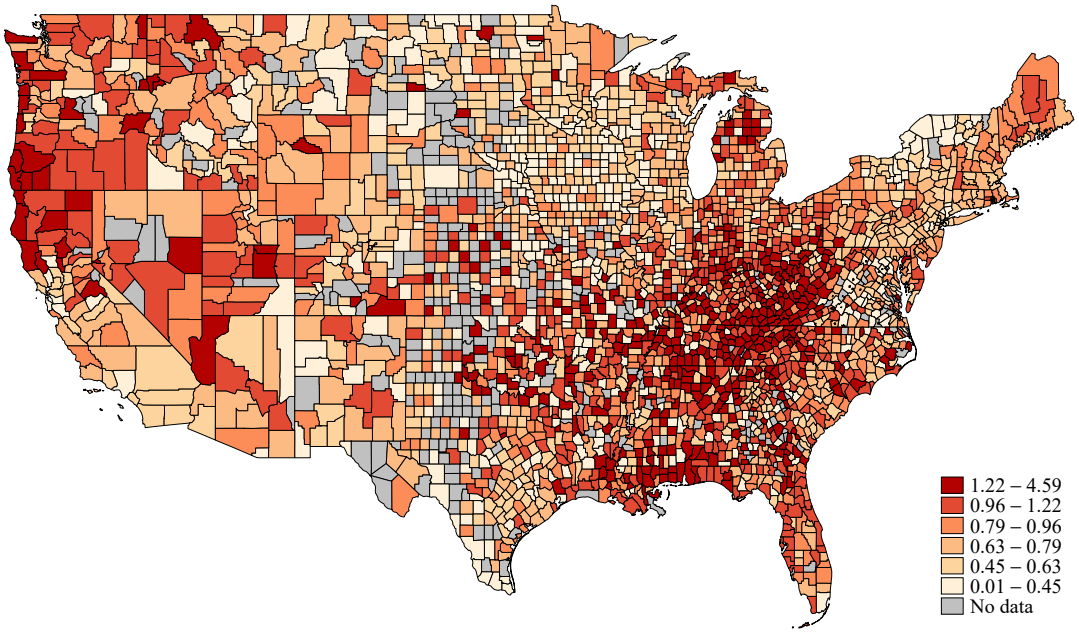
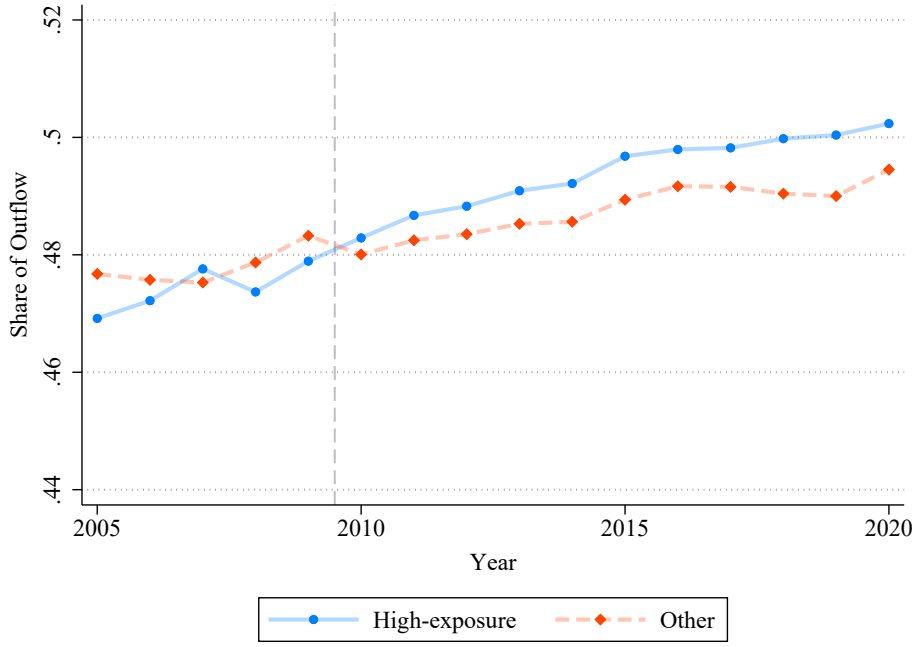
8 Figures and Tables

Figure 1: Geographic Variation in Exposure to Pre-Intervention Prescription Opioids Across Counties



Notes: This figure presents the distribution of opioid prescriptions per capita across U.S counties based on opioid prescription rates from the Centers for Disease Control (CDC). The CDC data represent an 85 percent sample of retail pharmacy providers but exclude hospitals.

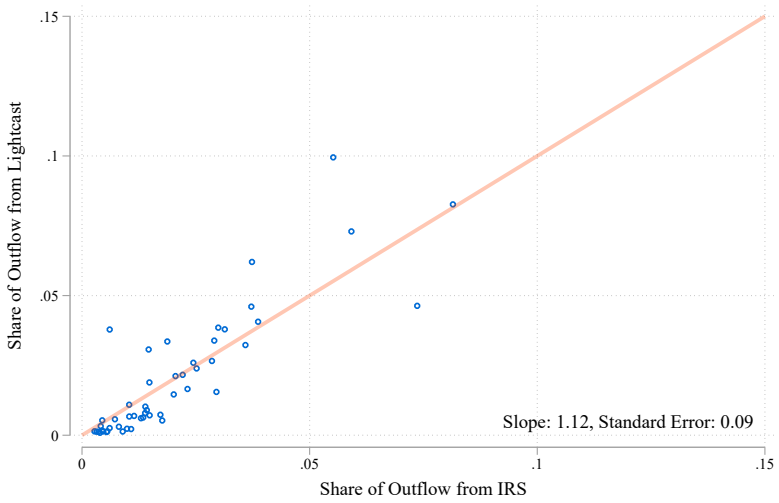
Figure 2: Trends in Share of Outflow of Workers in Total Worker Flow



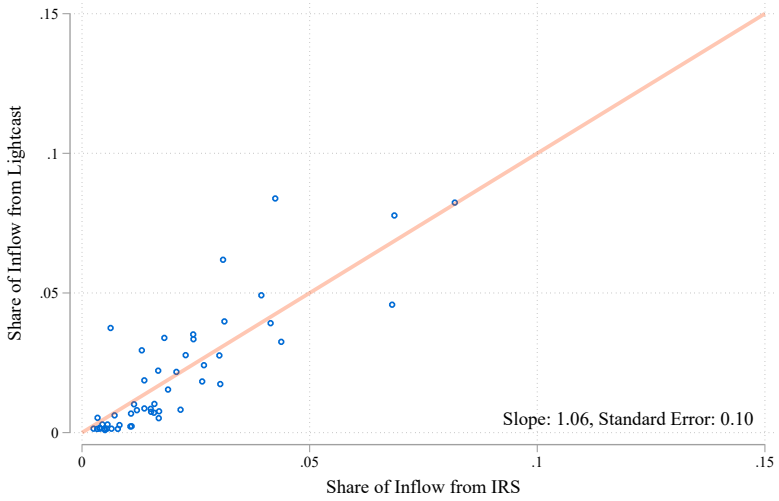
Notes: This figure shows the trend in the average share of outflow of workers among total relocating workers (outflow/(outflow + inflow)) from Lightcast Job Profile Database. The high-exposed counties are the top 5% counties with the highest pre-reformulation opioid prescriptions.

Figure 3: Cross-state Worker Flow in Lightcast and IRS

(a) Outflow of Workers

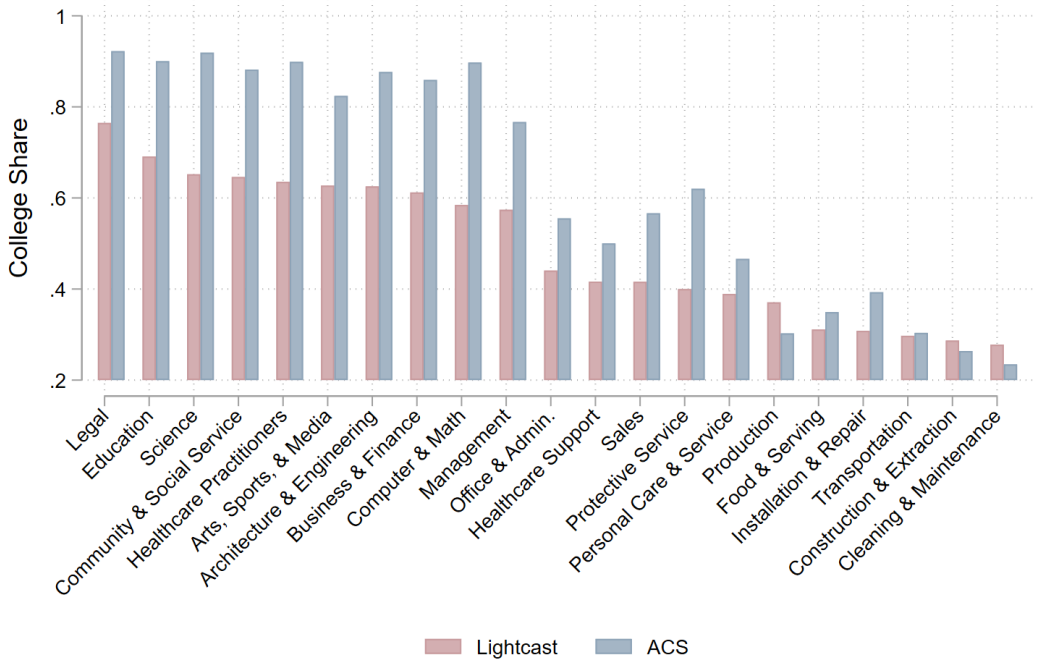


(b) Inflow of Workers



Notes: This figure depicts the correlation of the state share in the number of out-migrants to other states (panel a) and of in-migrants from other states (panel b) between IRS SOI and Lightcast Job Profile Database. The Y-axis in each panel plots the shares from Lightcast, and the X-axis plots the shares from IRS SOI. Each plot represents a state, and the blue lines represent the 45-degree line as a benchmark. The shares are calculated based on 2007 data.

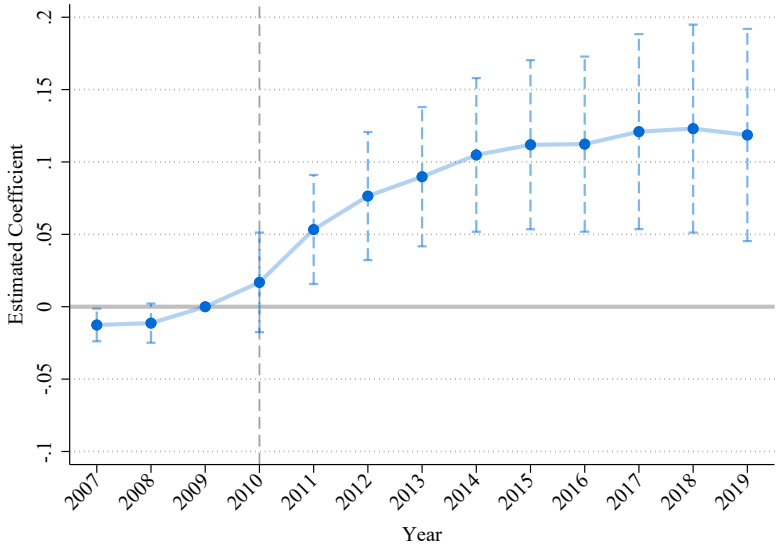
Figure 4: Share of College Graduates by Occupation in Lightcast and ACS



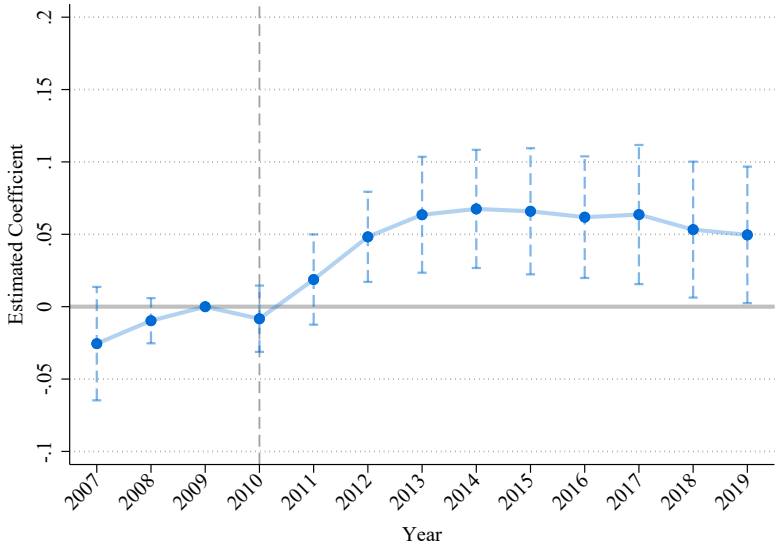
Notes: This figure reports the share of workers with a college degree by 2-digit SOC occupation (excluding public, military, and farming occupations) from Lightcast and IPUMS ACS from 2007 to 2019. In Lightcast, about 45% of workers do not report their college information, reflecting under-reporting. The correlation of the cross-occupation college shares between Lighcast and ACS is 0.965.

Figure 5: Dynamic Effect of OxyContin Reformulation on Relocation of Workers

(a) Outflow of Workers

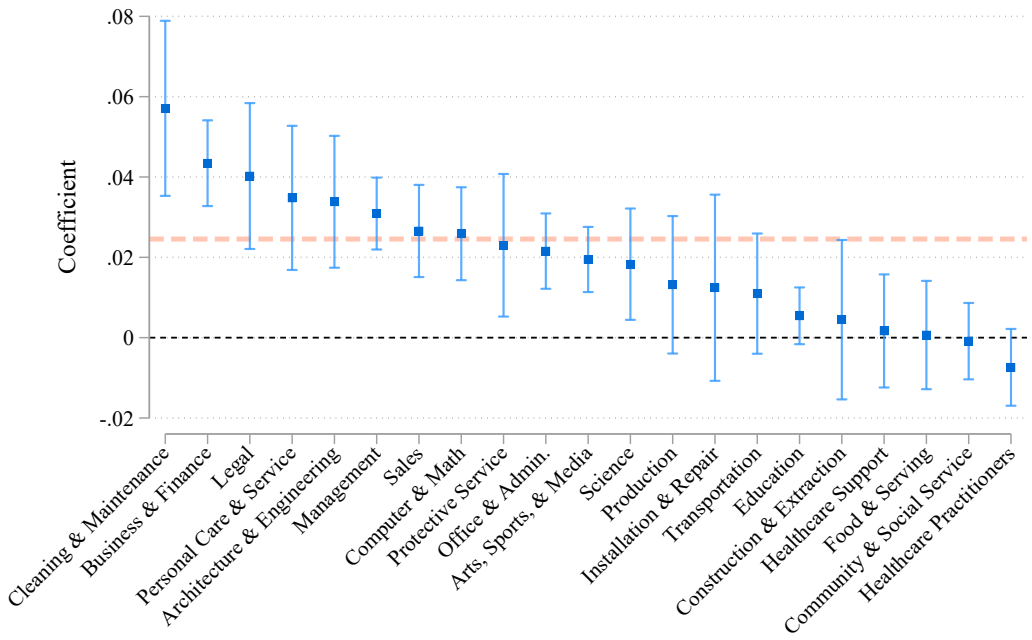


(b) Inflow of Workers



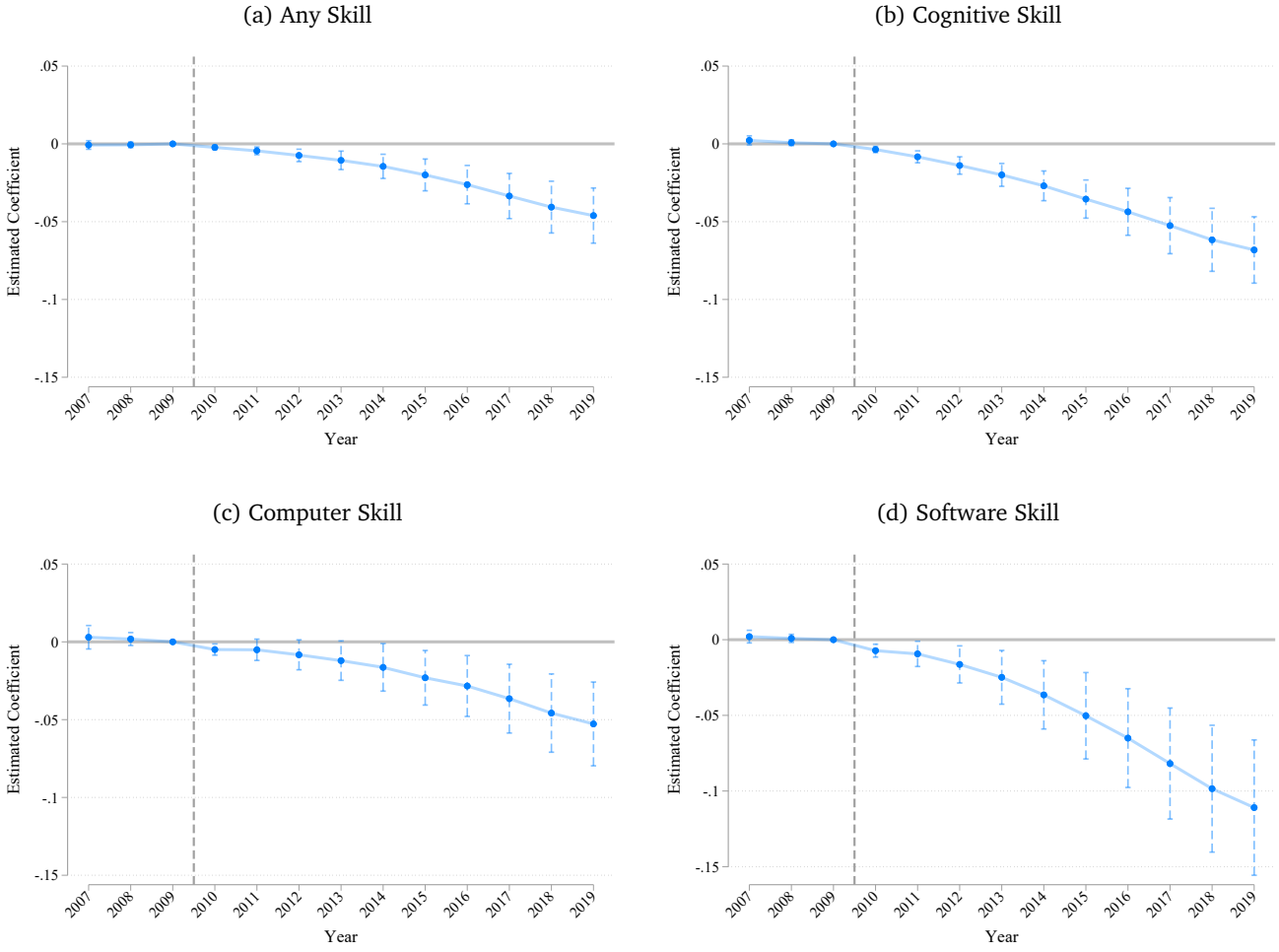
Notes: Each figure reports point estimates and 95 percent confidence intervals on the interaction terms ($Exposure_i \cdot 1[t = k]$) from Equation (1) with the county-level pre-intervention exposure standardized. The year 2009, which is one year prior to the OxyContin reformulation, is set as the reference point and normalized to zero. The controls include county-level recession shock interacting with year dummies, county fixed effects, and year fixed effects. The observations are weighted by the number of migrants in 2009 and are clustered at the county level.

Figure 6: Effect of OxyContin Reformulation on Outflow/Inflow by Occupation



Notes: This figure reports point estimates and 95 percent confidence intervals on the interaction terms ($Exposure_i \cdot Post_t$) from the difference-in-difference version of Equation (1) with the county-level pre-intervention exposure standardized for 2-digit SOC occupations excluding farming and military jobs. The dependent variable is the log of (outflow/inflow) in each occupation group. The controls include county-level recession shock interacting with year dummies, county fixed effects, and year fixed effects. The observations are weighted by the number of migrants in 2009 and are clustered at the county level.

Figure 7: Dynamic Effect of OxyContin Reformulation on Skill Level in County



Notes: Each figure reports point estimates and 95 percent confidence intervals on the interaction terms ($Exposure_i \cdot 1[t = k]$) from Equation (1) with the county-level pre-intervention exposure standardized. The year 2009, which is one year prior to the OxyContin reformulation, is set as the reference point and normalized to zero. The controls include county-level recession shock interacting with year dummies, county fixed effects, and year fixed effects. The observations are weighted by the number of migrants in 2009 and are clustered at the county level.

Table 1: Summary Statistics

	Mean	SD	25th percentile	75th percentile	Observations
A. County-level Pre-Intervention Prescription Opioid Use					
Per Capita Opioid Prescriptions	0.852	0.457	0.550	1.072	63625
B. County-level Characteristics					
# Job Profiles	8954	55908	101	1990	63294
# Out-Migrants	1282	8040	13	276	63294
# In-Migrants	1349	8485	14	283	63294
# Any Skills	14.509	3.728	11.892	16.852	63294
# Special Skills	9.874	2.970	7.768	11.655	63294
# Cognitive Skills	2.205	0.806	1.664	2.627	63294
# Software Skills	1.523	0.601	1.146	1.812	63294
# Patents	112	897	1	21	63294
# Patent Citations	1122	8720	0	161	63294
# Start-ups	518	2428	18	192	45583
Start-up Quanlity Index	0.274	2.328	0.003	0.049	45583
House Price Index	278	186	164	328	58887

Notes: This table presents the means of the main outcomes in our analysis. Panel A presents the county-level population-weighted average per capita opioid prescriptions from 2006 to 2009. Panel B reports the yearly averages of county-level characteristics over the years 2007–2019 except for start-up information. The start-up information covers 2007–2016.

Table 2: Effect of OxyContin Reformulation on Worker Flow

	(1) Outflow	(2) Outflow	(3) Inflow	(4) Inflow	(5) Outflow/Inflow	(6) Outflow/Inflow
Opioid Exposure × Post	0.101***	0.083***	0.060***	0.041***	0.027*	0.028***
	(0.027)	(0.017)	(0.015)	(0.013)	(0.014)	(0.007)
Observations	35,826	35,813	35,826	35,813	35,595	35,582
Untransformed Outcome Mean	971.282	971.282	1050.894	1050.894	1.050	1.050
County FE	Y	Y	Y	Y	Y	Y
Year FE	Y	N	Y	N	Y	N
State-Year FE	N	Y	N	Y	N	Y

Notes: This table reports weighted least squares estimates of the interaction terms between the reformulation exposure and the post-reformulation period from the difference-in-difference version of Equation (1) with the county-level pre-intervention exposure standardized. The controls include county-level recession shock interacting with the dummy for the post-reformulation period, county fixed effects, and year fixed effects in columns (1), (3), and (5). In columns (2), (4), and (6), year fixed effects are replaced with state-specific year fixed effects. The observations are weighted by the number of migrants in 2009, one year prior to the OxyContin reformulation, and are clustered at the county level.

Table 3: Effect of OxyContin Reformulation on Outflow of Workers by Destination

	(1) Higher Exposure	(2) Lower Exposure	(3) In-state	(4) Out-of-state	(5) Same Ind.	(6) Diff. Ind.	(7) Same Occ.	(8) Diff Occ.
Opioid Exposure × Post	0.046**	0.090***	0.060***	0.074***	0.088***	0.101***	0.065***	0.084***
	(0.020)	(0.014)	(0.013)	(0.017)	(0.022)	(0.019)	(0.016)	(0.018)
Observations	35,813	35,813	35,813	35,813	35,813	35,813	35,813	35,813
Untransformed Outcome Mean	296.373	289.351	118.502	515.834	139.256	386.635	335.453	490.935
County FE	Y	Y	Y	Y	Y	Y	Y	Y
State-Year FE	Y	Y	Y	Y	Y	Y	Y	Y

Notes: This table reports weighted least squares estimates of the interaction terms between the reformulation exposure and the post-reformulation period from the difference-in-difference version of Equation (1) with the county-level pre-intervention exposure standardized. The outcome variables are the logs of the outflow of workers across destination classes: counties with higher prescribed opioid use (column 1), counties with lower prescribed opioid use (column 2), counties in the same state (column 3), counties in a different state (column 4), a job in the same industry (column 5), a job in a different industry (column 6), a job in the same occupation (column 7), and a job in a different occupation (column 8). The controls include county-level recession shock interacting with the dummy for the post-reformulation period, county fixed effects, and state-specific year fixed effects. The observations are weighted by the number of migrants in 2009, one year prior to the OxyContin reformulation, and are clustered at the county level.

Table 4: Effect of OxyContin Reformulation on Worker Flow by Demographics

	(1) Women	(2) Men	(3) Low Exp.	(4) Middle Exp.	(5) High Exp.
Panel A: Inflow of Workers					
Opioid Exposure × Post	0.034***	0.029**	0.047***	0.037***	0.020
	(0.011)	(0.014)	(0.013)	(0.013)	(0.013)
Panel B: Outflow of Workers					
Opioid Exposure × Post	0.080***	0.081***	0.101***	0.085***	0.064***
	(0.017)	(0.018)	(0.019)	(0.018)	(0.016)
County FE	Y	Y	Y	Y	Y
State-Year FE	Y	Y	Y	Y	Y

Notes: This table reports weighted least squares estimates of the interaction terms between the reformulation exposure and the post-reformulation period from the difference-in-difference version of Equation (1) with the county-level pre-intervention exposure standardized. The outcome variables are the logs of the inflow of workers (Panel A) and the outflow of workers (Panel B) by gender and experience years. Columns (3) through (5) report the estimates for workers with low experience (less than 4 years), middle experience (4-9 years), and high experience (more than 9 years). The controls include county-level recession shock interacting with the dummy for the post-reformulation period, county fixed effects, and state-specific year fixed effects. The observations are weighted by the number of migrants in 2009, one year prior to the OxyContin reformulation, and are clustered at the county level.

Table 5: Effect of OxyContin Reformulation on Worker Flow by Skill Level

	(1) Low Any	(2) High Any	(3) Low Cognitive	(4) High Cognitive	(5) Low Computer	(6) High Computer	(7) Low Software	(8) High Software
Panel A: Inflow of Workers								
Opioid Exposure × Post	0.050***	0.016	0.051***	0.017	0.037***	0.015	0.077***	0.016
	(0.012)	(0.014)	(0.013)	(0.013)	(0.011)	(0.018)	(0.014)	(0.015)
Panel B: Outflow of Workers								
Opioid Exposure × Post	0.090***	0.062***	0.088***	0.065***	0.082***	0.059***	0.110***	0.064***
	(0.016)	(0.019)	(0.017)	(0.018)	(0.016)	(0.021)	(0.019)	(0.020)
County FE	Y	Y	Y	Y	Y	Y	Y	Y
State-Year FE	Y	Y	Y	Y	Y	Y	Y	Y

Notes: This table reports weighted least squares estimates of the interaction terms between the reformulation exposure and the post-reformulation period from the difference-in-difference version of Equation (1) with the county-level pre-intervention exposure standardized. The outcome variables are the logs of the inflow of workers (Panel A) and the outflow of workers (Panel B) of the low- or high-skill group in terms of each skill category (any skills, cognitive skills, computer skills, and software skills). The controls include county-level recession shock interacting with the dummy for the post-reformulation period, county fixed effects, and state-specific year fixed effects. The observations are weighted by the number of migrants in 2009, one year prior to the OxyContin reformulation, and are clustered at the county level.

Table 6: Effect of OxyContin Reformulation on Innovation in County

	(1) Patents	(2) Patent Citations	(3) Startup Formation	(4) Startup Quality
Opioid Exposure × Post	-0.052**	-0.104***	-0.065***	-0.090***
	(0.026)	(0.039)	(0.008)	(0.017)
Observations	35,722	35,722	26,426	26,426
Untransformed Outcome Mean	90.373	1207.190	444.776	0.212
County FE	Y	Y	Y	Y
State-Year FE	Y	Y	Y	Y

Notes: This table reports weighted least squares estimates of the interaction terms between the reformulation exposure and the post-reformulation period from the difference-in-difference version of Equation (1) with the county-level pre-intervention exposure standardized. The controls include county-level recession shock interacting with the dummy for the post-reformulation period, county fixed effects, and state-specific year fixed effects. The observations are weighted by the number of migrants in 2009, one year prior to the OxyContin reformulation, and are clustered at the county level.

Table 7: Effect of OxyContin Reformulation on Housing Price in County

	(1) House Price Index	(2) House Price Index	(3) House Price Index	(4) House Price Index
Opioid Exposure × Post	-0.016	-0.019***	-0.018***	-0.015**
	(0.016)	(0.007)	(0.006)	(0.006)
Observations	31,192	31,179	31,179	31,179
County FE	Y	Y	Y	Y
Year FE	Y	N	N	N
State-Year FE	N	Y	Y	Y
Lagged Building Permits	N	N	Y	Y
Current Building Permits	N	N	N	Y

Notes: This table reports weighted least squares estimates of the interaction terms between the reformulation exposure and the post-reformulation period from the difference-in-difference version of Equation (1) with the county-level pre-intervention exposure standardized. The controls include county-level recession shock interacting with the dummy for the post-reformulation period, county fixed effects, and year fixed effects (column 1). In column (2), year fixed effects are replaced with state-specific year fixed effects. The number of permits for residential buildings in the last year is added in column (3). The number of permits for residential buildings in the current year is added in column (4). The observations are weighted by the number of migrants in 2009, one year prior to the OxyContin reformulation, and are clustered at the county level.

Table 8: Effect of OxyContin Reformulation on Worker Flow with Additional Controls

	(1) Outflow	(2) Outflow	(3) Inflow	(4) Inflow	(5) Outflow/Inflow	(6) Outflow/Inflow
Opioid Exposure × Post	0.085***	0.082***	0.042***	0.042***	0.029***	0.026***
	(0.015)	(0.014)	(0.010)	(0.010)	(0.007)	(0.007)
Observations	35,813	35,813	35,813	35,813	35,582	35,582
County FE	Y	Y	Y	Y	Y	Y
State-Year FE	Y	Y	Y	Y	Y	Y
Medical Workforce	Y	Y	Y	Y	Y	Y
US-China Tariffs	N	Y	N	Y	N	Y

Notes: This table reports weighted least squares estimates of the interaction terms between the reformulation exposure and the post-reformulation period from the difference-in-difference version of Equation (1) with the county-level pre-intervention exposure standardized. The controls include county-level recession shock interacting with the dummy for the post-reformulation period, county fixed effects, state-specific year fixed effects, and logs of the medical workforce (doctors, nurses, other health practitioners, and technicians). In columns (2), (4), and (6), we additionally control for county-level tariff rates to the US exports (set by the Chinese government) and to the Chinese exports (set by the US government). The observations are weighted by the number of migrants in 2009, one year prior to the OxyContin reformulation, and are clustered at the county level.

Table 9: Effect of OxyContin Reformulation on Worker Flow with Different Definitions

	(1) Outflow	(2) Outflow	(3) Inflow	(4) Inflow	(5) Outflow/Inflow	(6) Outflow/Inflow
Panel A: Worker Flow with Separate Timing						
Opioid Exposure × Post	0.101***	0.083***	0.064***	0.038***	0.025*	0.031***
	(0.027)	(0.017)	(0.015)	(0.014)	(0.015)	(0.008)
Panel B: Internal Worker Flow						
Opioid Exposure × Post	0.101***	0.083***	0.053***	0.034***	0.040*	0.040***
	(0.027)	(0.017)	(0.016)	(0.012)	(0.023)	(0.010)
Observations	35,826	35,813	35,826	35,813	35,277	35,264
County FE	Y	Y	Y	Y	Y	Y
Year FE	Y	N	Y	N	Y	N
State-Year FE	N	Y	N	Y	N	Y

Notes: This table reports weighted least squares estimates of the interaction terms between the reformulation exposure and the post-reformulation period from the difference-in-difference version of Equation (1) with the county-level pre-intervention exposure standardized. The controls include county-level recession shock interacting with the dummy for the post-reformulation period, county fixed effects, and year fixed effects in columns (1), (3), and (5). In columns (2), (4), and (6), year fixed effects are replaced with state-specific year fixed effects. The observations are weighted by the number of migrants in 2009, one year prior to the OxyContin reformulation, and are clustered at the county level.

Table 10: Effect of OxyContin Reformulation on Worker Flow by Education Level

	(1) Non-College	(2) Bachelor	(3) Master	(4) Doctorate
Panel A: Inflow of Workers				
Opioid Exposure × Post	0.050***	0.020*	0.026**	0.025**
	(0.015)	(0.011)	(0.011)	(0.012)
Panel B: Outflow of Workers				
Opioid Exposure × Post	0.084***	0.087***	0.085***	0.085***
	(0.018)	(0.018)	(0.018)	(0.018)
County FE	Y	Y	Y	Y
State-Year FE	Y	Y	Y	Y

Notes: This table reports weighted least squares estimates of the interaction terms between the reformulation exposure and the post-reformulation period from the difference-in-difference version of Equation (1) with the county-level pre-intervention exposure standardized. The outcome variables are the logs of the inflow of workers (Panel A) and the outflow of workers (Panel B) by education level (non-college, bachelor's, master's, and doctorate degrees). The controls include county-level recession shock interacting with the dummy for the post-reformulation period, county fixed effects, and state-specific year fixed effects. The observations are weighted by the number of migrants in 2009, one year prior to the OxyContin reformulation, and are clustered at the county level.

Table 11: Effect of OxyContin Reformulation on Worker Flow at Origin-Destination Level

	(1) Worker Flow	(2) Worker Flow	(3) Worker Flow	(4) Worker Flow
Origin Exposure × Post	0.025**		0.026**	0.029***
	(0.010)		(0.010)	(0.011)
Destination Exposure × Post		-0.009	-0.012*	-0.012*
		(0.007)	(0.007)	(0.007)
Observations	1,698,007	1,698,007	1,698,007	1,698,007
Origin-by-Destination FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Recession Shock Controls	N	N	N	Y

Notes: This table reports weighted least squares estimates of the interaction terms between the reformulation exposures at the origin and destination counties and the post-reformulation period with the county-level pre-intervention exposure standardized. The observations are at the origin-by-destination level, and the outcome variable is the log of total worker flow. The observations are weighted by the number of moving workers in 2009, one year before the OxyContin reformulation, and are clustered at the origin-by-destination level. The recession shocks are at both the origin and destination counties.

Table 12: Effect of OxyContin Reformulation on Worker Flow at Origin-Destination Level by Skill Level

	(1) Low Any	(2) High Any	(3) Low Cognitive	(4) High Cognitive	(5) Low IT	(6) High IT	(7) Low Software	(8) High Software
Origin Exposure × Post	0.059***	-0.014	0.055***	-0.011	0.052***	-0.024**	0.076***	-0.025**
	(0.011)	(0.011)	(0.011)	(0.011)	(0.009)	(0.011)	(0.012)	(0.011)
Destination Exposure × Post	0.013*	-0.053***	0.013*	-0.055***	-0.002	-0.055***	0.048***	-0.074***
	(0.008)	(0.007)	(0.008)	(0.007)	(0.007)	(0.008)	(0.009)	(0.007)
Observations	1,698,007	1,698,007	1,698,007	1,698,007	1,698,007	1,698,007	1,698,007	1,698,007
Origin-by-Destination FE	Y	Y	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y	Y	Y
Recession Shock Controls	Y	Y	Y	Y	Y	Y	Y	Y

Notes: This table reports weighted least squares estimates of the interaction terms between the reformulation exposures at the origin and destination counties and the post-reformulation period with the county-level pre-intervention exposure standardized. The observations are at the origin-by-destination level, and the outcome variables are the logs of worker flow of the low- or high-skill group in terms of each skill category (any skills, cognitive skills, computer skills, and software skills). The observations are weighted by the number of moving workers in 2009, one year before the OxyContin reformulation, and are clustered at the origin-by-destination level. The recession shocks are at both the origin and destination counties.

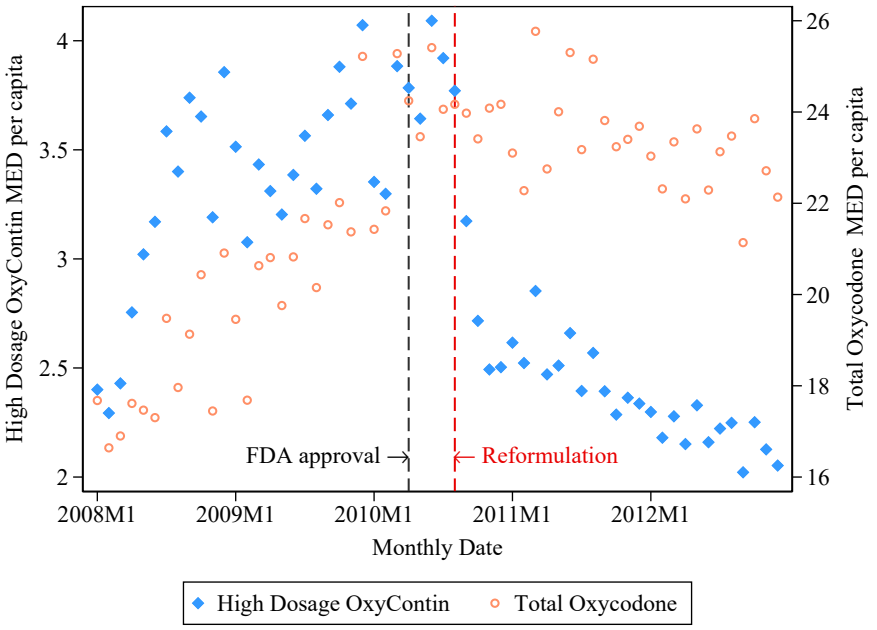
For Online Publication

"The Opioid Crisis and the Location of Work:
Evidence from Online Job Profile Data"

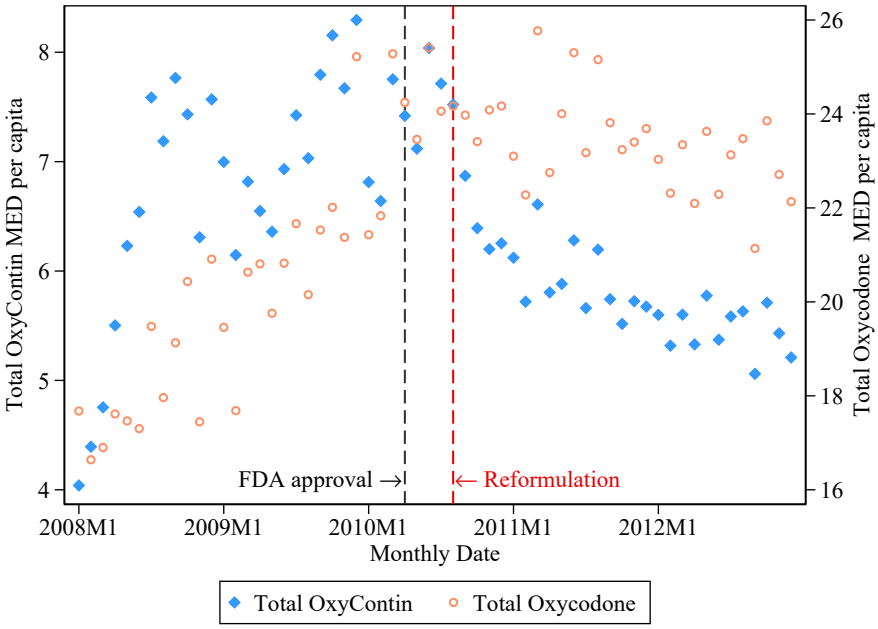
Kim, Kim, and Park (2024)

Figure A1: National Trends in OxyContin and Oxycodone Prescriptions

(a) High Dosage OxyContin and Total Oxycodone



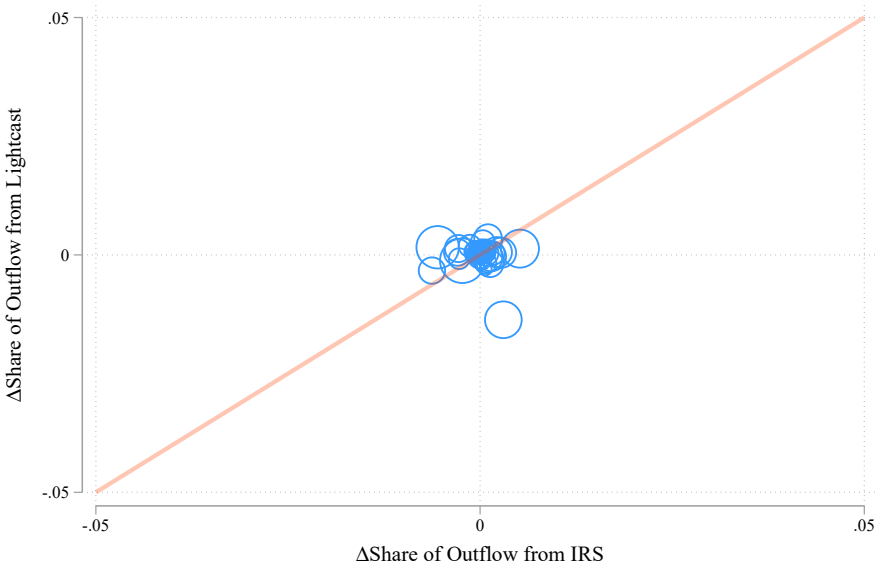
(b) Total OxyContin and Total Oxycodone



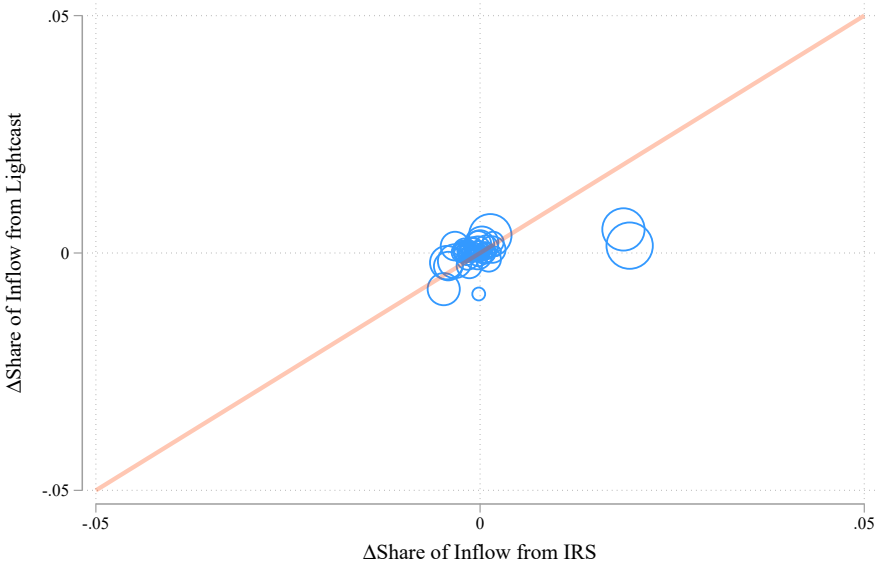
Notes: These figures present raw trends in the legal supply of OxyContin and oxycodone from 2008 to 2012, based on Automated Reports and Consolidated Ordering System (ARCOS) data. Red diamonds represent the per capita Morphine Equivalent Dose (MED) of OxyContin, and blue hollow circles indicate the per capita oxycodone MED. In Panel (a), we focus specifically on high-dosage OxyContin (80 mg), which is more susceptible to abuse. In Panel (b), we present the trends in the total supply of OxyContin. The black dashed vertical line indicates April 2010, when the FDA approved the new OxyContin formula. The red dashed vertical line indicates August 2010, when the new formula was released and replaced the original version of OxyContin.

Figure A2: Change in Cross-state Worker Flow in Lightcast and IRS

(a) Outflow of Workers

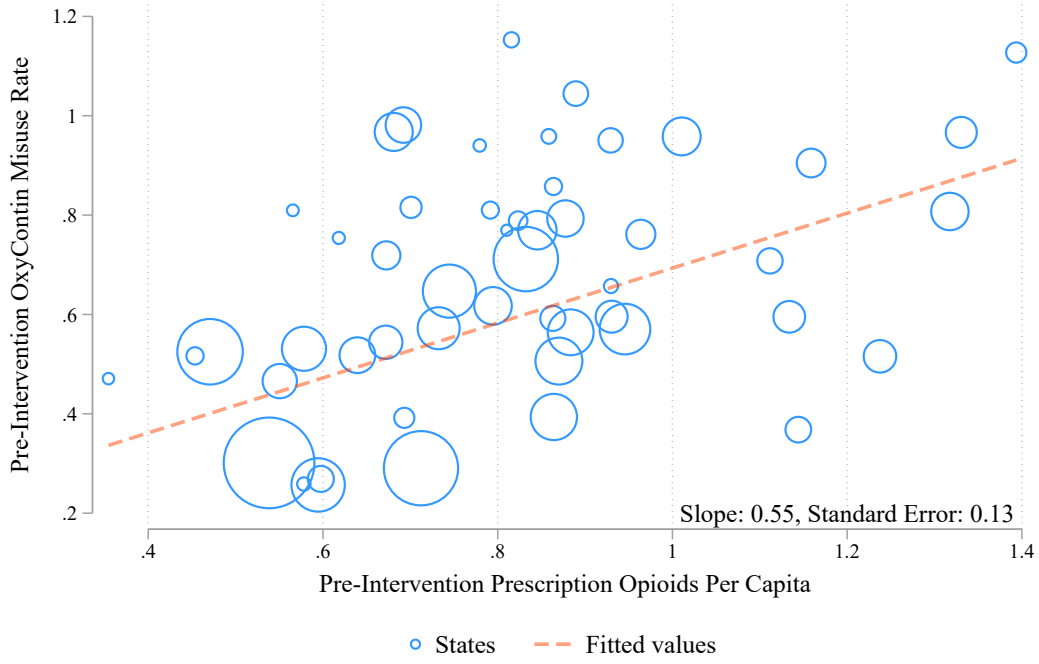


(b) Inflow of Workers



Notes: This figure presents the change in the representativeness across states in Lightcast and IRS SOI among out-migrants to other states (panel a) and in-migrants from other states (panel b). The Y-axis in each panel plots the change in the state share from Lightcast from 2007 to 2013, and the X-axis plots the change in the state share from IRS SOI during the same period. Each point represents a state, and the size of a circle indicates the share from Lightcast in the base year 2007. We plot the 45-degree line (blue line) as a benchmark.

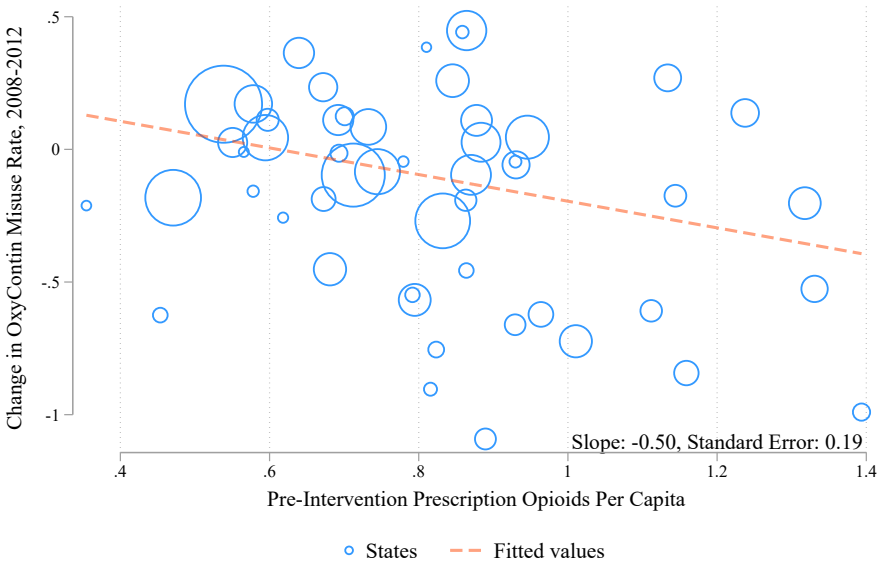
Figure A3: Relationship between 2006–2009 Prescription Opioid Use and 2004–2009 OxyContin Misuse



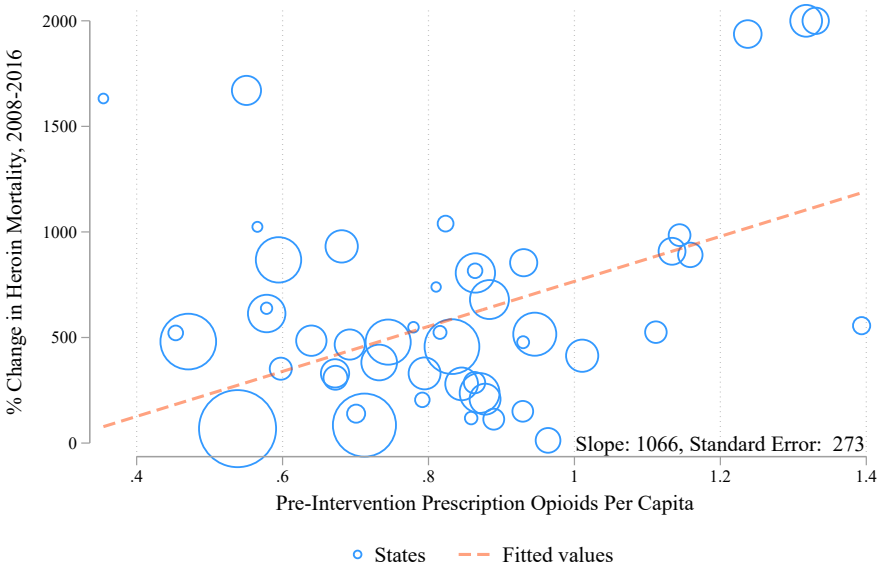
Notes: This figure presents the relationship between the state-level average of opioid prescriptions per capita from 2006 to 2009 (CDC data) and the state-level average of OxyContin misuse rates from 2004 to 2008 (NSDUH data). The NSDUH data on OxyContin misuse is obtained from Alpert et al. (2018). To calculate the state-level measure of opioid prescription use, we use the population-weighted average of our county-level opioid exposure measure. The size of the markers indicates the population size of each state as of 2009.

Figure A4: Relationship between Prescription Opioid Use and Changes in OxyContin Misuse and Heroin Mortality

(a) Pre-Intervention Exposure and Changes in OxyContin Misuse



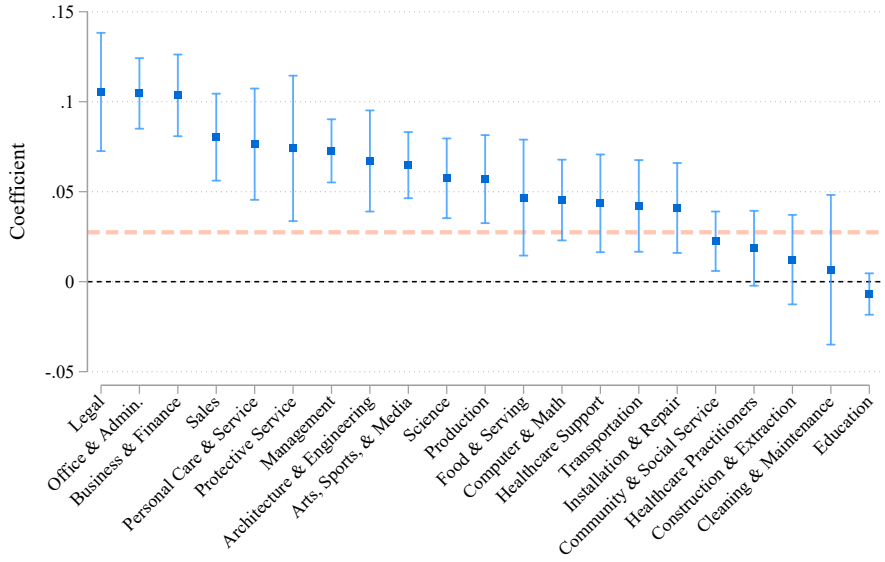
(b) Pre-Intervention Exposure and Changes in Heroin Mortality



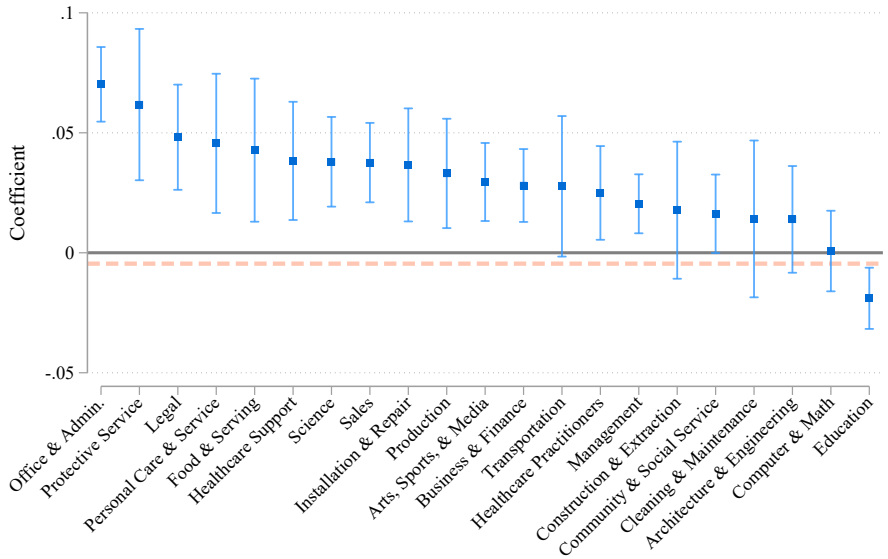
Notes: These figures present the state-level average of opioid prescriptions per capita from 2006 to 2009 (CDC data) and subsequent changes. Panel (a) shows the relationship between the CDC measure and level changes in OxyContin misuse rates between 2008 and 2012, and Panel (b) presents the relationship between the same CDC measure and percentage changes in heroin death rates per 100,000 from 2008 to 2016. The NSDUH data on OxyContin misuse is obtained from Alpert et al. (2018), and the data on heroin mortality are obtained from the National Vital Statistics System (NVSS). The percentage change in mortality is winsorized at 2000 percent. The size of the markers indicates the population size of each state as of 2009.

Figure A5: Effect of OxyContin Reformulation on Worker Flow by Occupation

(a) Outflow of Workers

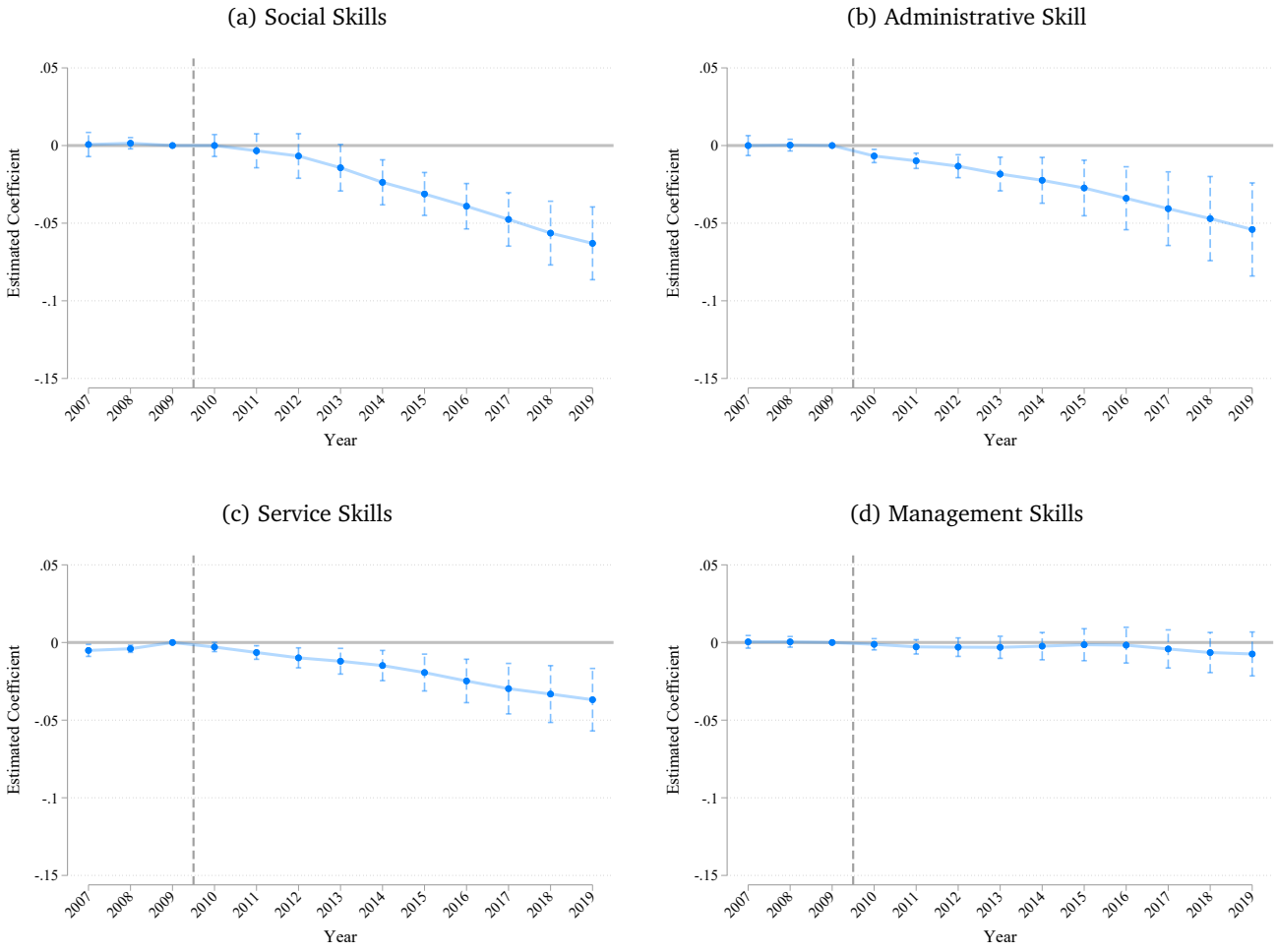


(b) Inflow of Workers



Notes: This figure reports point estimates and 95 percent confidence intervals on the interaction terms ($Exposure_i \cdot Post_t$) from the difference-in-difference version of Equation (1) with the county-level pre-intervention exposure standardized for all 2-digit SOC occupations. The dependent variables are the logs of outflow and inflow in each occupation group. The controls include county-level recession shock interacting with year dummies, county fixed effects, and year fixed effects. The observations are weighted by the number of migrants in 2009 and are clustered at the county level

Figure A6: Dynamic Effect of OxyContin Reformulation on Skill Level in County



Notes: Each figure reports point estimates and 95 percent confidence intervals on the interaction terms ($Exposure_i \cdot 1[t = k]$) from Equation (1) with the county-level pre-intervention exposure standardized. The year 2009, which is one year prior to the OxyContin reformulation, is set as the reference point and normalized to zero. The controls include county-level recession shock interacting with year dummies, county fixed effects, and year fixed effects. The observations are weighted by the number of migrants in 2009 and are clustered at the county level.

Table A1: Skill Categorization

Category	Key words and phrases
Cognitive	Problem Solving, Research, Analytical, Critical Thinking, Math, Statistics
Software (specific)	Programming language or specialized software (e.g. Java, SQL, Python, etc.)
Social	Communication, Teamwork, Collaboration, Negotiation, Presentation
Service	Customer, Sales, Client, Patient
Computer (general)	Computer, Spreadsheets, Common Software (e.g. Microsoft Excel, Powerpoint)
Financial	Budgeting, Accounting, Finance, Cost
Management	Project Management, People Management (Supervisory, Leadership, Management, Mentoring, Staff)
Writing	Writing
Administrative	Organized, Detail-oriented, Multi-tasking, Time Management, Meeting Deadlines, Energetic

Notes: Categorization of skill requirements in Lightcast from Deming and Kahn (2018).

Table A2: Effect of OxyContin Reformulation on Skill Level in County

	(1) Any Skills	(2) Special Skills	(3) Cognitive Skills	(4) Software Skills
Opioid Exposure × Post	-0.013***	-0.016***	-0.022***	-0.037***
	(0.004)	(0.005)	(0.004)	(0.008)
Observations	35,722	35,719	35,707	35,702
Untransformed outcome mean	14.908	10.142	2.277	1.573
County FE	Y	Y	Y	Y
State-Year FE	Y	Y	Y	Y

Notes: This table reports weighted least squares estimates of the interaction terms between the reformulation exposure and the post-reformulation period from the difference-in-difference version of Equation (1) with the county-level pre-intervention exposure standardized. The outcome variables are the logs of the average level of any skills, cognitive skills, computer skills, and software skills of all workers at the county level. The average skill levels are calculated after an individual's skill set is fixed in 2009. The controls include county-level recession shock interacting with the dummy for the post-reformulation period, county fixed effects, and state-specific year fixed effects. The observations are weighted by the number of migrants in 2009, one year prior to the OxyContin reformulation, and are clustered at the county level.

Table A3: Effect of OxyContin Reformulation on Worker Flow Excluding Appalachian Counties

	(1) Outflow	(2) Outflow	(3) Inflow	(4) Inflow	(5) Outflow/Inflow	(6) Outflow/Inflow
Opioid Exposure × Post	0.114***	0.103***	0.060***	0.031**	0.036*	0.049***
	(0.039)	(0.024)	(0.019)	(0.013)	(0.019)	(0.011)
Observations	23,177	23,164	23,177	23,164	23,022	23,009
Untransformed Outcome Mean	1073.538	1073.538	1160.130	1160.130	1.054	1.054
County FE	Y	Y	Y	Y	Y	Y
Year FE	Y	N	Y	N	Y	N
State-Year FE	N	Y	N	Y	N	Y

Notes: This table reports weighted least squares estimates of the interaction terms between the reformulation exposure and the post-reformulation period from the difference-in-difference version of Equation (1) with the county-level pre-intervention exposure standardized. The counties in the Appalachian area are excluded. The controls include county-level recession shock interacting with the dummy for the post-reformulation period, county fixed effects, and year fixed effects in columns (1), (3), and (5). In columns (2), (4), and (6), year fixed effects are replaced with state-specific year fixed effects. The observations are weighted by the number of migrants in 2009, one year prior to the OxyContin reformulation, and are clustered at the county level.