The Impact of Medical Innovation on Health and Disability*

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Abstract

This paper investigates the impact of one of the most important surgical innovations in recent decades: the move from traditional open surgery to minimally invasive surgery. Using an instrumental variables strategy along with administrative data on injured workers undergoing orthopedic surgery, we quantify the impact of minimally invasive surgery (compared to analogous open surgery) on subsequent health care use, return to work, long-term disability, and social insurance payments. The findings suggest minimally invasive surgery reduces health care spending in the two years following surgery by 30%—through both reduced complexity of the surgery itself and large reductions in subsequent health care use. Analysis by type of service suggests minimally invasive surgery reduces subsequent office visits, opioid use, and revision surgeries. Moreover, we document that minimally invasive surgery also improves broader measures of patient health and disability—speeding return to work (by 37 days), reducing the severity of permanent disabilities (by 30%), and reducing associated social insurance costs (by 28%). We conclude by documenting trends in the adoption of minimally invasive surgeries and exploring the policy implications of our findings in light of these trends.

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There has been tremendous progress in medical technology over the last century. Such innovation has been credited with major improvements in health—through enabling life-saving interventions and promoting longevity. Beyond enabling longer lives, medical innovation also has the potential to improve quality of life. Despite the incredible promise of medical innovation, it is challenging to quantify the impacts of innovation on health for several reasons. First, finding reliable measures of health is difficult—particularly at scale. Thus, much of the research analyzing the health impacts of innovation focuses on acute impacts of interventions that may plausibly impact mortality or hospitalizations. Second, identification is challenging. Individuals offered cutting-edge treatment may differ from those using the standard of care. Clinical trials tend to be small and often have insufficient power to detect effects on many outcomes. And quasi-experimental evidence is challenging, as it requires both isolating plausibly exogenous variation and obtaining data on innovation exposure and outcomes. Third, many medical innovations—including nearly all non-pharmaceutical medical innovations—do not require clinical trials. For example, innovations in medical procedures—such as surgical treatments—are often passed along through professional networks and informal training and do not typically require clinical trials or government approval. Thus, clinical trials are not available to evaluate the impacts of the vast majority of non-pharmaceutical medical innovations, and causal evidence beyond clinical trials on the impacts of such innovations is also scarce.

This paper addresses these challenges and provides novel evidence on the impact of an important non-pharmaceutical medical innovation. Specifically, we focus on arguably the largest surgical innovation in the last several decades: the move from traditional "open surgery"—where a surgeon makes a large incision and performs a surgical intervention in the area uncovered by the incision—to "minimally invasive surgery"—surgery performed via small incision with the assistance of scopes (e.g., arthroscopic or laparoscopic surgeries). Our study estimates the impact of minimally invasive surgery relative to open surgery in the context of orthopedic surgery on the musculoskeletal system. Orthopedic surgeries are a large and growing segment of surgeries, making up 26% of all operating room procedures excluding obstetrics in 2011 and having increased by 38% in the previous decade. Moreover, the introduction of minimally invasive surgery techniques has revolutionized orthopedic surgery, with the share minimally invasive increasing roughly 9% from 2008 to 2020.[1]

Orthopedic surgery is generally considered low-risk surgery and is typically performed on a reasonably healthy population; thus, we may not expect modern innovation in orthopedic surgery to have large impacts on immediate post-surgical mortality from risks directly resulting from the surgery itself. Nevertheless, innovation in orthopedic surgery may have large impacts on health through affecting an individual's recovery from physical impairments necessitating surgery and from recovery from surgery itself. And these impacts may be long lasting, affecting an individual's healing trajectory and overall health for weeks, months, or years after the procedure. In this way,

[1]Based on the authors' calculations, there was roughly a 9% increase in the use of minimally invasive techniques for "target surgeries" analyzed in this paper—musculoskeletal surgeries that can be preformed using either open or minimally invasive techniques—controlling for the composition of target surgeries over time.

surgical innovation may have important impacts on overall health, daily living limitations, and the ability to resume normal activities including work—both in the short- and long-run. We estimate the comprehensive impacts of surgical innovation on health, health care use, labor supply, and disability using comprehensive administrative data on injured workers in Texas.

Our analysis leverages comprehensive administrative claims data combined with a unique dataset we compile on surgeries that may be performed using either open or minimally invasive techniques. Drawing extensively on medical coding guidelines, we compile a novel dataset representing a comprehensive set of orthopedic surgeries that can be performed using either open or minimally invasive techniques. We first document that there is tremendous variation in whether a given surgery is performed using open or minimally invasive techniques, over time and across surgeons. While no prior systematic empirical evidence exists, minimally invasive techniques are often thought to represent an important innovation beyond traditional open techniques, as the smaller incisions involved in minimally invasive surgeries can reduce rates of infection and are thought to potentially shorten recovery periods. However, after a minimally invasive technique is first developed for a particular surgery, adoption of this technique slowly diffuses over time, as knowledge and practices are disseminated through professional networks and across regions. And widespread or near-universal adoption can take years or decades. As we demonstrate, at any given point in time, there is substantial variation across regions and surgeons in the use of minimally invasive techniques for a given surgery, and generally there is a trend toward the use of more minimally invasive methods over time.

When minimally invasive techniques are available for a particular surgery, whether a given patient receives the open or minimally invasive version of the surgery may also depend on factors related to the patient or situation—e.g., health risk of the patient, circumstances of the surgery, or differences in the nature of the problem the surgery is meant to address. We demonstrate that whether a given patient receives the open or minimally invasive version of a surgery is strongly related to baseline patient and surgery characteristics. This presents a key identification challenge for estimating the causal effect of minimally invasive techniques. To overcome this challenge, we construct an instrument for whether that surgery was performed using minimally invasive or open techniques based on the associated surgeon's propensity to perform minimally invasive surgeries. Specifically, we instrument for the use of minimally invasive techniques for a given surgery using the surgeon's propensity to use minimally invasive techniques on the surgeon's other patients, controlling for basic characteristics of the surgery and patient. Using rich baseline administrative data, we demonstrate the instrument appears unrelated to baseline observables of the patient or surgery—supporting the exclusion restriction. Moreover, we demonstrate that the instrument is a strong predictor of the actual technique used for the surgery.

We apply this empirical design to estimate the impact of minimally invasive surgery among injured workers covered by workers' compensation insurance. Workers' compensation insurance provides workers with workplace injuries cash benefits to compensate for missed work due to injury and coverage for health care associated with these injuries. While workplace injuries vary in circumstances, the vast majority of workers' compensation insurance claims are for musculoskeletal injuries, and orthopedic surgery is commonly used to address such injures. There are several strengths of this setting for this analysis. First, we are able to leverage comprehensive administrative data on workers' compensation claimants to investigate impacts of surgical innovation on recovery from injury in a very granular fashion. These data include all the typical information in health claims data, as well as several additional measures of health, disability, and labor supply including the duration an individual is out of work receiving wage replacement benefits while recovering from their injury, the dates a worker is out of work receiving benefits, and measures of impairment that reflect a worker's degree of permanent disability after healing has plateaued. The data also include rich baseline information on patients, allowing us to provide evidence supporting the validity of the empirical design and to investigate heterogeneity. Second, beyond the empirical evidence we present supporting the exclusion restriction, institutional features of the workers' compensation insurance setting suggest the exclusion restriction is likely to hold. Health care provided to workers' compensation claimants is managed using a gatekeeper model, where the primary treating doctor oversees all health care and is responsible for all referrals. This strict gatekeeper model means injured workers needing surgery have limited influence on whether they obtain the surgery or the surgeon who performs their surgery.

We begin by presenting evidence validating our instrument, showing it is both a strong predictor of actual technique used and not related to baseline characteristics of the patient or surgery. We then investigate the impact of having minimally invasive surgery (relative to an analogous open surgery), beginning with impacts on immediate outcomes pertaining to the surgery itself. Relative to analogous open surgery, minimally invasive surgeries are less complex and involve fewer complementary services. For instance, our estimates suggest minimally invasive surgeries are substantially less likely to involve an overnight stay (a 2.7 p.p. or 2.9% reduction, on average) and are much more likely to be performed at an outpatient surgery center rather than an inpatient hospital (a 28.4 p.p or a 39.9% increase, on average). This reduced complexity may contribute to lower health care spending on the surgery date, with point estimates suggesting that, on average, health care spending on the surgery date is 14.6% lower for minimally invasive surgeries compared to analogous open surgeries.

We then turn to analyzing outcomes after the surgery—considering both cumulative impacts up to two years after surgery and impacts by quarter since surgery. Relative to open surgeries, minimally invasive surgeries, on average, involve $5,274 or 30.4% less total health care spending in the two years after surgery, reflecting reductions in both medical and prescription drug spending. The estimates indicate the reduction in health care spending in dollars is largest in the quarter immediately following surgery, though the reductions in spending are persistent, reflect similar percent changes over time, and remain statistically distinguishable from zero up to two years after the surgery. We also analyze impacts on specific categories of health care that are commonly associated with post-surgical recovery or recovery from injury including office visits, physical therapy visits, and opioid use. During the two years after surgery, minimally invasive surgery, on average, involves 5.1 fewer office visits (63.6% of the mean). While we find no impact on physical therapy visits immediately after surgery, we find suggestive evidence that minimally invasive surgery decreases physical therapy utilization several quarters after surgery. Our estimates indicate that minimally invasive surgery is associated with large reductions in opioid use. Relative to those with open surgery, those receiving minimally invasive surgery have 40.9 (or 85.3%) fewer opioid days supplied in the two years following surgery. Moreover, we present evidence illustrating these reductions in opioid use appear immediately following surgery and persist for at least two years after the surgery, with impacts increasing—in terms of implied percent effects and statistical significance—over time since surgery. We also analyze impacts on subsequent musculoskeletal surgery on the same body part—as subsequent surgery is often required when issues remain unresolved after the initial surgery. Minimally invasive surgery is associated with a 7.5 p.p. reduction (a 43.9% decrease) in the likelihood of subsequent surgery on the same body part.

Beyond analyzing impacts on health care utilization, we also analyze impacts on disability and associated social insurance costs. Relative to those with open surgeries, those with minimally invasive surgery receive, on average, $3,981—or 25.0%—less in subsequent cash disability benefits in the two years following surgery. Minimally invasive surgery is associated with 37.1 fewer days out of work receiving temporary income benefits after surgery—a 29.1% decrease relative to the open surgery mean. These impacts reflect intensive margin responses, as there is no impact on the likelihood of any time out of work receiving temporary income benefits. In addition, our estimates suggest minimally invasive surgery may improve recovery from the injury in the long term—with our estimates indicating minimally invasive surgery is, on average, associated with a 1.06 p.p. (or 30.4%) reduction in the rated severity of permanent impairments among injured workers. Relative to open surgery, minimally invasive surgery is associated with a $9,255 (27.8%) average decrease in total workers' compensation costs, aggregating across cash disability benefits and health spending.

Heterogeneity analysis reveals the impacts of minimally invasive surgery seem to be universal—with estimates suggesting minimally invasive surgery leads to an across-the-board improvement in health and disability outcomes across all subgroups examined. Patterns in these estimates suggest impacts may be larger among women and younger workers. Additionally, we conduct supplemental analysis illustrating the robustness of these basic findings. For instance, we demonstrate we obtain similar estimates when focusing on planned surgeries, excluding surgeries preformed on an emergency basis. We also demonstrate our findings are not driven by any particular surgery type, through illustrating we obtain similar estimates when excluding each surgery type one at a time. Moreover, we demonstrate that doctor characteristics correlated with minimally invasive intensity do not explain our findings.

Next, we analyze trends in adoption of minimally invasive surgical techniques and interpret our primary findings in light of these trends. We document that the share of target surgeries performed using minimally invasive techniques grew substantially over time, rising from 67.1% in 2008 to 73.2% in 2020. Combining this descriptive evidence with our baseline causal estimates, we assess the aggregate impact of the growing use of minimally invasive surgery. This analysis indicates that the increased adoption of minimally invasive surgery from 2008 to 2020 meaningfully improved aggregate post-surgical outcomes for injured workers, leading to declines in mean subsequent health care spending (1.9%), opioid use (5.3%), subsequent surgeries (3.1%), missed work days (1.8%), and permanent disability severity (1.9%). This improvement in outcomes substantially influenced overall trends in these outcomes over time, with our estimates suggesting diffusion of minimally invasive surgery can explain 15.0% of the reduction in post-surgical health care spending over this period. Additionally, we document vast geographic variation in the diffusion of minimally invasive surgery techniques, with estimates suggesting the 20% slowest-adopting areas have adoption rates roughly a decade behind the 20% fastest-adopting areas. We conclude with back-of-the-envelope calculations considering the potential impact of policies aimed at accelerating the diffusion of minimally invasive techniques or aimed at narrowing geographic disparities in adoption.

Our study contributes to a broad interdisciplinary literature on the health impacts of innovation. A large medical literature documents immediate, short-run impacts of pharmaceutical innovations on various treatment-specific measures (e.g., management of particular chronic conditions, adverse side effects, etc.), using observational variation or small-scale clinical trials. Recent work in the economics literature uses quasi-experimental methods to analyze the impact of specific pharmaceutical innovations in the early 20th century in contributing to mortality and longevity trends over time. For example, some work has explored the invention of sulfa drugs (antibiotics used to treat a range of bacterial infections)—on mortality and life expectancy (Jayachandran, Lleras-Muney and Smith, 2010), women's fertility (Bhalotra, Venkataramani and Walther, 2023), or later life outcomes among those with access to these treatments in childhood (Lazuka, 2020). Other recent work has examined impacts of antitoxins for Diphtheria (Ager, Hansen and Lin, 2024). In addition, an emerging literature has used quasi-experimental methods to analyze the impact of more recent pharmaceutical innovations on labor market trends and employment outcomes, including work on Cox-2 Inhibitor painkillers (Garthwaite, 2012; Bütikofer and Skira, 2018), mental health drugs (Bütikofer, Cronin and Skira, 2020; Shapiro, 2022; Biasi, Dahl and Moser, 2021), cancer drugs (Jeon and Pohl, 2019), and opioids (e.g., Beheshti (2023); Park and Powell (2021)). While the practice of medicine has evolved tremendously over the last few decades, little is known about the effects of medical innovations that go beyond pharmaceuticals. This is an important gap in the literature. Unlike newly developed pharmaceuticals, medical innovations are typically not required to undergo clinical trials or demonstrate efficacy according to any metric. Beyond challenges in isolating plausibly exogenous variation to estimate causal impacts, estimating the impact of medical innovation is also challenging because it requires data on both outcomes and exposure to the innovation—which is often not universal as diffusion tends to be gradual. As a consequence, existing evidence on the causal impacts of medical innovation is very limited. Moreover, understanding the impacts of medical innovation is important, as policy decisions can impact the diffusion of these innovations. Diffusion for such medical innovations is typically slower than adoption of pharmaceutical innovations and there is potential scope for public policy to influence diffusion patterns—through impacting incentives to adopt innovations or facilitating more rapid dissemination of these methods across areas and providers.

Our work makes several contributions. First, in contrast to prior work that has largely focused on pharmaceutical innovations, our study provides novel evidence on a major medical innovation. The medical innovation we study—the move from open surgery to minimally invasive surgery—is arguably one of the most significant surgical innovations in the past half century. Understanding the impacts of medical innovation is important to inform policy, and our paper provides novel evidence on one such major innovation. Second, our study provides evidence on the impact of this major medical innovation on a broad range of outcomes—including on health, health care costs, and broader outcomes. Through leveraging unique linked administrative data on medical claims and social insurance benefits, we provide evidence on impacts on health care utilization, health, work limitations, labor supply, and disability benefit receipt in the short, medium and long runs. Third, we document novel evidence on diffusion patterns of this medical innovation, illustrating the dynamics of diffusion of minimally invasive surgery techniques across areas and across different types of surgeries. Combining these descriptive patterns with our estimates of the causal impact of minimally invasive surgery (relative to traditional open surgery), we illustrate how diffusion contributes to broader trends in outcomes and benchmark how policy aimed at impacting diffusion patterns could potentially impact outcomes.

1 Background and Data

1.1 Setting and Data Sources

Workers' Compensation Insurance Workers' compensation is a state-regulated insurance program that provides cash and health care benefits to employees who suffer workplace injuries and illnesses. Differences in state programs exist, but the basic structure of workers' compensation insurance is similar across states. Employers purchase insurance policies or self-insure, and injured workers are eligible for benefits that are set by the state. Injured workers choose a "treating doctor"—typically a primary care doctor—who serves as their gatekeeper for both health care and cash benefits.[2] While workers' compensation insurance covers a broad range of work-related health issues, the majority of claims are for musculoskeletal injuries.

Workers' compensation insurance provides full coverage for health care related to workplace injuries, and injured workers have no out-of-pocket expenses for injury-related health care, regardless of their work status or receipt of cash disability benefits. Workers' compensation insurance is the first and only payer for all injury-related health care. Treating doctors are responsible for coordinating and approving all non-emergency health care provided to injured workers and for making any necessary referrals to other providers, including surgeons and other specialists. Treating doctors can bill insurers for standard medical services they provide to injured workers, as well

[2] In Texas, doctors of any specialty with an active medical license can be treating doctors, though the majority of treating doctors are general practitioners.

as for "case management services" related to overseeing workers' compensation insurance claims. Providers are paid based on a state-specified fee schedule or on contracts with insurers.

Injured workers can receive two main types of cash benefits: temporary income benefits and permanent impairment benefits. Claimants who have to miss work because of their injuries are eligible to receive temporary income benefits while they recover from their injuries. Temporary income benefits replace 70% of a claimant's average weekly wage, subject to minimum and maximum weekly benefit amounts, and begin after a waiting period. In Texas, injured workers are eligible for temporary income replacement benefits after they miss at least 7 days of work because of their injuries. Temporary income benefits continue until the earliest of the following: (i) injured workers return to work, (ii) their treating doctor determines they have reached "maximum medical improvement," or (iii) they reach the statutory limit for temporary income benefits, which in Texas is 104 weeks. In practice, it is uncommon for workers to receive temporary income benefits for the full two years. Temporary income benefit spells average 18 weeks in Texas, and most beneficiaries return to work when temporary income benefits terminate, regardless of whether they have some degree of partial permanent impairment. Leveraging linked administrative data from workers' compensation insurance and unemployment insurance earnings records, the Texas Department of Insurance documents that 76% of temporary income benefit recipients returned to work within six months of injury and 95% returned to work within three years of injury among those injured in 2011 (TDI, 2015).

After temporary income benefits end, workers can receive additional permanent impairment benefits if they have an ongoing (partial) permanent impairment. The degree of permanent impairment is assessed after the treating doctor determines the worker has reached maximum medical improvement. Treating doctors assign permanent impairment ratings based on the percentage of whole-body impairment caused by the injury. Permanent impairments in this population are typically minor and do not prevent return to work, with the mean claimant rated as 6% impaired (on a scale of 0% to 100%) among claimants with a non-zero permanent impairment rating. Permanent impairment benefits are calculated based on this impairment rating and on workers' prior average weekly wages, and these benefits are unconditional in that they are paid regardless of whether the claimant returns to work or their earnings upon returning to work.

Data To examine the impact of minimally invasive surgeries in workers' compensation insurance, we compiled a unique dataset on surgeries for workplace injuries that combines multiple administrative data sources obtained through open records requests submitted to the Texas Department of Insurance. The administrative data are supplemented with additional information from various publicly available data sources and from data sources obtained through open records requests to other agencies. The data contain information on all workers' compensation claims that occurred in Texas from January 2005 to May 2023.

Data on worker's compensation claimants include health care data, which include all medical, pharmacy, and case management bills paid for by workers' compensation insurance. These data contain procedure type (CPT codes), amount paid, diagnoses (ICD codes), date and place of service, and provider information, as well as a claim identifier that allows all health care to be linked back to the associated injury claim and to other administrative data sources. These health care data are used to identify surgeries, surgery dates, and surgeons. The workers' compensation insurance data also include rich demographic and injury information about each claim, including claimant sex, birth date (month-year), injury date (month-year), and zip code. For claimants who receive cash benefits, the data contain information on the type of cash benefits received, total benefits received, prior average weekly wages, and benefit start and end dates. Our primary analysis focuses on health care and cash benefit outcomes using two years of information after surgeries and adjusting all monetary values to December 2020 dollars using the Consumer Price Index (BLS, 2025).

Our analysis sample includes surgeries occurring from June 2007 to April 2021 for whom we can identify the surgeon. We focus on surgeries that happened from June 2007 onward because we use provider National Provider Identifiers (NPI) to identify surgeons and NPIs became effective beginning in May 2007. We focus on surgeries happening before May 2021 to ensure that we have two years of post-surgery information for all surgeries, and we focus on surgeries performed within 360 days of the claim start date. For claimants with multiple surgeries, we classify surgeries based on the earliest surgery because subsequent surgeries and health care use are endogenous to the first surgery performed.

For basic information on doctors, including sex and taxonomy code, we draw on data from the Centers for Medicare & Medicaid Services' (CMS) NPI registry (CMS, 2024). We supplement these data with additional information on doctor characteristics from the Medicare Physician Compare File (CMS, 2025) and the Texas Medical Board website (TMB, 2025).

1.2 Definitions and Descriptive Statistics

Definition of Surgical Procedures Our analysis focuses on the impact of medical innovation—specifically the use of minimally invasive surgery techniques—for musculoskeletal surgeries. In this paper, we use the term "musculoskeletal surgeries" to refer to surgical procedures on the musculoskeletal system or aimed at addressing musculoskeletal injuries (e.g., rotator cuff repair, knee meniscus surgery), excluding procedures that are purely diagnostic or non-invasive (i.e., do not involve an incision).

Our main analysis focuses on "target surgeries"—which we define as musculoskeletal surgeries with procedure codes that reflect that these surgeries can be performed using either open or minimally invasive techniques. To compile a comprehensive list of target surgeries, we first identified all procedure codes for musculoskeletal surgeries that involve the use of minimally invasive methods facilitated by scopes (i.e., arthroscopic surgery, laparoscopic surgery). We then grouped these procedure codes into "surgery types"—that reflect the nature of the surgery and the body part on which the surgery was conducted. For each surgery type group, we then identified all procedure codes for analogous open surgeries through consulting numerous medical coding references and guides. Appendix Section A provides further details.

To facilitate our analysis, we define "target encounters" as dates on which a given individual has a target surgery, focusing on target surgeries that were the primary procedure performed on that date (defined as the procedure with the highest charges on that date). Our final sample includes 93,350 target encounters, where these surgeries were performed by 978 surgeons. We code an encounter as "minimally invasive" if the associated target surgery employed minimally invasive surgery techniques and as "open" otherwise. Appendix Section B provides more detail on these definitions.

Descriptive Statistics Table 1 lists the most common target surgeries among injured workers in our data, along with basic information including the share of these surgeries that are minimally invasive over the analysis period and some basic demographic information on patients receiving these surgeries. The most common target surgeries are knee meniscectomy, shoulder rotator cuff repair, and knee ACL/PCL reconstruction, which collectively account for approximately half of target surgeries. The next most common target surgeries include shoulder subacromial decompression, wrist/forearm fracture fixation, and shoulder biceps tenodesis. It is important to note that minimally invasive surgical methods were developed at different times for different types surgeries, and hence the mean share of surgeries that are minimally invasive differs dramatically across common target surgeries over this time frame. For instance, over the sample period, 63.1% of shoulder rotator cuff repair surgeries are minimally invasive, whereas only 8.2% of wrist/forearm fracture fixation surgeries are minimally invasive.

Table 2 summarizes patients with target surgeries included in our analysis. Column (1) describes the full sample, while columns (2) and (3) describe the subsets of patients with open and minimally invasive surgeries, respectively. Panel A summarizes basic characteristics. Seventy percent of patients are male and the mean age is 46.8. The mean age and share male are similar among patients with open and minimally invasive surgery. Overall, 70.1% of surgeries are minimally invasive. Target surgeries span a range of body parts, with the most common being knee, shoulder, wrist/forearm, and hand. The prevalence of minimally invasive techniques compared to open techniques varies across surgeries and body parts, with minimally invasive techniques relatively more common among surgeries on the knee and shoulder.

Table 2 Panel B summarizes pre-surgery characteristics among patients with target surgeries included in our analysis. We note that the observed period before surgery is limited to the time from injury to surgery, and health care is limited to injury-related health care. On average, 101 days pass between a worker's injury and the target surgery, with only 1.4% of surgeries taking place on the first day the injury was treated.[3] Among injured workers in our sample, 31.4% first received treatment for their injury through the Emergency Department (ED), and mean health care spending on the first day the injury is treated is $644. For workers with more than two weeks between injury and surgery, we also summarize total pre-surgery health care use over the first two weeks of the

[3]Figure 8 illustrates our findings are robust when dropping surgeries potentially done on an emergency basis—these first-day surgeries and surgeries on the same day as an Emergency Department visit.

claim.[4] During the first two weeks after injury, injured workers have, on average, $\$1,237$ in health care spending, 1.8 office visits and 0.9 physical therapy visits to treat their injury; 34.8% of injured workers fill an opioid prescription in the first two weeks after injury, and the mean days supplied of opioids is 2.9.

2 Empirical Strategy

2.1 Econometric Model

Our baseline specification aims to estimate the impact of receiving a given surgery using minimally invasive techniques rather than traditional open surgery. Because whether an individual receives the minimally invasive or open version a of a surgery may depend on individual characteristics and circumstances, we use an instrument variables strategy leveraging variation across surgeons in their general propensity to use minimally invasive techniques. Specifically, we estimate the following instrumental variables specification:

$$\begin{aligned} Y_i &= \delta Minimally\_Invasive_i + \boldsymbol{X}_i\boldsymbol{\theta} + \omega_{s(i)t(i)} + \epsilon_i && (1) \\ Minimally\_Invasive_i &= \zeta z_{id(i)} + \boldsymbol{X}_i\boldsymbol{\beta} + \nu_{s(i)t(i)} + e_i, && (2) \end{aligned}$$

where i represents an individual, $d(i)$ represents the surgeon associated with individual i, $s(i)$ the surgery type individual i received, and $t(i)$ the year individual i had surgery. Equation (2) is the first stage equation relating the potentially endogenous indicator for whether a surgery was minimally invasive ($Minimally\_Invasive_i$) to the doctor minimally invasive intensity instrument ($z_{id(i)}$), fixed effects for surgery type by year ($\nu_{s(i)ti)}$), and additional controls ($\boldsymbol{X}_i$) for demographics (individual age and gender) and for the medical market in which the individual resides (fixed effects for the Hospital Referral Region as defined by the Dartmouth Atlas (DAP, 2021)). Equation (1) models the relationship between outcomes of interest (Y_i) and the surgery being minimally invasive ($Minimally\_Invasive_i$), including surgery type by year fixed effects ($\omega_{s(i)t(i)}$) and the same additional controls ($\boldsymbol{X}_i$). We measure outcomes at different time intervals since the surgery was performed. Standard errors are clustered at the doctor level.

The doctor intensity instrument we construct relies on the idea that a doctor's overall propensity to use minimally invasive surgery techniques can be measured by a doctor's average propensity to do minimally invasive surgery among all other surgeries, averaging over surgeries leaving out the surgery on individual i. Because the composition of surgeries varies across doctors, we use a UJIVE ("unbiased jacknife instrumental variables estimator") approach to construct an instrument that isolates variation across doctors in their leave-out propensity to use minimally invasive techniques,

[4] For these descriptive statistics, we focus on the 87.2% of claims with at least 17 days between the claim start date and the surgery. These variables measure health care over the first 14 days since claim start. Because we aim for these measures to capture pre-surgery health care spending, we construct these measures for claimants with at least 17 days between claim start and surgery—ensuring a minimum of three days between this window and the surgery—to exclude health care directly related to the surgery itself.

controlling for the mix of surgeries they perform through observed characteristics of these surgeries. Specifically, for each individual i, we first estimate the following two equations using a leave-out sample—excluding the index individual i—denoted by the subscript $-i$:

$$Minimally\_Invasive_{-i} = \boldsymbol{X}_{-i}\boldsymbol{\alpha} + \gamma_{s(-i)t(-i)} + \mu_{-i} \tag{3}$$

$$Minimally\_Invasive_{-i} = \boldsymbol{X}_{-i}\boldsymbol{\pi} + \phi_{s(-i)t(-i)} + \kappa_{d(-i)} + v_{-i}. \tag{4}$$

We then obtain the doctor intensity instrument for individual i by subtracting the fitted value of Equation (3) from the fitted value of Equation (4), where each fitted value is separately calculated using the estimated coefficients for the characteristics associated with individual i in each equation: $z_{id(i)} \equiv \left(\boldsymbol{X}_i\widehat{\boldsymbol{\pi}} + \widehat{\phi}_{s(i)t(i)} + \widehat{\kappa}_{d(i)}\right) - \left(\boldsymbol{X}_i\widehat{\boldsymbol{\alpha}} + \widehat{\gamma}_{s(i)t(i)}\right)$.

The key identification assumption is that $z_{id(i)}$ satisfies the exclusion restriction: $z_{id(i)}$ only impacts outcomes of interest Y_i through impacting the likelihood a surgery is minimally invasive $Minimally\_Invasive_i$. Institutional features—such as the strict gatekeeper model for workers' compensation covered health care and the limited scope for patients to influence which surgeon performs their surgery—support the plausibly of this assumption. Moreover, while this assumption is fundamentally untestable, we use several strategies to empirically assess the plausibility of this assumption. First, we demonstrate that baseline pre-surgery patient characteristics—and predictions of our main dependent variables based on baseline characteristics—are unrelated to the identifying variation within our estimation sample. Second, we illustrate the robustness of our results when varying sample restrictions. Third, we demonstrate that the results are not driven by other observed doctor characteristics correlated with the identifying variation.

2.2 Identifying Variation

Figure 1 displays a histogram of $z_{id(i)}$. There is substantial residual variation in $z_{id(i)}$ with an interquartile range of 15.0 p.p. and an interdecile range of 28.4 p.p. Figure 2 Panel A shows a binned mean residual plots, relating $Minimally\_Invasive_i$ residualized using the baseline controls to $z_{id(i)}$. This figure indicates the likelihood an individual receives the minimally invasive version of a surgery strongly increases in the doctor's minimally invasive intensity based on the doctor's other patients ($z_{id(i)}$), the magnitude of this relationship is approximately one-for-one, and this relationship is roughly linear. This provides strong evidence supporting the relevance of the instrument in predicting the likelihood a patient has minimally invasive surgery.

For $z_{id(i)}$ to serve as a valid instrument for identifying causal impacts, $z_{id(i)}$ must also satisfy an exclusion restriction: the instrument only impacts post-surgical patient outcomes through the causal impact on the likelihood the surgery is minimally invasive. Figure 2 Panel B provides evidence supporting the exclusion restriction through presenting binned mean residual plots relating residualized *predicted* $Minimally\_Invasive_i$ based on baseline patient characteristics to $z_{id(i)}$.[5] In contrast to the patterns seen in Panel A of Figure 2 relating the actual surgical method to

[5]We construct each patient's predicted probability of minimally invasive surgery by regressing an indicator for

the instrument, Panel B indicates there is no relationship between predicted $Minimally\_Invasive_i$ based on baseline characteristics and $z_{id(i)}$.

We present further evidence supporting the plausibility of the exclusion restriction. Specifically, we leverage rich baseline data on patients to illustrate that pre-surgery characteristics appear unrelated to the identifying variation conditional on the included controls. For this analysis, we re-estimate the IV specification outlined in Equations (1) and (2) above replacing the dependent variable with pre-surgery characteristics. For comparison, this figure also presents estimates from OLS regressions of baseline patient characteristics on $Minimally\_Invasive_i$, capturing the observational relationship between the use of minimally invasive surgery and baseline patient characteristics. We examine a wide range of baseline (pre-surgery) patient characteristics including proxies for the severity of the injury (an indicator for whether the claim originated with an ED visit, log of health spending on the first day of claim, indicator for surgery on first day of claim), time between injury and surgery, measures of health care utilization in the first two weeks of the claim (pre-surgery physical therapy visits, opioid use, mean health care spending) among claimants with sufficient time between injury and surgery. Appendix Section B contains details on how these measures are calculated.

Figure 3 displays these estimates. The figure displays the coefficient of interest on the minimally invasive indicator from separate regressions—estimated via OLS or IV as indicated in the figure heading—along with the associated 95% confidence interval. Appendix Table A1 displays the corresponding estimates, along with their standard errors and p-values. There are two key takeaways from this analysis. First, the coefficients on the instrumented minimally invasive measure are small and statistically indistinguishable from zero for all pre-surgery characteristics. Moreover, when estimating a reverse regression relating the instrument to all pre-surgery characteristics simultaneously, we cannot reject these characteristics are jointly unrelated to the instrument, with a joint F-stat of 1.73. This suggests the identifying variation is unrelated to baseline characteristics, consistent with the exclusion restriction. Second, in contrast to the IV estimates, the coefficients from the OLS regressions are often large and nearly always statistically distinguishable from zero. This highlights the importance of using our research design to isolate plausibly exogenous variation in the use of minimally invasive surgical techniques.

We note that if treatment effects are not constant, a further assumption is needed to causally interpret the instrumental variables estimates: average monotonicity. In this setting, the average monotonicity condition means that having a surgeon with higher $z_{id(i)}$ weakly increases the likelihood that the patient receives minimally invasive surgery. Under this average monotonicity condition, the estimates described above represent a weighted average treatment effect with appropriate LATE weights. A common test for average monotonicity is to examine whether the key coefficient in the first stage regression is consistently positive across subgroups (Frandsen, Lefgren and Leslie, 2023). Appendix Table A2 presents first stage estimates relating $Minimally\_Invasive_i$ to $z_{id(i)}$ across several subgroups defined by pre-surgery patient characteristics: age, sex, and health

minimally invasive surgery on all pre-surgery characteristics used in Table 2 Panel B.

care use. Across all subgroups, the coefficient relating $Minimally\_Invasive_i$ to $z_{id(i)}$ is positive and statistically significant, providing support for the average monotonicity assumption.

Because our main analysis focuses on patients who received the target surgeries, a natural question to ask is whether patients select into receiving surgery based on doctor propensities to do minimally invasive versus open surgery. We note that selection of this type would only bias our estimates if this selection were related to patient level determinants of our outcomes of interest, and hence the evidence discussed above on balance in baseline observable characteristics among patients receiving surgery is reassuring that such selection (if present) may not interfere with identification. Nevertheless, we directly explore the possibility of selection into surgery through some supplemental analysis. Specifically, we consider a broader sample of individuals potentially eligible to have surgery—all patients in the data who ever had an office visit with an orthopedic surgeon. Typically, patients have an office visit with their surgeon prior to surgery, but not all office visits with surgeons result in later surgery (because, for example, surgery is not recommended as treatment or other factors lead patients to not follow through with surgery, etc.). Within this broader sample, we predict the likelihood a claimant will have any target surgery subsequent to an office visit with an orthopedic surgeon, by regressing an indicator of having any subsequent target surgery on patient demographic information (age, sex), medical market fixed effects (HRR), and diagnoses by year fixed effects based on diagnoses at the initial office visit with an orthopedic surgeon. We interpret fitted values from this regression as the ex ante predicted probability of surgery, and analyze whether this predicted probability varies with our instrument within the baseline sample by re-estimating the IV specification with predicted probability of surgery as the dependent variable. See Appendix Section C for further details on this analysis. Appendix Figure A1 reports these estimates along with an associated plot relating the residualized predicted probability of surgery to $z_{id(i)}$. This analysis suggests the predicted probability of surgery is not related to our instrument $z_{id(i)}$—and thus the ex ante likelihood of surgery is not related to our identifying variation in surgical method.

3 Impact of Minimally Invasive Surgery

This section presents estimates of the impacts of minimally invasive surgery. We begin by presenting the baseline estimates of the impacts of minimally invasive surgery—estimates of both the cumulative impacts on outcomes and the dynamics of these impacts. We then analyze heterogeneity in these impacts and the robustness of the findings.

3.1 Main Estimates

This section presents estimates of the impacts of minimally invasive surgery. Table 3 reports the key coefficient on $Minimally\_Invasive_i$ from the IV regression outlined in Equations (1) and (2). Each row represents results from a separate regression for the indicated dependent variable. Columns (1) and (2) report the mean and standard deviation of the dependent variable among those receiving open surgery, whereas the remaining columns report the coefficient estimate on $Minimally\_Invasive_i$, the associated standard error and p-value, and the implied impact as a percent to the mean among those with open surgery. Figures 4 through 6 and Appendix Figures A2 and A3 plot analogous estimates by quarter since surgery to illustrate the dynamics of the cumulative impacts on health care, disability, and social insurance outcomes reported in Table 3.

Surgery Outcomes Table 3 Panel A describes impacts on surgery outcomes—outcomes describing the surgery encounter itself. The first two rows report the impacts on total health care spending and target surgery procedure spending. The point estimates are statistically insignificant but suggestive that minimally invasive surgery is associated with lower health care spending on the surgery date. The point estimate of $-\$1,078$ for total health care spending on the surgery date reflects a 14.6% decrease in spending for minimally invasive surgery relative to open surgery.

Beyond spending, Panel A also describes impacts on other surgery outcomes such as length of stay and the location of the surgery. Minimally invasive surgeries are 2.7 p.p (or 2.9%) more likely to be a "day surgery"—a surgery where there is no overnight stay required. Relative to the analogous open surgeries, minimally invasive surgeries are 28.4 p.p. (39.9%) more likely to be performed in an outpatient surgery center and 9.6 p.p. (54.3%) less likely to be performed at an inpatient hospital. These estimates suggest that minimally invasive surgeries require less time and are more likely to be performed in settings that typically require fewer resources than analogous open surgeries.

Health Care Outcomes Table 3 Panel B describes cumulative impacts on health care outcomes in the two years following surgery (including the surgery encounter itself), while Figures 4 and 5 and Appendix Figure A2 explore the dynamics of these impacts by quarter since surgery. Compared to the analogous open surgeries, minimally invasive surgeries, on average, involve $\$5,274$ less total health care spending in the two years after the surgery; this impact is large and represents a 30.4% reduction relative to the mean among injured workers with open surgery. Decomposing this difference, minimally invasive surgeries are associated with $\$4,553$ less medical spending (p-value 0.033) and $720 less prescription drug spending (p-value 0.011). Figure 4 Panels (a) through (c) explore the dynamics of these impacts. While the reduction in health care spending—both aggregate and by category—is largest in the first few quarters following surgery, we see that the reductions in spending are persistent, reflect similar or larger percent changes as time passes after surgery, and remain statistically significant even toward the end of the two-year follow-up period we examine.

In addition to analyzing health care spending, we examine impacts on health care services particularly relevant for post-surgical recovery including office visits, physical therapy visits, and prescription pain medication—in particular, opioids. Based on the estimates, minimally invasive surgery, on average, involves 5.1 fewer office visits (63.6% of the mean) in the two years following surgery and is associated with $505 (54.8%) less spending on office visits. We find suggestive evidence of a reduction in physical therapy utilization for those with minimally invasive surgery, with point estimates suggesting a $1,353 (p-value 0.064) decline in physical therapy spending over the two years after surgery. Figure 5 and Appendix Figure A2 report impacts by quarter relative to surgery. These results indicate that the impact of minimally invasive surgery relative to open surgeries on office visits is largest in the quarter immediately after the surgery, though the impacts remain negative and statistically significantly distinguishable from zero for each quarter in the two years after surgeries. While minimally invasive surgery does not have a clear impact on physical therapy utilization immediately following surgery, the estimates suggest minimally invasive surgery reduces the duration patients receive physical therapy after surgery—as the estimates indicate minimally invasive surgery is associated with significant reductions in physical therapy utilization down the line months after the surgery.

Opioids are commonly prescribed to ease pain during recovery from surgery and to manage pain from musculoskeletal injuries more generally. Motivated by this, we examine impacts on opioid use. Although there is no strong evidence that minimally invasive surgery influences the likelihood of any opioid use after surgery, patients undergoing minimally invasive surgery experience large reductions in overall opioid use on the intensive margin. Relative to those with an analogous open surgery, those with minimally invasive surgery have 40.9 (or 85.3%) fewer days supplied of opioids (p-value 0.005) and 1.4 (or 38.9%) fewer distinct prescriptions for opioids (p-value 0.065) in the two years following surgery. Figure 5 Panels (c) and (d) and Appendix Figure A2 Panel (c) display the dynamics of these impacts. While lower opioid use is observed starting the quarter of the surgery, the reduction in opioid use associated with minimally invasive surgery increases—in both implied percent impacts and statistical significance—as time passes after surgery. For instance, in the eighth quarter after surgery, we see that minimally invasive surgery is associated with a 4.0 p.p. (84.5%) decline in the likelihood of any opioid prescription, 2.5 (or 83.3%) fewer days supplied, and 0.11 (or 76.6%) fewer prescriptions. This long-run reduction in opioid use is substantial and suggests minimally invasive surgery may meaningfully reduce long-term opioid dependence compared to open surgery.

In addition, we examine whether there are impacts on outcomes that may indicate surgical complications. Specifically, we investigate impacts on emergency department (ED) visits and subsequent musculoskeletal surgeries on the same body part to address the worker's injury. We do not find that minimally invasive surgery impacts subsequent ED visits or ED spending, either for the full two-year post-surgery window in Table 3 or when considering the dynamics of the impacts in Appendix Figure A2.

Treating musculoskeletal injuries is complex. If an initial surgery is not fully successful in addressing the injury, subsequent surgery may be needed and subsequent surgery is fairly common, with 17.0% of injured workers in our sample receiving a subsequent surgery on the same body part to treat their injury after an initial open surgery. We turn to investigating whether minimally invasive surgery impacts the likelihood of subsequent surgeries to address the injury. Based on the estimates, minimally invasive surgery is associated with fewer subsequent surgeries to address the injury. Relative to those with open surgery, workers receiving minimally invasive surgery, on average, have a 7.5 p.p. (43.9%) lower likelihood of any subsequent surgery to address the injury and receive 0.2 (49.5%) fewer subsequent surgeries addressing their injury in the two years following the initial surgery. Fewer subsequent surgeries contributes to lower subsequent overall health care spending among those with minimally invasive surgery, with the estimates indicating minimally invasive surgery is associated with $405—or 62.8%—less health care spending on subsequent surgeries. Appendix Figure A2 considers dynamics of the impacts on subsequent surgeries. The estimates indicate that, relative to open surgeries, minimally invasive surgeries reduce rates of subsequent surgeries on the same body part immediately after initial surgeries, with effects that become smaller in magnitude over time.

Disability and Social Insurance Outcomes Table 3 Panel C reports impacts on outcomes related to disability and workers' compensation benefit receipt in the two years following surgery. Figure 6 and Appendix Figure A3 display analogous estimates of the impacts by quarter since surgery. We begin by examining impacts on total cash disability benefits received through workers' compensation insurance. Compared to open surgery, minimally invasive surgery is associated with $3,981 less in cash disability benefits over the subsequent two years, which is a 25.0% reduction relative to the mean subsequent cash disability benefits received by those with analogous open surgeries. The estimated reduction in cash disability benefits for those with minimally invasive surgery is driven by differences in both temporary income benefits and permanent impairment benefits. Overall, roughly 65.6% of the total reduction in cash disability benefits associated with minimally invasive surgery is accounted for by temporary income benefits, while the remaining 34.4% is due to permanent impairment benefits. Figure 6 Panel (a) displays the dynamics of the impact on total cash disability benefits. These estimates indicate minimally invasive surgery reduces cash disability benefits in the quarter following surgery and this reduction increases over time since surgery—in terms of implied percent impacts and statistical precision.

We turn to investigating impacts on workers' compensation benefits in greater detail to understand how minimally invasive surgery impacts injury recovery, return to work, and permanent disability. Relative to open surgery, minimally invasive surgery is associated with 37.1 fewer missed days of work while receiving temporary income benefits—a 29.1% reduction relative to those with open surgery. This is driven by changes on the intensive margin rather than the extensive margin, as the vast majority of injured workers (roughly 88.3%) have some compensated time off work in the two years after surgery and the estimates suggest there is no statistically significant (or economically meaningful) change in the likelihood of having any compensated time off work after the surgery. Figure 6 Panel (b) displays the impact on weeks out of work receiving temporary income benefits by quarter, and the results indicate the impact is largest in the first two quarters after surgery, with effects halving by one year after surgery and slowly converging to zero by two years after surgery.

Additionally, we examine whether minimally invasive surgery improves recovery from the injury in the long term—and hence ongoing permanent impairments among workers. Minimally invasive surgery is, on average, associated with a 1.06 p.p. reduction in the severity of permanent impairments among injured workers—or a 30.4% reduction relative to the mean severity of permanent impairments among workers receiving an analogous open surgery. We note that this aggregate change in permanent impairment appears to be driven by changes in the severity of permanent impairments among those with some permanent impairment rather than changes in the likelihood of having any permanent impairment. Note permanent impairments are only rated and compensated after the worker has completed temporary income benefits, and most workers are out of work receiving temporary income benefits directly after the surgery. Thus, impacts on permanent impairment benefits may only appear months after the surgery. Consistent with this expected pattern, Figure 6 Panel (c) illustrates that impacts on permanent impairment benefits appear in the third quarter after surgery and persist until two years after surgery.

Lastly, we examine impacts of minimally invasive surgery on total subsequent workers' compensation insurance costs—aggregating subsequent cash disability benefits and health spending. Our estimates indicate that those with minimally invasive surgery have $9,255 lower total subsequent workers' compensation insurance costs—27.8% less than the mean among those with open surgery. Figure 6 Panel (d) displays the dynamic impacts on total subsequent workers' compensation insurance costs. The reduction on total workers' compensation costs begins in the first quarter after surgery and grows in percent terms and statistical significance as time increases since surgery. In the eighth quarter after surgery, total workers' compensation costs are $482 lower (p-value 0.005)—66.9% of the mean—among patients undergoing minimally invasive surgery.

3.2 Heterogeneity

We explore heterogeneity in the impact of minimally invasive surgery by pre-surgery patient characteristics, including demographics (sex and age) and characteristics of the injury (e.g., severity proxies). Figure 7 plots the key coefficient estimates on $Minimally\_Invasive_i$—along with implied 95% confidence intervals—obtained when re-estimating the baseline IV specification for the indicated subgroups. Each panel reports estimated impacts for the indicated dependent variable: total health spending (Panel (a)), total medical spending (Panel (b)), total prescription drug spending (Panel (c)), total cash benefits (panel d), days of temporary income benefits (Panel (e)), permanent impairment benefits (Panel (f)), and total workers' compensation costs (Panel (g)). Appendix Tables A3 and A4 report the underlying estimates, standard errors, and percent impacts relative to the subgroup mean.

There are several patterns worth noting. First, the impacts appear universal—across all subgroups and outcomes. For all groups, minimally invasive surgery leads to decreases in subsequent health care spending—both medical and prescription drug spending—and minimally invasive surgery leads individuals to return to work faster, reduces the severity of partial permanent disabilities, and reduces overall workers' compensation insurance costs. In other words, the evidence suggests minimally invasive surgery (relative to open surgery) improves health and reduces disability severity across the board. Second, patterns in the point estimates suggest that some subgroups may be more affected than others, though the estimated impacts are not always statistically distinguishable across subgroups. For instance, the estimates suggest that minimally invasive surgery has heterogeneous effects by claimant age, with larger impacts for claimants below the median age, especially for health care spending and for total workers' compensation costs. The point estimates of the impact of minimally invasive surgery on health care spending are larger for women than for men. Moreover, the pattern in the point estimates suggests impacts on health care spending may be larger for claimants with more severe injuries— those with higher first day health care spending and those with first treatment for their injury in an ED—though these differences in impacts are not statistically distinguishable at conventional levels.

3.3 Robustness

Next, we investigate the robustness of our findings. Specifically, we consider alternative specifications varying the sample definition or including further controls. This analysis focuses on three primary dependent variables: total health spending, total disability benefits, and total workers' compensation insurance costs.

Sample Definition We investigate the robustness of our results when varying the sample definition. First, we consider robustness when excluding emergency surgeries. Few surgeries in our sample are done on an emergency basis—with only 2.5% of surgeries performed on the same day as an ED visit or on the first day an injury was treated. Because patients with these surgeries may be fundamentally different, we investigate the robustness of the results to excluding them. Figure 8 plots the key coefficient estimates and confidence intervals for $Minimally\_Invasive_i$, comparing estimates from the baseline sample to those in the restricted sample excluding emergency surgeries. Across the outcomes analyzed, the estimates are nearly identical when excluding patient with emergency surgeries.

Second, we investigate whether our results are driven by any one type of surgery. To consider this, we re-estimate our main specification excluding each surgery type one at a time. Appendix Figure A4 plots the estimates of this exercise, where the baseline estimates are included in the top row for reference. Across these regressions, the estimates are statistically distinguishable from zero and in the same range. The similarity of the estimates across these regressions indicates that our findings are not driven by one particular surgery type.

Other Doctor Characteristics Given our research design, one concern is that other doctor characteristics could be correlated with the instrument and could contribute to our findings. We conduct two complementary related analyses to assess this concern. First, we document the association between our instrument and observable doctor characteristics—such as sex, education, and experience. Second, we investigate the robustness of our findings when controlling for observed doctor characteristics.

Appendix Figure A5 displays binned mean residual plots relating residualized doctor characteristics to our instrument. We consider several characteristics including sex and education (an indicator for having graduated from a top 25 medical school, credential). In addition, we examine doctor experience—years since medical school graduation and volume of target surgeries performed (in our data)—where these measures are specific to the surgery and capture experience accrued before the surgery date. Appendix Figure A5 suggests no relationship between the likelihood that doctors perform minimally invasive surgeries and doctor education or volume. Doctor sex and doctor experience are associated with the propensity to use minimally invasive surgery techniques, though the magnitude of this association is modest—with a one standard deviation increase in the instrument ($z_{id(i)}$) being associated with a 0.88 p.p. decrease in the likelihood the surgeon is female and 1.9 fewer years of experience.

Because some doctor characteristics are correlated with our instrument, we investigate the robustness of our findings when controlling for observed doctor characteristics. Specifically, we re-estimate the main IV specification including observable doctor characteristics as additional controls—both individually and simultaneously. Figure 9 displays the coefficient estimates and confidence intervals for $Minimally\_Invasive_i$, comparing estimates from the baseline specification to those from specifications with additional controls for the indicated doctor characteristics. The estimated impacts of minimally invasive surgery are nearly identical when including these additional controls. Overall, this evidence suggests that our findings are not driven by correlated doctor characteristics.

4 Diffusion of Innovation

This section presents descriptive evidence on the diffusion of minimally invasive surgery over time. We then combine this descriptive evidence with our estimates of the causal impact of minimally invasive surgery to assess the role of this surgical innovation in contributing to trends in outcomes over time and the potential impacts of policies aimed at accelerating the adoption of surgical innovation.

4.1 Descriptive Evidence

We begin by providing descriptive evidence of trends in minimally invasive surgery over time based on our data. This analysis focuses a period spanning 13 years from 2008 to 2020, the years of coverage for the data on the key measures we analyze. Figure 10 reports trends in the use of minimally invasive techniques among target surgeries accounting for the composition of surgeries (i.e., the trend net of surgery type fixed effects). This figure illustrates there is substantial growth in the use of minimally invasive techniques for these surgeries over this period—from 67.1% to 73.2%.

Appendix Figure A6 plots the share of target surgeries that are minimally invasive by surgery type over time. Appendix Table A5 summarizes these trends along with information on surgery prevalence. There are a few patterns worth noting. First, minimally invasive techniques have diffused more rapidly over this period for some surgeries than others. Surgeries with the largest increases in share minimally invasive over this period include: shoulder distal clavicle resection (32.5 p.p.), shoulder rotator cuff repair (31.4 p.p.), elbow loose/foreign body removal (28.0 p.p.), and wrist/forearm carpal tunnel release (22.2 p.p.). Second, there has been staggered development of minimally invasive surgical techniques for different surgery types over time, leading to large cross-sectional variation across surgery types in the share minimally invasive in any given year. For instance, some surgeries were among the earliest to develop minimally invasive versions of the surgery, and for these surgeries, minimally invasive techniques had reached near universal adoption by the beginning of our analysis period; these surgeries include knee meniscectomy, shoulder loose/foreign body removal, knee synovectomy, and shoulder SLAP lesion repair.

Figure 11 also displays the share of target surgeries that are minimally invasive by Hospital Referral Region (HRR), shading the quintiles of this distribution. This figure illustrates there is wide variation across regions in the diffusion of minimally invasive surgery—with the slowest adopting 20% of regions having mean share minimally invasive roughly 10 p.p. less than the fastest adopting 20% of regions. Contextualizing this relative to aggregate growth rates, this difference suggests the slowest adopting one-fifth of regions are more than a decade behind the fastest adopting one-fifth of regions.

4.2 Interpretation of Estimates and Discussion

We explore the consequences of the documented diffusion patterns for minimally invasive techniques, combining this descriptive evidence with our main estimates of the causal effect of minimally invasive surgery relative to open surgery. We explore how diffusion trends have impacted overall outcomes and contribute to trends in outcomes. Moreover, we analyze how altering the pace of diffusion could impact outcomes through some back-of-the-envelope calculations.

Impact of Diffusion on Outcomes. We begin by exploring how diffusion of minimally invasive surgery over time has impacted outcomes. Specifically, we assess the aggregate implications of diffusion over time for outcomes through combining our descriptive evidence on the diffusion of minimally invasive surgery over time with the estimates of the causal effect of minimally invasive surgery relative to open surgery. Appendix Table A6 summarizes this analysis. Columns (1) and (2) report the estimated impact of the aggregate diffusion over time on the indicated outcome, in levels and as a percent of the baseline mean. To further interpret the estimates, we compare these to the overall change in outcomes over this period (reported in column (3)) and calculate share of the observed change in outcomes due to diffusion (reported in column (4)).

Among injured workers, the observed diffusion of minimally invasive surgery from 2008 to 2020 is responsible for meaningful improvements in outcomes over this period: a 1.9% decline in health care spending, 5.3% decline in opioid days supplied, 3.1% decline in subsequent surgeries, 1.8% decline in days out of work collecting temporary disability benefits, a 1.9% decline in the severity of permanent disability, and 1.7% in total workers' compensation insurance costs. We note that these patterns represent substantial declines in the overall expenses associated with treatment and recovery of these injured workers, with diffusion over this period leading to an average decline of $324 in post-surgical health spending, $245 in post-surgical cash disability benefits, and $569 in total post-surgical workers' compensation costs. Further, the improvement in outcomes due to the diffusion of minimally invasive surgery substantially influences overall trends in these outcomes among these injured workers. For instance, based on our estimates, the diffusion of minimally invasive surgery can explain 15.0% of the reduction in health spending over this period. Moreover, the growth in cash disability benefits would have been 11.6% larger in the absence of the diffusion of minimally invasive surgeries seen over this period.

Potential Impact of Changing Diffusion Rate Next, we conduct some back-of-the-envelope calculations exploring the potential impact of policies aimed at speeding the diffusion of minimally invasive surgery. For these calculations, we extrapolate from the estimates of the causal impact of minimally invasive surgery assuming constant treatment effects, and we consider impacts on outcomes over the 13 year period from 2008 to 2020 under the indicated scenario. We note that these calculations focus on characterizing how increased diffusion impacts the outcomes we analyze. Given the positive impacts of minimally invasive surgery we document, this analysis informs us about the potential gains from speeding diffusion, without considering the feasibility of specific policies that may achieve faster diffusion (e.g., subsidies, payment policy, educational outreach) or the cost of implementing such policies. Through characterizing the potential benefits of promoting faster diffusion, this analysis informs policy discussions on whether efforts to promote faster diffusion may be worthwhile and suggests further research is needed to estimate the costs and feasibility of specific policies.

First, we consider the impact of the overall diffusion rate. Evidence in Appendix Figure A6 suggests the share minimally invasive increases roughly linearly for surgery types with non-trivial growth over the analysis period. Motivated by this evidence, we approximate the impact of small changes in the diffusion rate by linearly scaling our estimates, and Appendix Table A6 column (5) displays these results. By the end of the analysis period, 20% faster diffusion of minimally invasive techniques among surgeries performed on injured workers would have decreased mean subsequent injury-related health care spending by $386, mean days off work due to disability by 2.7, mean severity of permanent disability by 7.8 p.p., and mean total subsequent workers' compensation costs by $677.

Second, we explore the impact of reducing regional variation in diffusion patterns. Specifically, we consider the impact accelerating diffusion in slower-adopting regions to resemble diffusion in faster-adopting regions such that the share minimally invasive is equalized across regions at the maximum observed level across regions over this period. Appendix Figure A7 presents this analysis, where regions are colored according to the associated quintile of improvement in outcomes relative to the baseline observed diffusion patterns. Among injured workers, this acceleration in the rate of diffusion improves average outcomes by 6.2%; this improvement in outcomes varies widely by region, where the most affected one fifth of regions experience gains between 9.2% and 15.5% in mean outcomes, while the least affected one fifth of regions experience gains of at most 3.1% in mean outcomes.

5 Conclusion

This paper provides novel evidence on the impact of a major medical innovation—the move from traditional open surgery to minimally invasive surgery. Leveraging administrative data on injured workers in Texas and plausibly exogenous variation in surgical technique for orthopedic surgery, we estimate the causal impact of minimally invasive surgery relative to open surgery on subsequent health and disability outcomes. Our findings suggest that receiving minimally invasive surgery rather than open surgery substantially improves health, reduces subsequent health care spending, speeds return to work, reduces disability severity, and lowers associated social insurance costs. For example, our estimates suggest minimally invasive surgery (relative to open surgery) reduces subsequent injury-related health care spending by roughly a third—both because of a reduction in the complexity of the surgery and a large reduction in health care use over the two years following surgery. Estimates by service type indicate that minimally invasive surgery leads to a reduction in subsequent office visits, opioid use, and the likelihood of revision surgery. Leveraging detailed data on disability, our analysis illustrates minimally invasive surgery hastens return to work (by 37 days), reduces permanent disability severity (by 30%), and lowers associated social insurance costs (by 28%). These effects are large and suggest that the diffusion of these techniques in recent years is responsible for notable improvements in overall outcomes among injured workers.

Over the past few decades, the practice of medicine has evolved substantially, yet we still know very little about the impact of medical innovations beyond pharmaceuticals. This represents a critical gap in the existing research. Unlike new pharmaceuticals, medical innovations typically don't have to undergo clinical trials or prove their effectiveness. This lack of a formal review process—along with challenges isolating appropriate data and plausibly exogenous variation—means there is very little evidence on the causal impacts of these innovations. Understanding the effects of medical innovations is crucial because policy decisions can influence how they spread. The adoption of these innovations is often much slower than the adoption of new pharmaceuticals, given the spread of these innovations often involves providers acquiring new skills or investing in complementary technologies. And public policy has the potential to play a central role in influencing the diffusion of these innovations, as policymakers can create incentives to encourage faster adoption of new methods across regions and healthcare providers—for example, through the design of targeted subsidies, payment policy, and continuing education for providers. Our results speak directly to the impacts of minimally invasive surgeries for musculoskeletal injuries, which are among the most common surgeries performed on prime-age adults. The large estimated impacts on health, health care use, and disability this context highlight the need for further research on the impacts of other types of minimally invasive surgeries and other medical innovations more broadly.

Our findings move forward the literature on medical innovation in several ways. First, we provide novel evidence on the impacts of a major medical innovation—the shift from open surgery to minimally invasive surgery—which is arguably one of the most significant surgical advances in recent decades. Unlike prior work that has typically focused on pharmaceutical innovations, we analyze how a major medical innovation affects a wide range of outcomes. Second, we use unique linked administrative data to examine the effects of this innovation on health care utilization, health, work limitations, labor supply, and disability benefit receipt. Our findings illustrate how medical innovation impacts a broad range of health outcomes—and highlights how these impacts are complex and affect many aspects of well-being beyond mortality. Moreover, our findings illustrate how innovation—through improving health—can reduce downstream health care spending and broader social insurance costs. Third, we document new evidence on the diffusion patterns of this innovation, illustrating how minimally invasive surgery techniques spread across different areas and types of surgeries. By combining this descriptive evidence with our causal estimates, we quantify the role of this diffusion in explaining broader trends in outcomes and how policies targeting these patterns could affect outcomes.

Through quantifying the impacts of minimally invasive surgery, our study sheds light on the potential benefits of policies that accelerate the adoption of medical innovation. Our study also highlights the need for further work analyzing how medical innovations spread—particularly innovation in medical care similar to surgical techniques that may require providers to acquire new skills or invest in complementary technologies. Moreover, our study highlights the need for more research quantifying the efficacy of specific policy proposals aimed at encouraging the diffusion of medical innovations (e.g., subsidies, payment policy, educational outreach) and points to the potential benefits of such policies.

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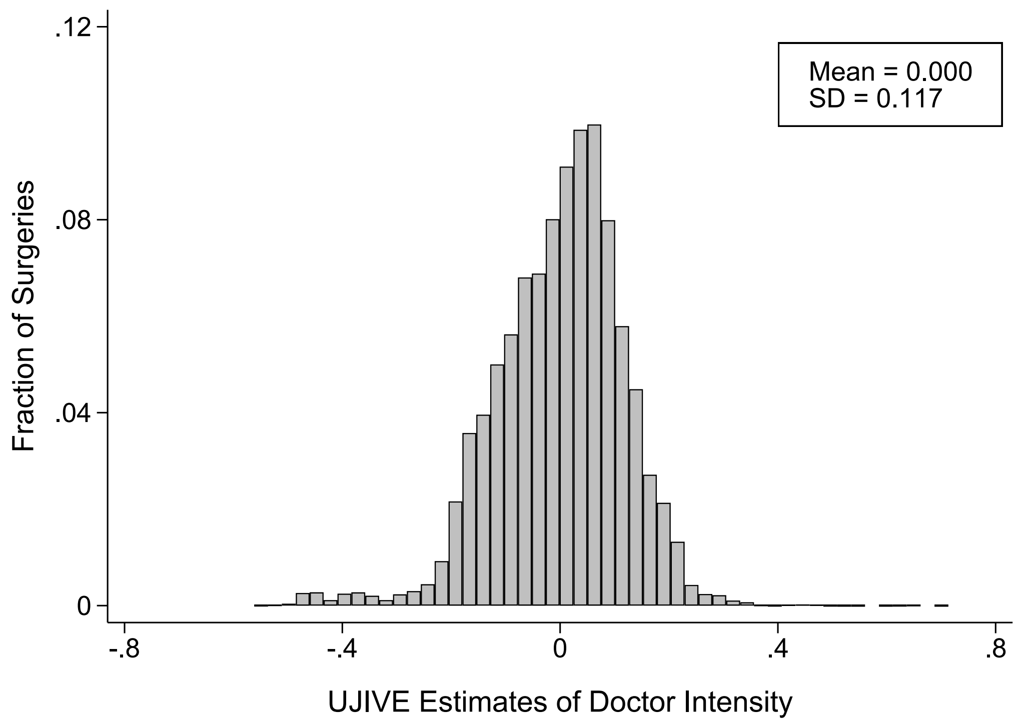
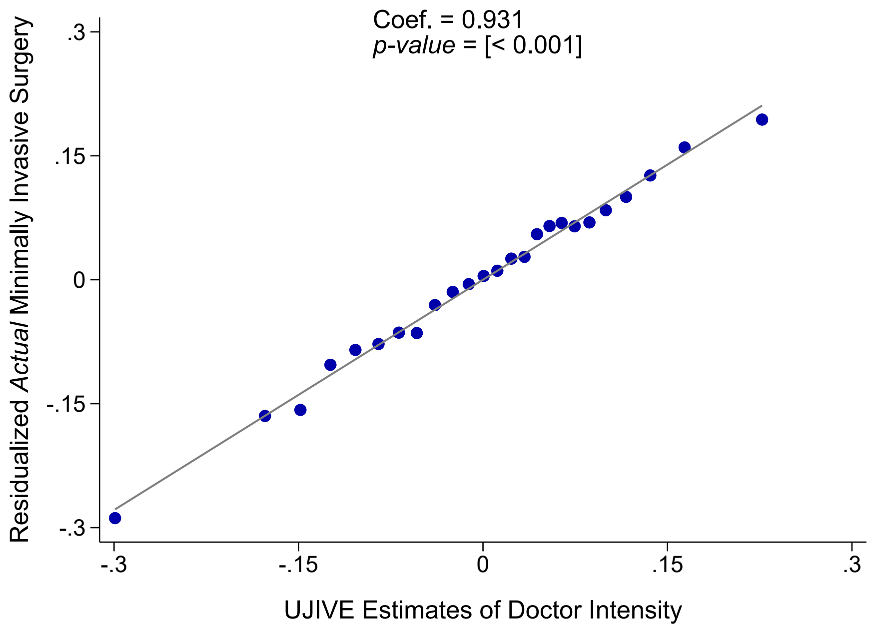
Figure 1: Distribution of Doctor Intensity Instrument



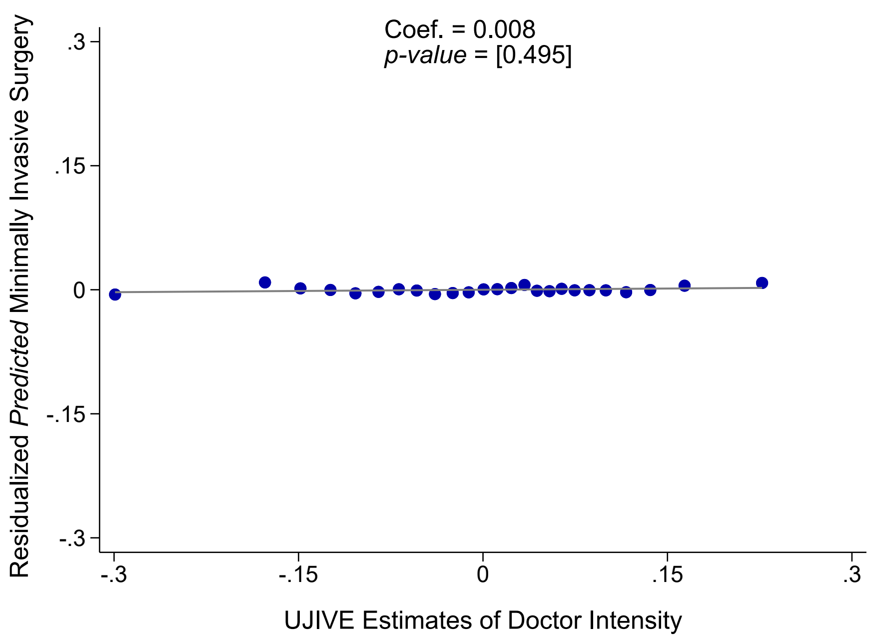
NOTES: This histogram displays the distribution of the UJIVE measure of doctor intensity for minimally invasive surgery, $z_{id(i)}$, estimated from Equations (3) and (4) ($N = 93,350$ surgeries). See Section 2 for details on the estimation procedure.

Figure 2: Graphical Evidence on Validity of Doctor Intensity Instrument

(a) Relevance

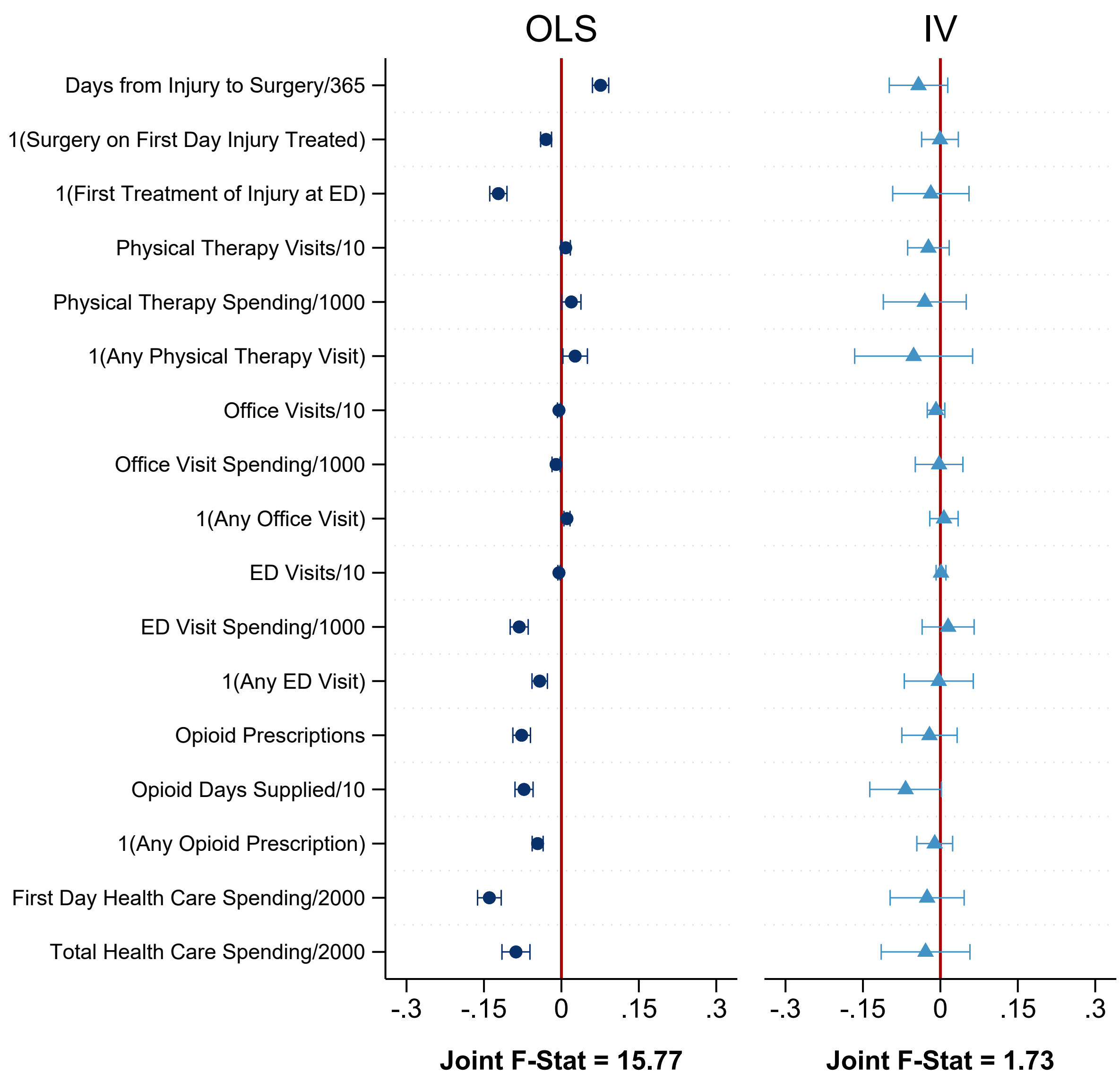


(b) Exclusion



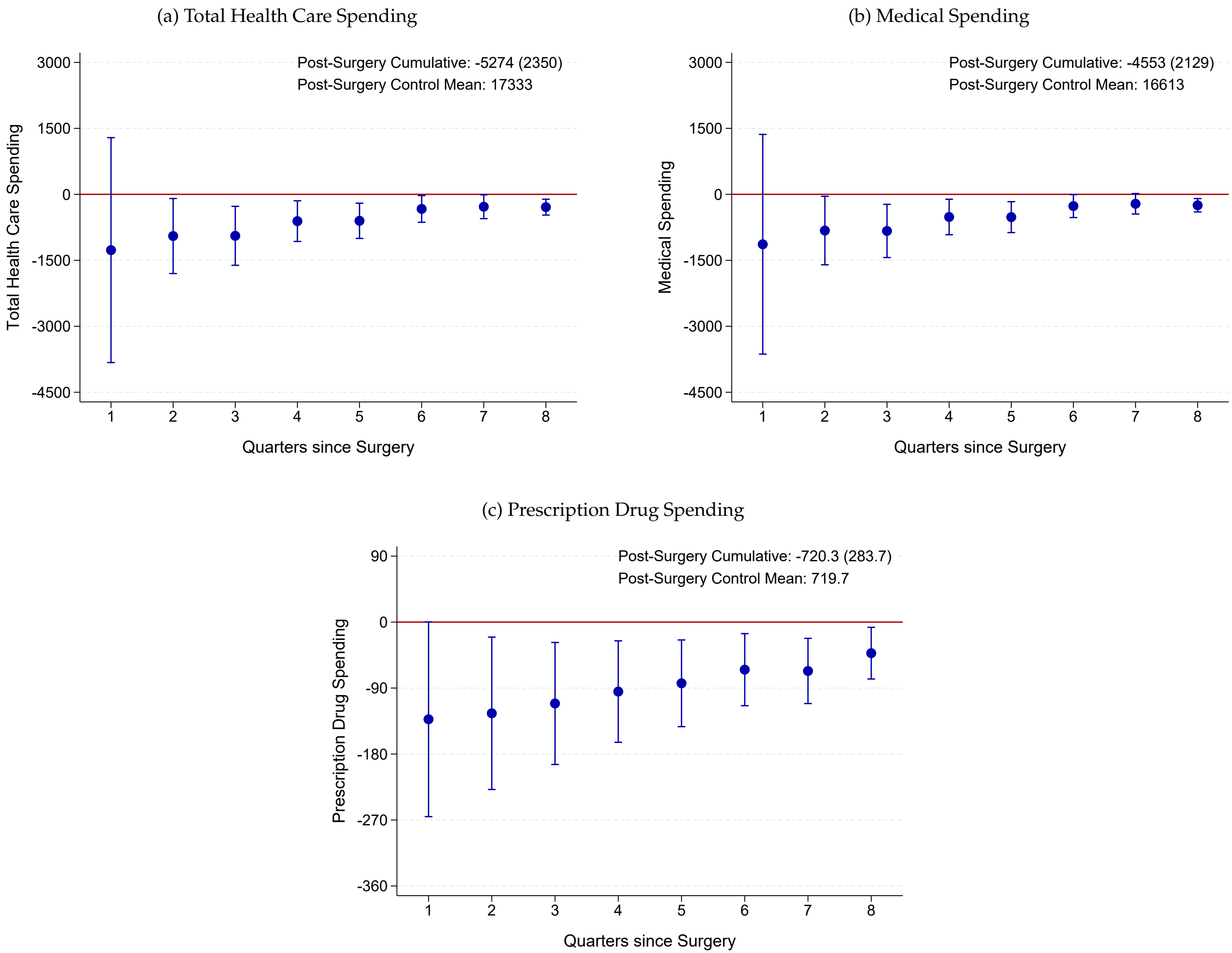
Notes: This figure provides a graphical illustration of the validity of our instrument—relevance in panel (a) and exclusion in panel (b). Panel (a) plots the *actual* share of minimally invasive surgeries, residualized with respect to the baseline controls (i.e., age, gender, Hospital Referral Region, and surgery type by year), against 25 equal-sized bins of the doctor intensity instrument. Panel (b) plots the *predicted* share of minimally invasive surgeries, residualized with respect to the baseline controls, against the same bins. We construct each patient's predicted probability of minimally invasive surgery by regressing an indicator for minimally invasive surgery on all pre-surgery characteristics used in the balance test (shown in Figure 3). The coefficients reported at the top of each panel are estimated from Equation (2) using the underlying patient-level data, whereas the line of best fit is obtained using the 25 plotted points.

Figure 3: Balance



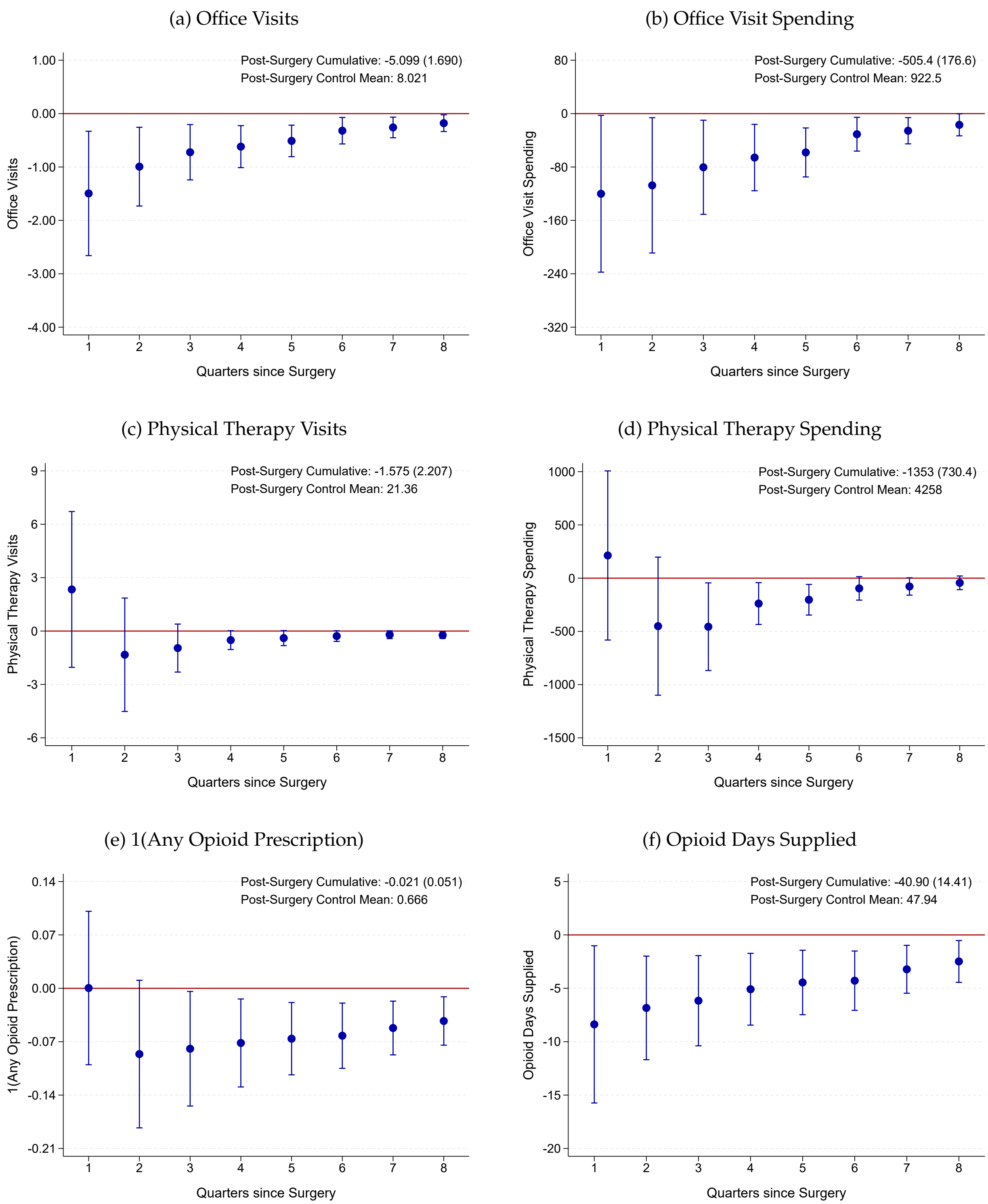
NOTES: This figure displays coefficients and 95% confidence intervals from regressions of patient pre-surgery characteristics on either the endogenous variable ($Minimally\_Invasive_i$) or the doctor intensity instrument ($z_{id(i)}$). The left panel—labeled OLS—shows estimated coefficients from separate bivariate regressions of each characteristic on the indicator for minimally invasive surgery. The right panel—labeled IV—shows estimated coefficients from separate regressions of each characteristic on the instrument, additionally controlling for the baseline controls (i.e., age, gender, Hospital Referral Region, and surgery type by year). The bottom of the figure reports the F-statistic from an F-test of joint significance in reverse multivariate regressions of the minimally invasive indicator on all pre-surgery characteristics (OLS panel) and of the instrument on all pre-surgery characteristics and the baseline controls (IV panel). Standard errors are clustered at the doctor level. The estimated coefficients, standard errors, and p-values are reported in Appendix Table A1. See Appendix Section B.3 for more detail on the measures used for this analysis.

Figure 4: Dynamic Effects of Minimally Invasive Surgery on Health Care Spending



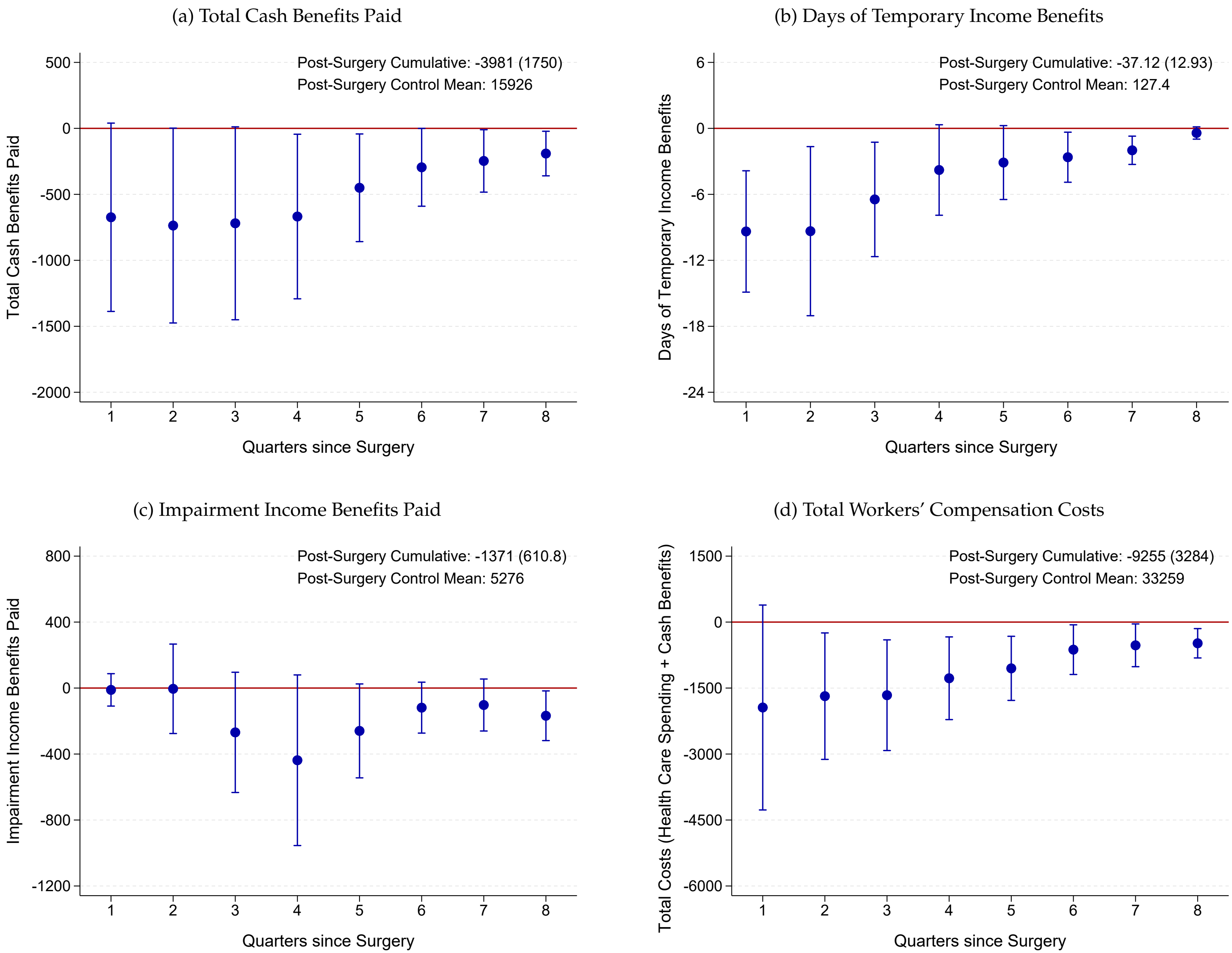
Notes: This figure plots the estimated coefficients on the indicator for minimally invasive surgery from the IV specification outlined in Equations (1) and (2), along with 95% confidence intervals based on standard errors clustered at the doctor level. Each quarter represents a separate regression, with the dependent variable measured over that quarter; for example, the first quarter spans the surgery date through surgery date + 90 days, and the second quarter covers the next 90-day period. The reported post-surgery cumulative effects are estimated using the dependent variables measured over all eight quarters. Post-surgery control means are calculated among patients who received open surgery.

Figure 5: Dynamic Effects of Minimally Invasive Surgery on Health Care Utilization



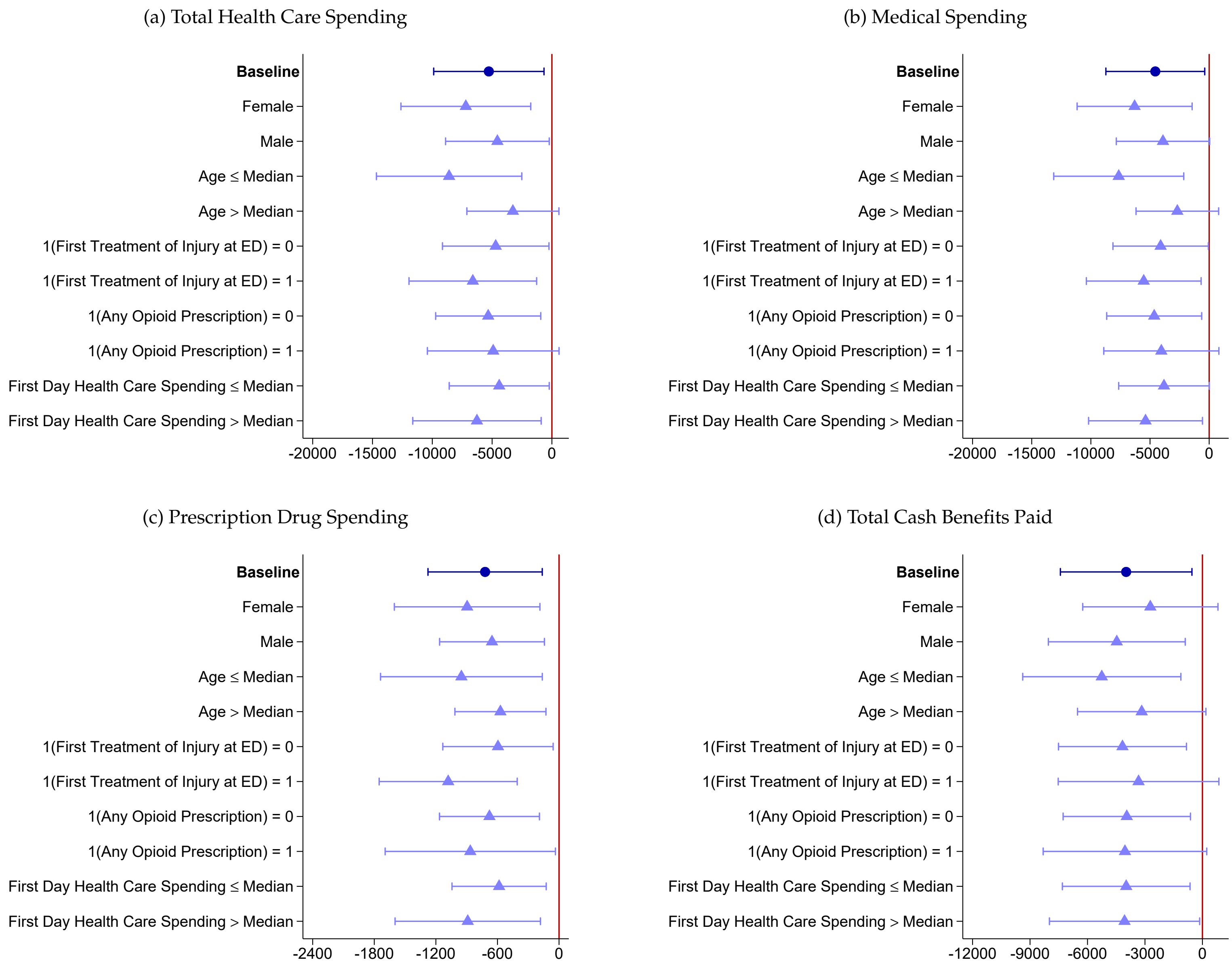
NOTES: This figure plots the estimated coefficients on the indicator for minimally invasive surgery from the IV specification outlined in Equations (1) and (2), along with 95% confidence intervals based on standard errors clustered at the doctor level. Each quarter represents a separate regression, with the dependent variable measured over that quarter; for example, the first quarter spans the surgery date through surgery date + 90 days, and the second quarter covers the next 90-day period. The reported post-surgery cumulative effects are estimated using the dependent variable measured over all eight quarters. Post-surgery control means are calculated among patients who received open surgery.

Figure 6: Dynamic Effects of Minimally Invasive Surgery on Disability and Benefit Outcomes



Notes: This figure plots the estimated coefficients on the indicator for minimally invasive surgery from the IV specification outlined in Equations (1) and (2), along with 95% confidence intervals based on standard errors clustered at the doctor level. Each quarter represents a separate regression, with the dependent variable measured over that quarter; for example, the first quarter spans the surgery date through surgery date + 90 days, and the second quarter covers the next 90-day period. The reported post-surgery cumulative effects are estimated using the dependent variable measured over all eight quarters. Post-surgery control means are calculated among patients who received open surgery.

Figure 7: Effects of Minimally Invasive Surgery on Health and Disability Outcomes: Heterogeneity by Patient Characteristics



(a) Total Health Care Spending

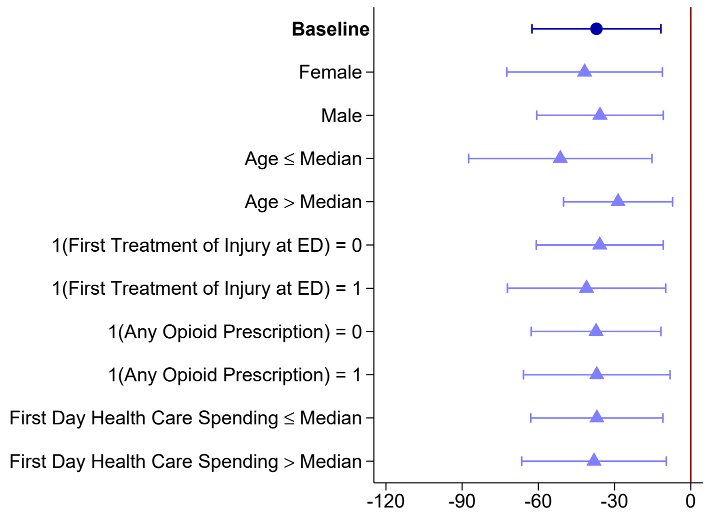
(b) Medical Spending

(c) Prescription Drug Spending

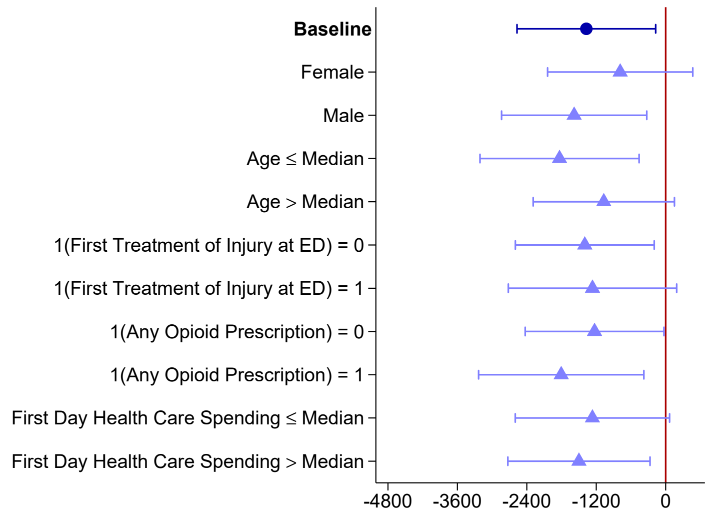
(d) Total Cash Benefits Paid

Figure 7 (Continued)

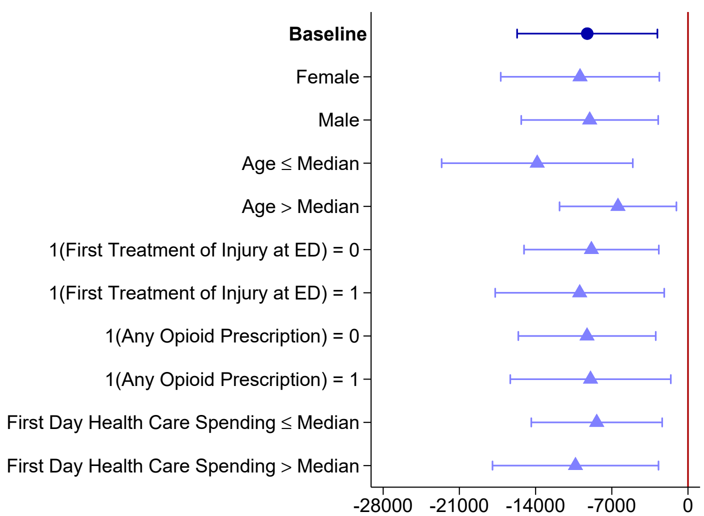
(e) Days of Temporary Income Benefits



(f) Impairment Income Benefits Paid

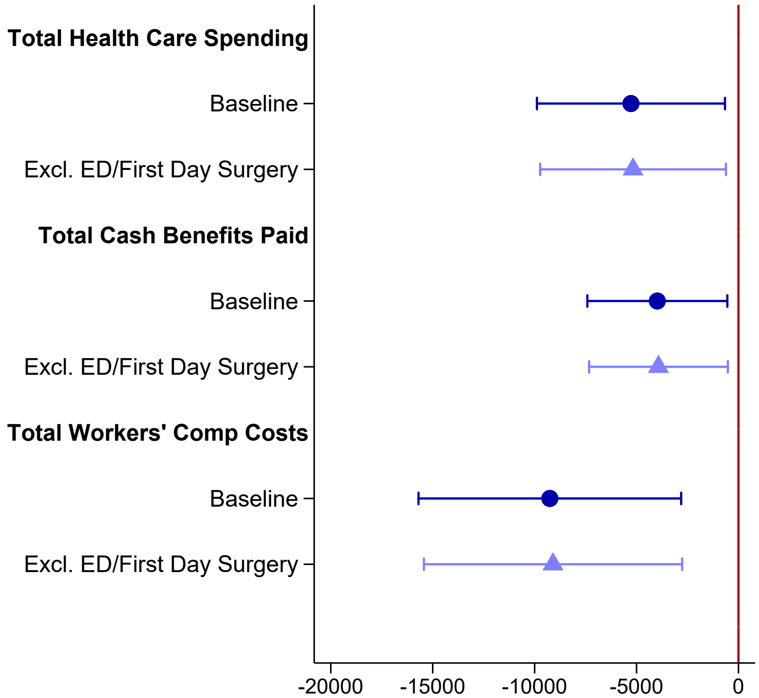


(g) Total Workers' Compensation Costs



Notes: This figure plots the estimated coefficients on the indicator for minimally invasive surgery from the IV specification outlined in Equations (1) and (2), estimated separately for each subsample denoted on the vertical axis, along with 95% confidence intervals based on standard errors clustered at the doctor level. The dependent variables are measured over the two years following surgery. Our baseline estimates are reproduced at the top of each panel. The estimated coefficients, standard errors, and p-values for each subsample, as well as for the differences between subsamples within each category (e.g., female vs. male patients), are reported in Appendix Tables A3 and A4, respectively.

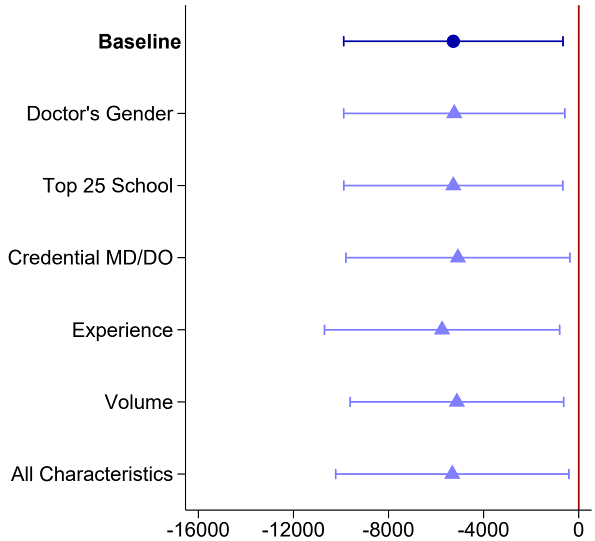
Figure 8: Robustness: Excluding Emergency Surgeries



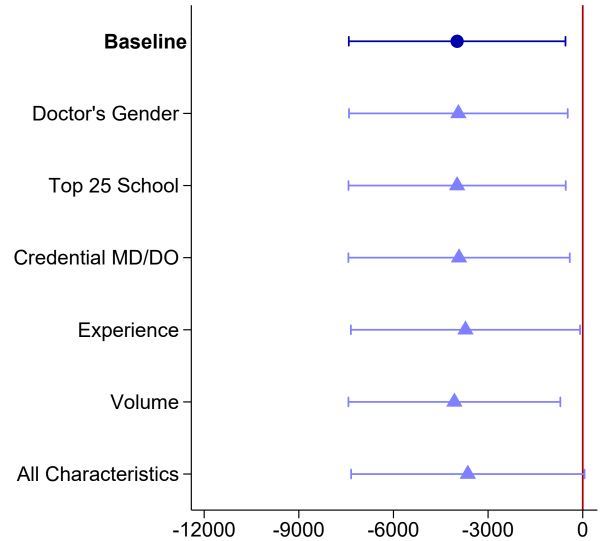
NOTES: This figure plots the estimated coefficients on the indicator for minimally invasive surgery from the IV specification outlined in Equations (1) and (2), along with 95% confidence intervals based on standard errors clustered at the doctor level. The dependent variables are measured over the two years following surgery. For each of the three dependent variables highlighted in bold on the vertical axis, we first reproduce the baseline estimates and then re-estimate the IV specification, excluding approximately 2.5% of patients (2,346 out of 93,350) who could have had surgery on an emergency basis—specifically, those who had surgery (i) on the same date as an ED visit or (ii) on the first day their injury was treated.

Figure 9: Robustness: Inclusion of Doctor's Characteristics

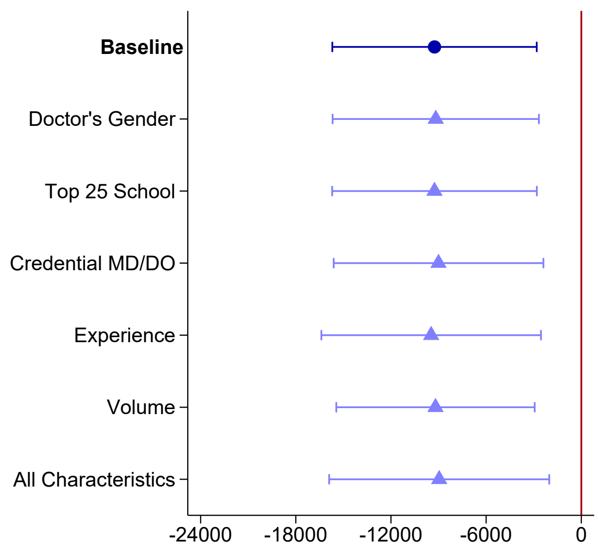
(a) Total Health Care Spending



(b) Total Cash Benefits Paid

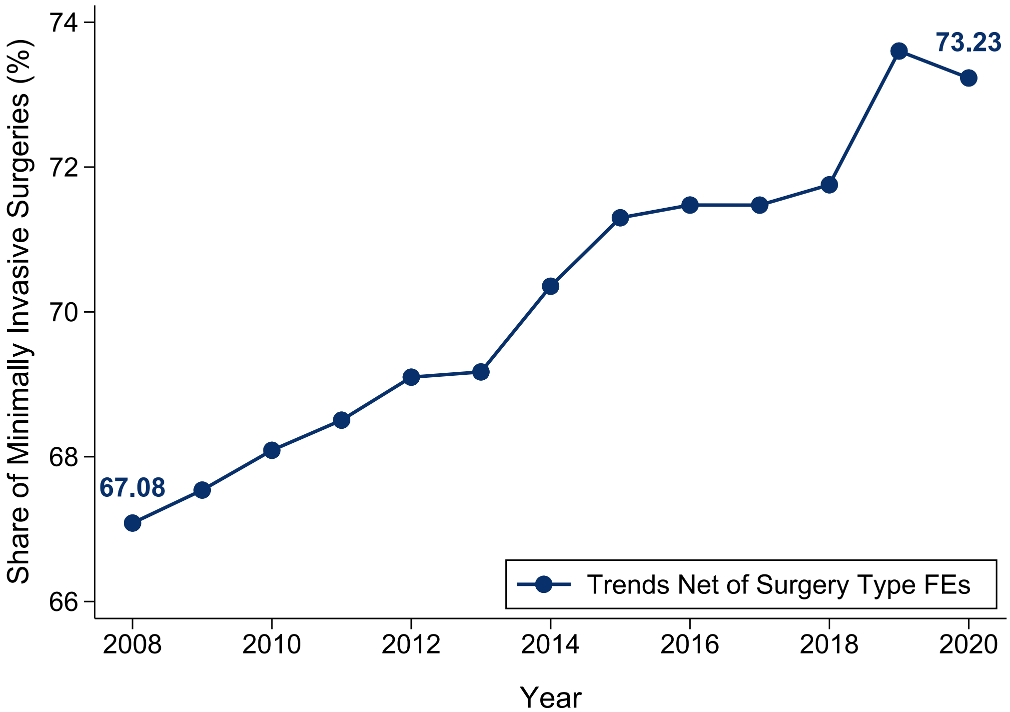


(c) Total Workers' Compensation Costs



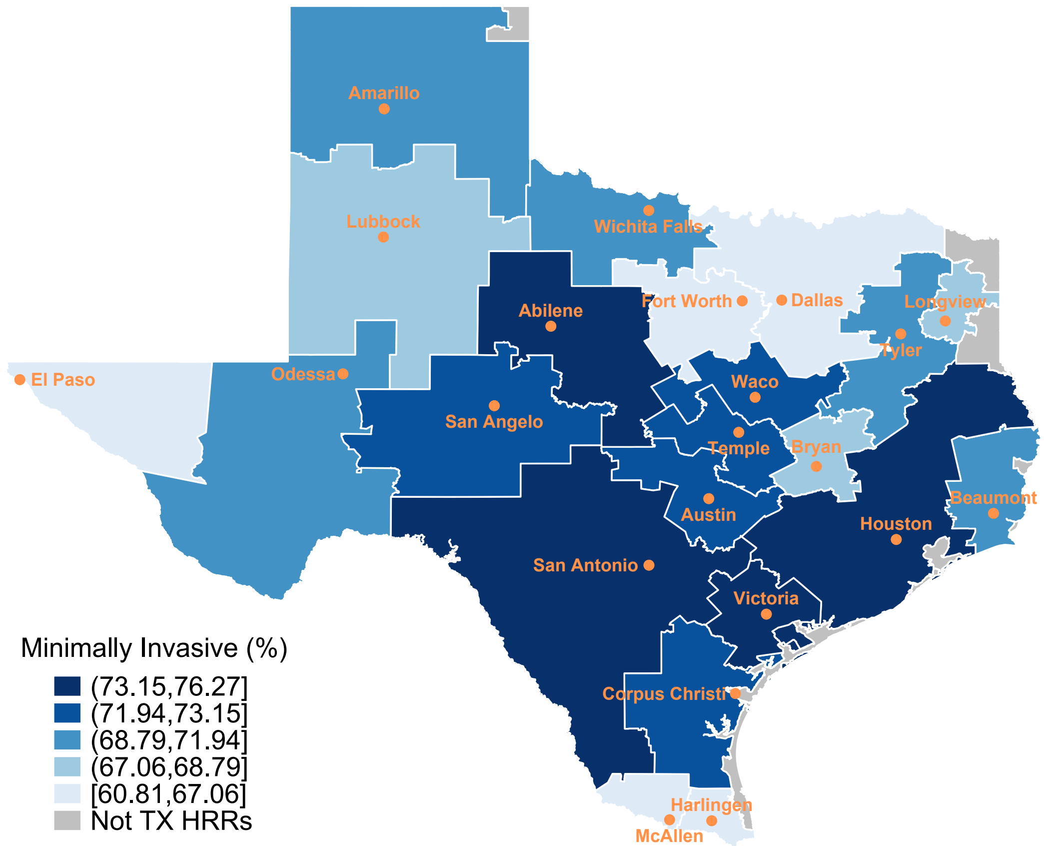
NOTES: This figure plots the estimated coefficients on the indicator for minimally invasive surgery from an alternative specification that adds controls for doctor characteristics to the baseline IV specification outlined in Equations (1) and (2), along with 95% confidence intervals based on standard errors clustered at the doctor level. The dependent variables are measured over the two years following surgery. For each panel, we first reproduce the baseline estimates (top row), then re-estimate the alternative IV specification by adding the indicated doctor characteristics one by one (second through sixth rows), and finally re-estimate the specification with all five characteristics included (last row).

Figure 10: Trends in Share of Minimally Invasive Surgeries



NOTES: This figure displays trends in the share of minimally invasive surgeries within our analysis sample, excluding years with partial coverage (i.e., 2007 and 2021). To account for changes in surgery composition, we compute the share using a mean-preserved residualized indicator, obtained by first residualizing the indicator for minimally invasive surgery with respect to surgery type and then adding back the overall mean to preserve the original level.

Figure 11: Variation in Minimally Invasive Surgery Share Across Hospital Referral Regions in Texas



Notes: This figure displays the geographic distribution of minimally invasive surgery shares, grouped into quintiles across 22 Texas Hospital Referral Regions (HRRs) within our analysis sample. We exclude approximately 1.2% of patients (1,137 out of 93,350) who lived in non-Texas HRRs at the time of surgery. To highlight geographic variation, we compute the share using a mean-preserved residualized indicator, obtained by first residualizing the indicator for minimally invasive surgery with respect to age, gender, surgery type, and surgery year, and then adding back the overall mean to preserve the original level.

Table 1: Top 25 Target Surgeries by Volume

	Number	Share	Mean Characteristics		
			Minimally Invasive	Patient Male	Patient Age
	(1)	(2)	(3)	(4)	(5)
Knee meniscectomy	26,884	0.288	0.999	0.696	48.08
Shoulder rotator cuff repair	17,646	0.189	0.631	0.716	53.33
Knee ACL/PCL reconstruction	6,623	0.071	0.924	0.711	36.77
Shoulder subacromial decompression	5,093	0.055	0.921	0.673	47.65
Wrist/forearm fracture fixation	4,520	0.048	0.082	0.491	50.48
Shoulder biceps tenodesis	3,658	0.039	0.237	0.810	50.79
Wrist/forearm carpal tunnel release	2,774	0.030	0.340	0.437	46.89
Spine discectomy	2,198	0.024	0.000	0.829	41.84
Hand phalangeal shaft fracture fixation	2,174	0.023	0.376	0.834	39.74
Hand distal phalangeal fracture fixation	2,167	0.023	0.202	0.887	40.23
Shoulder loose/foreign body removal	2,091	0.022	0.998	0.710	46.57
Knee synovectomy	2,041	0.022	0.992	0.629	42.66
Shoulder distal clavicle resection	1,910	0.020	0.652	0.711	48.51
Shoulder SLAP lesion repair	1,901	0.020	0.994	0.802	40.47
Hand metacarpal fracture fixation	1,440	0.015	0.216	0.826	38.67
Shoulder capsulorrhaphy	1,434	0.015	0.873	0.836	34.83
Wrist/forearm TFCC repair or debridement	1,219	0.013	0.907	0.512	43.54
Knee meniscus repair	858	0.009	0.967	0.690	38.73
Foot metatarsal fracture fixation	829	0.009	0.066	0.682	42.39
Knuckle ulnar collateral ligament repair	683	0.007	0.000	0.611	43.10
Ankle loose/foreign body removal	677	0.007	0.931	0.583	40.41
Elbow loose/foreign body removal	520	0.006	0.292	0.654	44.36
Foot calcaneal fracture fixation	498	0.005	0.028	0.908	46.58
Tibia plateau fracture treatment	459	0.005	0.100	0.704	47.04
Leg tibial shaft fracture fixation	457	0.005	0.007	0.838	40.56

NOTES: This table lists the 25 most common target surgeries in the analysis sample, ordered by volume (top to bottom). The first two columns report the absolute number and relative share of each surgery. The next three columns report the share that are minimally invasive, the share of male patients, and the mean age of patients for each surgery.

Table 2: Descriptive Statistics for Patients

	Full Sample (1)	Minimally Invasive = 0 (2)	Minimally Invasive = 1 (3)
Panel A. Basic Characteristics			
Male	0.699	0.713	0.693
Age	46.80	47.21	46.63
Surgery Body Part			
Ankle	0.013	0.008	0.015
Elbow	0.006	0.013	0.002
Femur	0.001	0.002	0.000
Finger	0.005	0.007	0.004
Foot	0.019	0.058	0.002
Hand	0.062	0.152	0.024
Hip	0.003	0.005	0.002
Humerus	0.000	0.000	0.000
Knee	0.396	0.023	0.555
Leg	0.005	0.016	0.000
Knuckle (Metacarpophalangeal)	0.007	0.024	0.000
Shoulder	0.364	0.379	0.357
Spine	0.024	0.079	0.001
Tibia	0.005	0.015	0.001
Wrist or Forearm	0.092	0.219	0.037
Share Minimally Invasive	0.701	0.000	1.000
Panel B. Pre-Surgery Characteristics			
Days from Injury to Surgery	101.1	81.69	109.4
1(Surgery on First Day Injury Treated)	0.014	0.035	0.005
1(First Treatment of Injury at ED)	0.314	0.399	0.277
Physical Therapy Visits	0.944	0.880	0.964
Physical Therapy Spending	169.0	154.3	173.6
1(Any Physical Therapy Visit)	0.315	0.295	0.322
Office Visits	1.785	1.821	1.774
Office Visit Spending	278.6	286.5	276.1
1(Any Office Visit)	0.916	0.907	0.918
ED Visits	0.377	0.413	0.366
ED Visit Spending	215.6	278.1	196.4
1(Any ED Visit)	0.293	0.325	0.283
Opioid Prescriptions	0.348	0.406	0.329
Opioid Days Supplied	2.863	3.416	2.692
1(Any Opioid Prescription)	0.251	0.286	0.240
First Day Health Care Spending	643.7	844.0	565.0
Total Health Care Spending	1,237	1,371	1,195
Number of surgeries	93,350	27,935	65,415
Number of unique surgeons	978	962	933

NOTES: This table reports summary statistics for patients in the analysis sample. Column (1) reports statistics for all patients, and columns (2) and (3) report statistics separately for patients who received open and minimally invasive surgeries, respectively. All statistics are means or shares of the indicated characteristics. Dollar values for spending measures are CPI-U–adjusted to December 2020 dollars. See Appendix Section B.3 for details on the construction of pre-surgery characteristics.

Table 3: Effects of Minimally Invasive Surgery on Health and Disability Outcomes

	Dependent Variable (Minimally Invasive = 0)		Minimally Invasive IV Estimates			% Relative to Control Mean
	Mean	Std. Dev.	Coefficient	Std. Error	p-value	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Outcomes on Surgery Date						
Total Health Care Spending	7,396	5,249	-1,078	(892.1)	[0.227]	-14.57%
Target Surgery Procedure Spending	2,984	2,284	-231.0	(616.8)	[0.708]	-7.74%
1(Day Surgery)	0.934	0.249	0.027	(0.012)	[0.026]	2.85%
Location of Surgery						
1(Inpatient Hospital)	0.168	0.374	-0.096	(0.047)	[0.041]	-57.31%
1(Outpatient)	0.712	0.453	0.284	(0.093)	[0.002]	39.87%
1(All Other Places)	0.120	0.325	-0.188	(0.055)	[< 0.001]	-156.86%
Panel B. Health Care Outcomes in Two Years Following Surgery						
Total Spending						
Total Health Care Spending	17,333	16,514	-5,274	(2,350)	[0.025]	-30.43%
Medical Spending	16,613	15,308	-4,553	(2,129)	[0.033]	-27.41%
Prescription Drug Spending	719.7	2,544	-720.3	(283.7)	[0.011]	-100.08%
Other Outcomes						
Office Visits	8.021	10.52	-5.099	(1.690)	[0.003]	-63.58%
Office Visit Spending	922.5	1,252	-505.4	(176.6)	[0.004]	-54.78%
Physical Therapy Visits	21.36	19.70	-1.575	(2.207)	[0.476]	-7.37%
Physical Therapy Spending	4,258	5,668	-1,353	(730.4)	[0.064]	-31.78%
1(Any Opioid Prescription)	0.666	0.471	-0.021	(0.051)	[0.675]	-3.18%
Opioid Days Supplied	47.94	132.9	-40.90	(14.41)	[0.005]	-85.31%
Opioid Prescriptions	3.536	7.337	-1.377	(0.745)	[0.065]	-38.94%
1(Any ED Visit)	0.122	0.327	-0.009	(0.024)	[0.713]	-7.13%
ED Visit Spending	96.37	566.0	8.917	(19.91)	[0.654]	9.25%
Subsequent Musculoskeletal Surgeries on Same Body Part						
1(Subsequent Surgery)	0.170	0.376	-0.075	(0.036)	[0.038]	-43.94%
Number of subsequent surgeries	0.201	0.489	-0.100	(0.045)	[0.027]	-49.54%
Spending on subsequent surgeries	645.0	2,173	-404.8	(216.2)	[0.061]	-62.75%
Panel C. Disability and Benefit Outcomes in Two Years Following Surgery						
Total Cash Benefits Paid	15,926	18,205	-3,981	(1,750)	[0.023]	-25.00%
1(Any Cash Benefit)	0.883	0.322	-0.021	(0.018)	[0.236]	-2.38%
Temporary Income Benefits Paid	10,650	15,043	-2,610	(1,257)	[0.038]	-24.51%
1(Any Temporary Income Benefit)	0.799	0.401	-0.050	(0.025)	[0.045]	-6.30%
Days of Temporary Income Benefits	127.4	156.5	-37.12	(12.93)	[0.004]	-29.13%
Impairment Income Benefits Paid	5,276	6,898	-1,371	(610.8)	[0.025]	-25.99%
1(Any Impairment Income Benefit)	0.643	0.479	-0.076	(0.034)	[0.024]	-11.88%
Impairment Severity Rating	3.490	4.276	-1.060	(0.322)	[0.001]	-30.36%
Total Workers' Compensation Costs	33,259	29,624	-9,255	(3,284)	[0.005]	-27.83%

NOTES: This table reports estimated coefficients on the indicator for minimally invasive surgery from the IV specification outlined in Equations (1) and (2). Each row represents a separate regression, with the dependent variable measured on the surgery date in Panel A and over the two years following surgery in Panels B and C. Columns (1) and (2) report the mean and standard deviation of each dependent variable, calculated among patients who received open surgery. Columns (3)–(5) report the estimated coefficients, standard errors, and p-values, respectively. Column (6) reports the estimated effects in percentage terms relative to the control means.

The Impact of Medical Innovation on Health and Disability

ONLINE APPENDIX

Marika Cabral Marcus Dillender Jinyeong Son

A Dataset on Musculoskeletal Surgeries Performed Using Minimally Invasive or Open Techniques

For this study, we compile a novel dataset covering all musculoskeletal surgeries that can be performed using either minimally invasive or open surgical techniques. This dataset consists of *minimally invasive* Current Procedural Terminology (CPT) codes and their corresponding *open* CPT codes—procedures that achieve the same goal but require larger incisions—by using various sources and cross-validation processes. We begin by collecting all CPT codes for minimally invasive musculoskeletal surgeries (e.g., arthroscopy). We then classify these CPT codes based on the associated body part and specific procedure (e.g., anterior cruciate ligament (ACL) repair in the knee), which we refer to as a *surgery type*.

Next, for each surgery type, we identify the corresponding open CPT codes using various methods. Specifically, we first conduct an extensive review of the medical literature that directly provides CPT code information for minimally invasive procedures and their alternative open surgical options with clinical equivalence in musculoskeletal surgeries. When such explicit information is not available in the medical literature, we primarily use two websites—the American Academy of Professional Coders and Generative Healthcare AI—to identify candidate open CPT codes by retrieving all CPT codes associated with the same body part and a similar surgical purpose.[6] We then carefully examine the description of each candidate CPT code to determine whether it corresponds to an open CPT code that performs an identical or nearly identical surgical procedure to the minimally invasive CPT code of interest. Finally, we cross-validate our data, particularly classifications not directly derived from the medical literature, using additional sources such as medical billing and coding forums and coding guideline articles.

Using the approach described above, we obtain a total of 290 CPT codes—134 for minimally invasive codes and 156 for open codes—for musculoskeletal surgeries across 98 surgery types (defined by the indicated body part and specific procedure). Among these surgery types, we exclude certain ones if: (i) a comparable open option is unavailable, (ii) the minimally invasive CPT codes pertain to diagnosis, or (iii) an open CPT code covers multiple surgery types. After these exclusions, our final dataset includes 81 surgery types in which both minimally invasive and open options are available, with 114 minimally invasive codes and 146 open codes, each assigned to a single surgery type.

[6] These two websites can be accessed at the following URLs: `https://www.aapc.com` and `https://genhealth.ai`.

B Data Construction

B.1 Sample Definition

We define an *encounter* as all interactions between a patient and healthcare provider(s) on a single date. As such, from a data perspective, each encounter typically generates multiple medical bills initiated that day. We use all medical bills submitted via the CMS-1500 form (for non-institutional providers) and the CMS-1450 form (for institutional providers) to construct the set of medical bills associated with each encounter. This allows us to more comprehensively identify surgery cases of interest—as either form can be used to bill for a day surgery—and to more accurately capture all medical services the patient receives. Finally, it is natural for a single patient to have multiple encounters, as they may receive medical services on different dates.

To construct our main sample of *target encounters*, we first consider all encounters in which an injured worker had any surgery listed in our musculoskeletal surgery dataset described in Appendix A. (We refer to such surgeries as *target surgeries*.) The sample is then limited to encounters where the target musculoskeletal surgical procedure has the highest billed amount among all procedures received on the encounter date, ensuring that it was the *primary* medical service that day. For individuals with multiple target musculoskeletal surgeries, we consider only the first surgery, as subsequent surgeries and health care are endogenous to it. We focus on surgeries performed between June 2007 and April 2021, as surgeons can be consistently identified using the National Provider Identifier (NPI), which became effective in May 2007, and we can measure various outcomes for two years following the surgery, given that our data end in July 2023.[7] We exclude surgeries if we cannot reliably identify a rendering NPI (see Section B.2). Additionally, we drop surgeries performed by doctors whose share of surgeries in emergency or urgent care settings is 10% or greater, as the nature of these settings may influence their decisions regarding minimally invasive versus open surgery differently from other doctors. Surgeries with missing values for gender, age, and hospital referral region, as well as those performed more than two years after the claim start date, are also dropped.[8] Finally, we require each category in the full set of fixed effects used for instrument construction—detailed in Section 2—to have at least 10 observations (i.e., every surgery group has at least 10 observations for each year). Our baseline sample consists of $93,350$ surgeries performed by 978 doctors.

B.2 Identifying Rendering Surgeons

We first construct a dataset that includes only National Provider Identifiers (NPIs) for general surgeons and orthopedic surgeons, using the National Plan and Provider Enumeration System (NPPES) file (CMS, 2024). Specifically, we retain only NPIs that represent individuals (as opposed to organizations) with 25 provider taxonomy codes associated with a Medicare Specialty Code of

[7]We apply a three-month margin to account for potential data lags.
[8]We define the first medical service date for the injury as the claim start date.

02 and define them as general surgeons. Among these general surgeons, we further classify those with eight provider taxonomy codes that have a prefix of 207X as orthopedic surgeons.[9]

B.3 Pre-Surgery Claim Characteristics

As discussed in the main text, we use the pre-surgery claim characteristics for the balance analysis. One set of pre-surgery characteristics is proxies for the severity of the injury, which include an indicator for whether the claim originated with an emergency department visit, log of medical spending on the first day of claim, indicator for surgery on first day of claim. For these measures, we define variables based on the date the injured worker first received medical treatment for the injury.[10] Another set of characteristics includes the number of days between injury and surgery and measures of health care utilization before the surgery. The pre-surgery health care utilization measures include pre-surgery physical therapy visits, opioid use, and medical spending. For these measures, we define variables using information from the date of first medical treatment to three days before surgeries. We exclude the three days before surgeries began to ensure we are not capturing health care related to the surgery that occurs in the few days before the surgery.

C Supplemental Analysis

Our main analysis focuses on patients who received the target surgeries. Given this, it is natural to ask: do patients select into receiving surgery based on doctor propensities to do minimally invasive versus open surgery? While selection of this type would only bias our estimates if this selection were related to patient level determinants of our outcomes of interest, we directly explore the possibility of selection into surgery based on doctor minimally invasive intensity. Section 2 in the main text summarizes this analysis, and below we provide further details.

For this analysis, we define a broader sample of individuals potentially eligible to have surgery: all patients in the data who ever had an office visit with an orthopedic surgeon who is represented in our baseline analysis. This analysis is premised on the fact that patients typically have an office visit with their surgeon prior to surgery, but not all office visits with surgeons result in later surgery.[11] Among this broader sample of patients potentially eligible to have surgery, we first estimate the following regression:

$$Surgery_i = \boldsymbol{X}_i\boldsymbol{\zeta} + \varphi_{k(i)t(i)} + \nu_i, \tag{A1}$$

where i denotes patient, $k(i)$ denotes the diagnosis of the patient from an office visit with surgeon, and $t(i)$ denotes the year of the initial visit with the surgeon. $Surgery_i$ indicates that the patient

[9] For a complete list of Medicare specialty and provider taxonomy codes, see here: `https://www.cms.gov/medicare/provider-enrollment-and-certification/medicareprovidersupenroll/downloads/taxonomycrosswalk.pdf`.

[10] The workers' compensation administrative data record the year and month of the injury, not the exact date. Therefore, we define the claim start date using the date of the first medical treatment received for the injury.

[11] In our main estimation sample focusing on individuals who received target surgeries, XX% of planned surgeries have a claims record indicating the patient attend an office visit with the surgeon within XX days prior to the surgery.

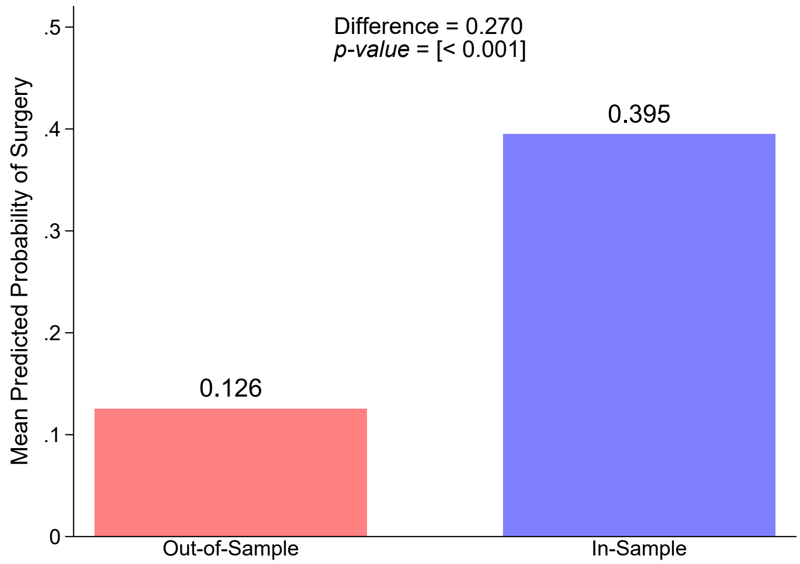
has surgery within three months of their initial office visit with the surgeon, $\varphi_{k(i)t(i)}$ represents diagnosis by year fixed effects, and $\boldsymbol{X}_i$ represents additional controls for demographics (individual age and gender) and medical market (Hospital Referral Region). When constructing $\varphi_{k(i)t(i)}$, we consider two ways to characterize diagnosis: (a) diagnosis from the initial office visit with the surgeon and (b) diagnosis at the most recent pre-surgery office visit with the surgeon within 3 months of the initial visit. As in the baseline UJIVE estimation, we require each category of fixed effects to have at least ten observations.

After estimating Equation (A1) using the sample of patients potentially eligible to have surgery, we then use the coefficients from this model to predict the likelihood that patients undergo surgery. Appendix Figure A1 Panel (a) reports the means of this ex ante predicted probability of surgery by eventual surgery status and indicates this ex ante predicted probability is highly predictive of whether patients actually receive surgery. For patients who receive surgery, we estimate the average ex ante predicted probability of having surgery is 39.5%. For patients who do no receive surgery, we estimate the average ex ante predicted probability of having surgery is 12.6%.

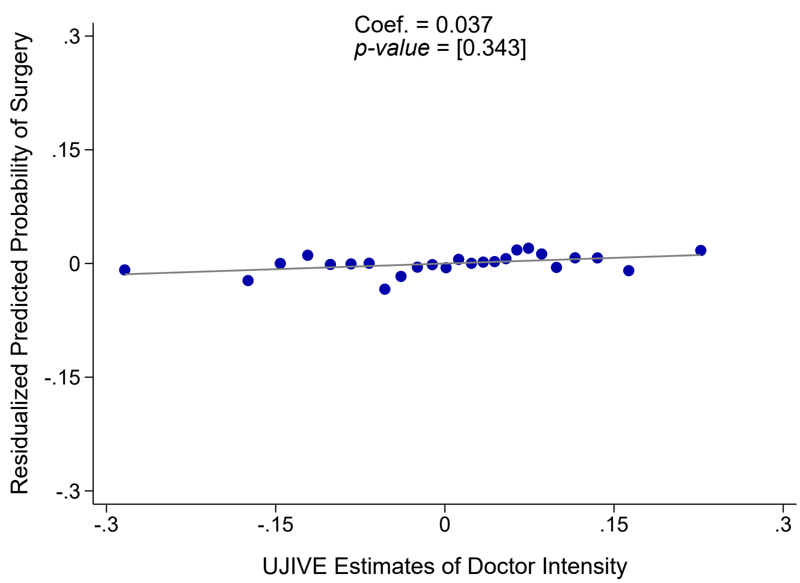
We then test for balance in this predicted surgery measure in our main analysis sample by setting it as the dependent variable in Equation (2) and regressing it on the instrument, $z_{id(i)}$, as we did with predetermined characteristics in Figure 3. Appendix Figure A1 Panel (b) reports the coefficient on $z_{id(i)}$ and an associated plot that relates the residualized predicted probability of surgery to $z_{id(i)}$. This analysis provides no evidence that the predicted likelihood of having a surgery based on baseline characteristics is associated with the surgeon's minimally invasive intensity measure. The coefficient on $z_{id(i)}$ is a statistically insignificant 0.037, and the residualized predicted probability of surgery is flat across the distribution of $z_{id(i)}$. This analysis suggests the predicted probability of surgery is not related to the instrument and thus the ex ante predicted probability of surgery is not related to our identifying variation.

Figure A1: Selection into Surgery by Doctor Intensity for Minimally Invasive Surgery

(a) Predicted Probability of Surgery

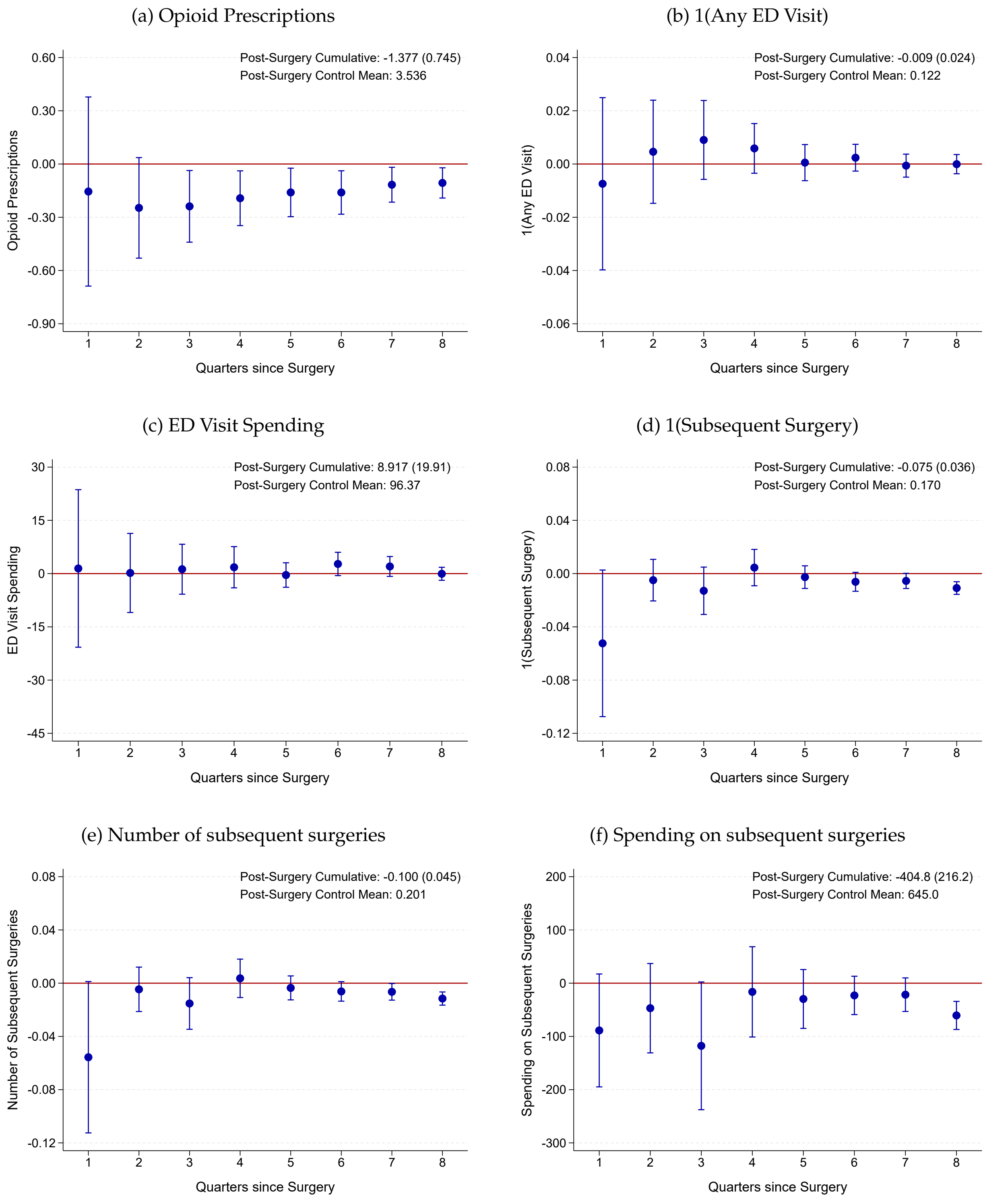


(b) Selection



NOTES: This figure assesses selection into receiving a target surgery based on doctor intensity for minimally invasive surgery. Panel (a) compares the mean predicted probability of receiving a target surgery between out-of-sample and in-sample patients, obtained by estimating Equation (A1). Out-of-sample patients are those who consulted any doctor in our analysis sample but did not receive a target surgery (and thus were not part of the analysis sample), whereas in-sample patients are those who were included in the analysis sample and received a target surgery within three months of their initial visit to the surgeon ($N_{\text{out-of-sample}} = 353,530$ and $N_{\text{in-sample}} = 70,090$). Panel (b) plots the predicted probability of surgery, residualized with respect to the baseline controls (i.e., age, gender, Hospital Referral Region, and surgery type by year), against 25 equal-sized bins of the doctor intensity instrument among in-sample patients. The coefficient reported at the top of Panel (b) is estimated from Equation (2) using the underlying patient-level data, whereas the line of best fit is obtained using the 25 plotted points. See Appendix Section C for further details on this analysis.

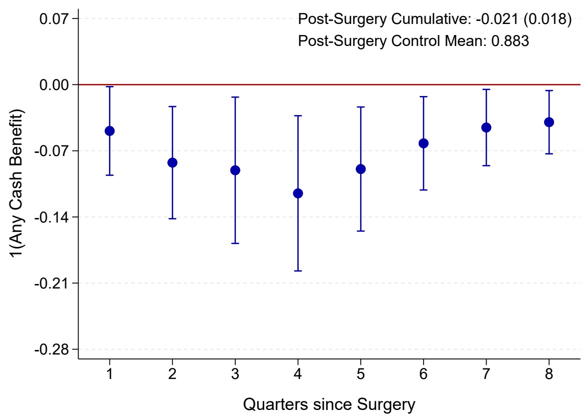
Figure A2: Dynamic Effects of Minimally Invasive Surgery on Health Care Utilization—Additional Outcomes



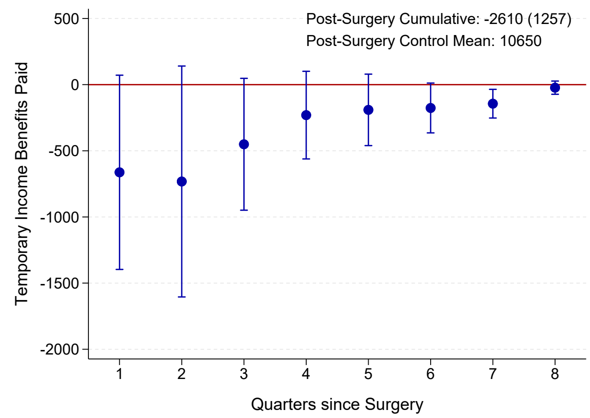
NOTES: This figure plots the estimated coefficients on the indicator for minimally invasive surgery from the IV specification outlined in Equations (1) and (2), along with 95% confidence intervals based on standard errors clustered at the doctor level. Each quarter represents a separate regression, with the dependent variable measured over that quarter; for example, the first quarter spans the surgery date through surgery date + 90 days, and the second quarter covers the next 90-day period. The reported post-surgery cumulative effects are estimated using the dependent variable measured over all eight quarters. Post-surgery control means are calculated among patients who received open surgery.

Figure A3: Dynamic Effects of Minimally Invasive Surgery on Disability and Benefit Outcomes—Additional Outcomes

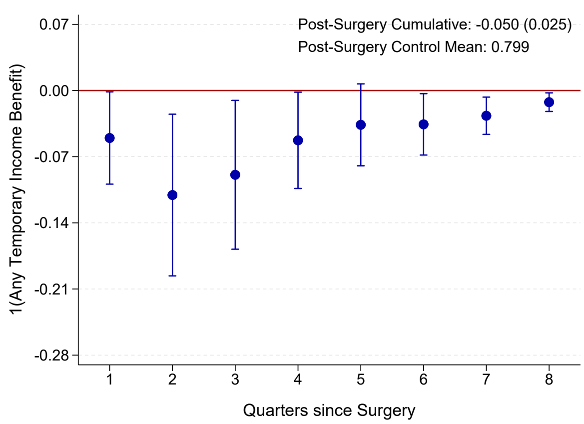
(a) 1(Any Cash Benefit)



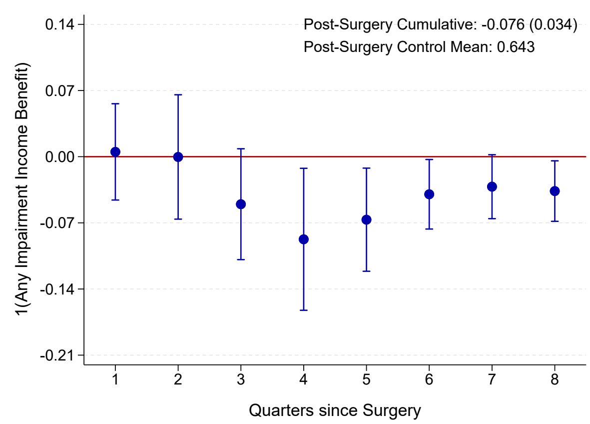
(b) Temporary Income Benefits Paid



(c) 1(Any Temporary Income Benefit)

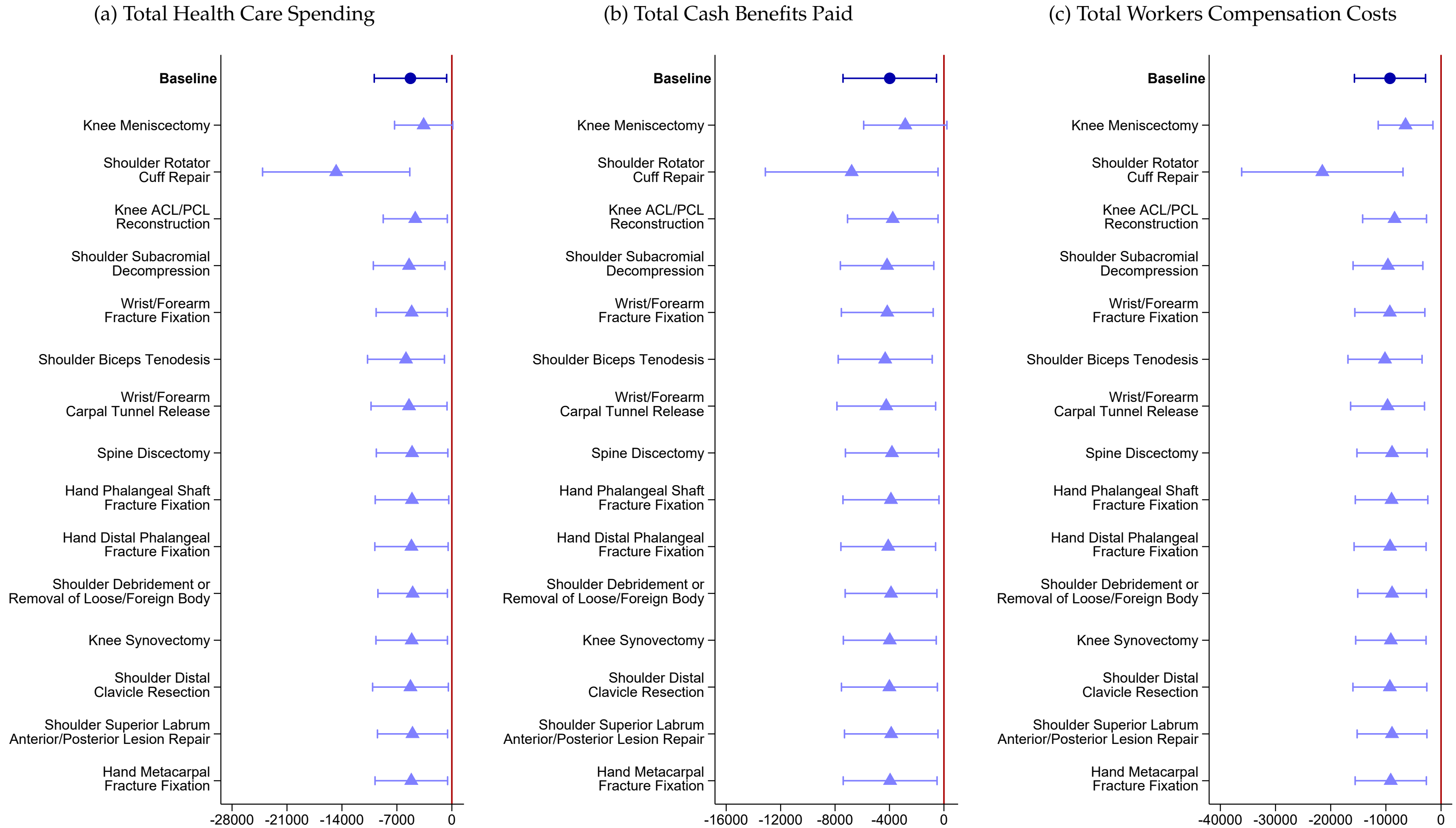


(d) 1(Any Impairment Income Benefit)



NOTES: This figure plots the estimated coefficients on the indicator for minimally invasive surgery from the IV specification outlined in Equations (1) and (2), along with 95% confidence intervals based on standard errors clustered at the doctor level. Each quarter represents a separate regression, with the dependent variable measured over that quarter; for example, the first quarter spans the surgery date through surgery date + 90 days, and the second quarter covers the next 90-day period. The reported post-surgery cumulative effects are estimated using the dependent variable measured over all eight quarters. Post-surgery control means are calculated among patients who received open surgery.

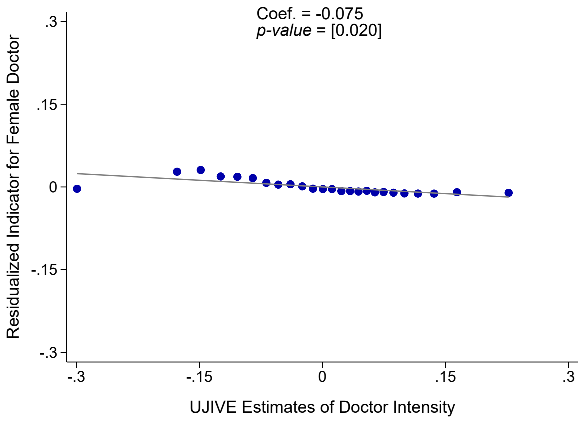
Figure A4: Robustness: Excluding One of Top 15 Target Surgeries



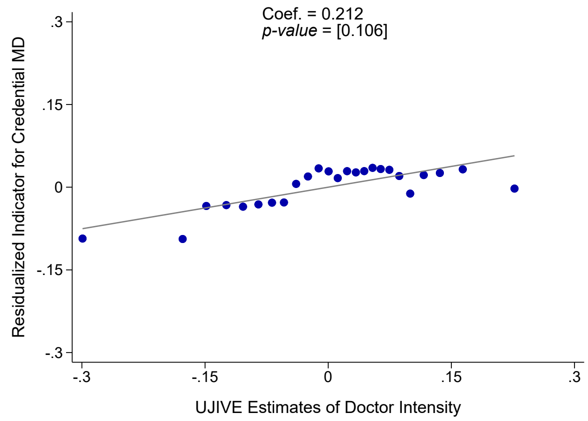
Notes: This figure plots the estimated coefficients on the indicator for minimally invasive surgery from the IV specification outlined in Equations (1) and (2), along with 95% confidence intervals based on standard errors clustered at the doctor level. The dependent variables are measured over the two years following surgery. For each panel, we first reproduce the baseline estimates (top row) and then re-estimate the IV specification after excluding one of the 15 most common surgery types denoted on the vertical axis at a time.

Figure A5: Correlation Between Doctor Characteristics and Intensity Instrument

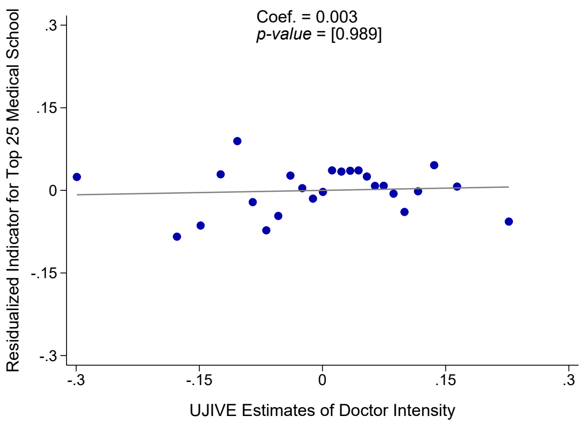
(a) Gender (Female)



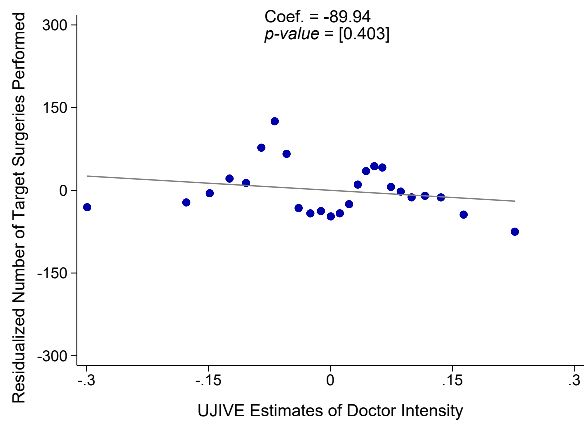
(b) Credential for MD



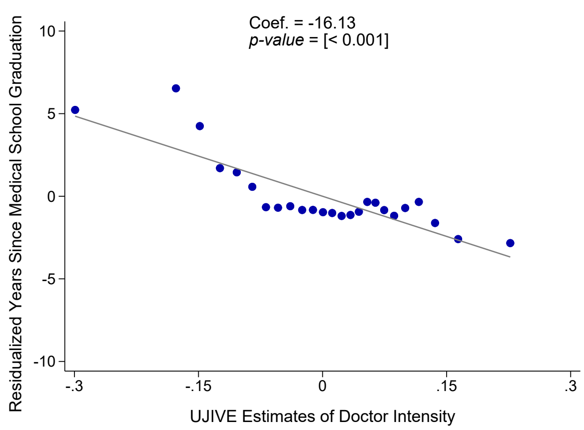
(c) Top 25 Medical School Graduate



(d) Volume (Number of Target Surgeries Performed)

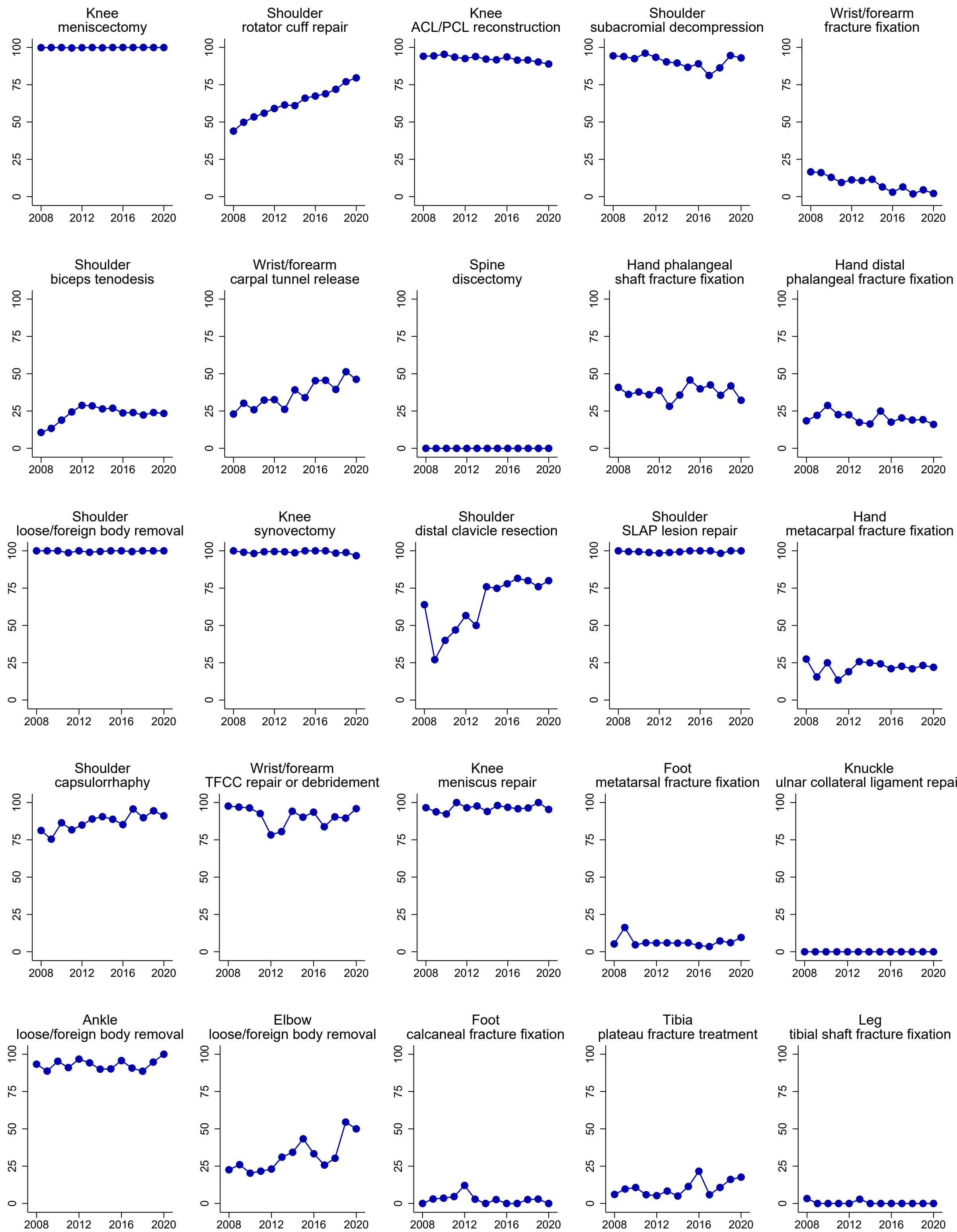


(e) Experience (Years Since Medical School Graduation)



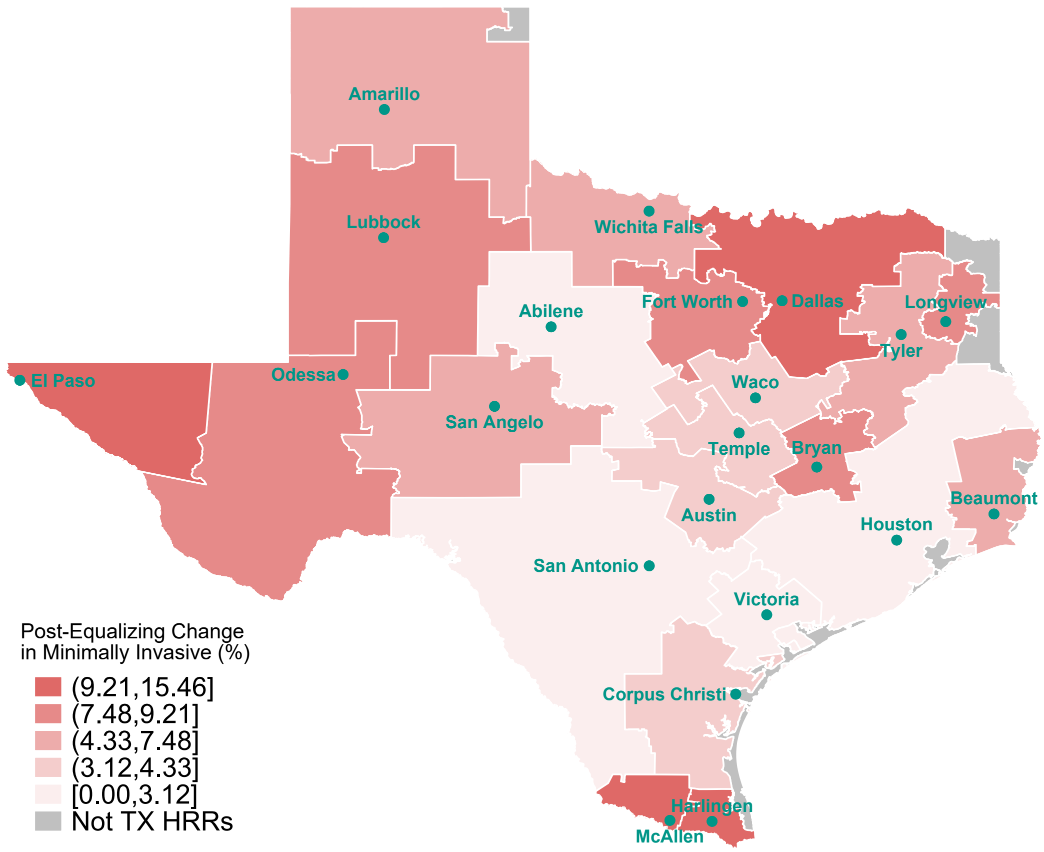
NOTES: This figure provides a graphical illustration of the correlation between doctor characteristics and the doctor intensity instrument. Each panel presents a binned scatter plot of the indicated doctor characteristic, residualized with respect to the baseline controls (i.e., age, gender, Hospital Referral Region, and surgery type by year), against 25 equal-sized bins of the doctor intensity instrument. he coefficients reported at the top of each panel are estimated from Equation (2) using the underlying patient-level data, whereas the line of best fit is obtained using the 25 plotted points.

Figure A6: Trends in Share of Minimally Invasive Surgeries by Surgery Type



NOTES: This figure displays trends in the share of minimally invasive surgeries within our analysis sample, separately for each of the 25 most common surgery types, excluding years with partial coverage (i.e., 2007 and 2021).

Figure A7: Minimally Invasive Surgery Share Change Across Hospital Referral Regions in Texas After Equalization



Notes: This figure displays the geographic distribution of the expected increases in the shares that are minimally invasive under a counterfactual policy that equalizes these shares across regions at the maximum observed level (76.27%).

Table A1: Balance

	OLS			IV		
	Coefficient	Std. Error	p-value	Coefficient	Std. Error	p-value
	(1)	(2)	(3)	(4)	(5)	(6)
Pre-Surgery Characteristics						
Days from Injury to Surgery	0.076	(0.008)	[< 0.001]	-0.042	(0.029)	[0.143]
1(Surgery on First Day Injury Treated)	-0.030	(0.005)	[< 0.001]	-0.001	(0.018)	[0.967]
1(First Treatment of Injury at ED)	-0.122	(0.009)	[< 0.001]	-0.018	(0.038)	[0.625]
Physical Therapy Visits	0.008	(0.005)	[0.066]	-0.023	(0.021)	[0.258]
Physical Therapy Spending	0.019	(0.009)	[0.043]	-0.030	(0.041)	[0.461]
1(Any Physical Therapy Visit)	0.027	(0.012)	[0.028]	-0.052	(0.058)	[0.374]
Office Visits	-0.005	(0.002)	[0.002]	-0.008	(0.009)	[0.331]
Office Visit Spending	-0.010	(0.004)	[0.010]	-0.002	(0.023)	[0.916]
1(Any Office Visit)	0.011	(0.003)	[< 0.001]	0.007	(0.014)	[0.620]
ED Visits	-0.005	(0.001)	[< 0.001]	0.001	(0.005)	[0.796]
ED Visit Spending	-0.082	(0.009)	[< 0.001]	0.015	(0.026)	[0.559]
1(Any ED Visit)	-0.042	(0.008)	[< 0.001]	-0.003	(0.034)	[0.928]
Opioid Prescriptions	-0.077	(0.009)	[< 0.001]	-0.021	(0.027)	[0.440]
Opioid Days Supplied	-0.072	(0.009)	[< 0.001]	-0.067	(0.035)	[0.057]
1(Any Opioid Prescription)	-0.046	(0.005)	[< 0.001]	-0.011	(0.018)	[0.537]
First Day Health Care Spending	-0.140	(0.012)	[< 0.001]	-0.026	(0.037)	[0.483]
Total Health Care Spending	-0.088	(0.014)	[< 0.001]	-0.029	(0.044)	[0.513]
F-Stat in Reverse Multivariate Regression		15.77			1.73	

NOTES: This table reports the estimated coefficients, standard errors, and p-values corresponding to Figure 3. Columns (1)–(3), labeled OLS, report estimated coefficients from separate bivariate regressions of each characteristic on the minimally invasive indicator. Columns (4)–(6), labeled IV, report estimated coefficients from separate regressions of each characteristic on the instrument, controlling for the baseline controls (age, gender, HRR, and surgery type by year). The bottom row reports the F-statistic from an F-test of joint significance in reverse multivariate regressions of the minimally invasive indicator on all pre-surgery characteristics (OLS panel) and of the instrument on all pre-surgery characteristics and the baseline controls (IV panel). Standard errors are clustered at the doctor level. See Appendix Section B.3 for details on the construction of pre-surgery characteristics.

Table A2: Average Monotonicity: First-Stage Estimates by Subgroup

	First-Stage Estimates		Minimally	N of Obs.
	Coefficient	Std. Error	Invasive = 1	
	(1)	(2)	(3)	(4)
Full Sample	0.931	0.009	0.701	93,350
Gender				
Female	0.924	0.020	0.714	28,100
Male	0.936	0.010	0.695	65,250
Age				
Below Median	0.695	0.025	0.713	47,601
Above Median	1.163	0.019	0.688	45,749
Days from Injury to Surgery				
Below Median	0.763	0.023	0.628	46,901
Above Median	1.075	0.019	0.774	46,449
1(First Treatment of Injury at ED)				
1(First Treatment of Injury at ED) = 0	0.985	0.010	0.738	64,082
1(First Treatment of Injury at ED) = 1	0.807	0.025	0.619	29,268
1(Any Physical Therapy Visit)				
1(Any Physical Therapy Visit) = 0	0.864	0.015	0.671	67,688
1(Any Physical Therapy Visit) = 1	1.102	0.026	0.780	25,662
1(Any Office Visit)				
1(Any Office Visit) = 0	0.637	0.041	0.440	18,819
1(Any Office Visit) = 1	1.008	0.012	0.766	74,531
1(Any ED Visit)				
1(Any ED Visit) = 0	0.927	0.010	0.688	69,531
1(Any ED Visit) = 1	0.959	0.021	0.739	23,819
1(Any Opioid Prescription)				
1(Any Opioid Prescription) = 0	0.901	0.012	0.692	72,898
1(Any Opioid Prescription) = 1	1.047	0.020	0.731	20,452
First Day Health Care Spending				
Below Median	0.959	0.015	0.707	46,675
Above Median	0.905	0.013	0.694	46,675
Total Health Care Spending				
Below Median	0.891	0.020	0.638	46,675
Above Median	0.977	0.016	0.764	46,675

NOTES: This table reports estimated coefficients from the first-stage specification outlined in Equation (2), estimated separately for each subgroup listed in the rows. Columns (1) and (2) report the estimated first-stage coefficients and standard errors. Columns (3) and (4) report the shares that are minimally invasive and the corresponding sample sizes.

Table A3: Heterogeneity Analysis by Patient Characteristics

	Baseline	Gender		Age		1(First Treatment of Injury at ED)		1(Any Opioid Prescription)		First Day Health Care Spending	
		Female	Male	≤ Median	> Median	ED = 0	ED = 1	Opioid = 0	Opioid = 1	≤ Median	> Median
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Panel A. Total Health Care Spending											
Coefficient	-5,274	-7,197	-4,557	-8,596	-3,263	-4,698	-6,612	-5,325	-4,908	-4,405	-6,268
Std. Error	(2,350)	(2,765)	(2,208)	(3,097)	(1,961)	(2,269)	(2,719)	(2,238)	(2,805)	(2,131)	(2,736)
p-value	[0.025]	[0.009]	[0.039]	[0.006]	[0.096]	[0.039]	[0.015]	[0.018]	[0.080]	[0.039]	[0.022]
95% CI	{-9,880, -666.7}	{-12,617, -1,778}	{-8,885, -228.7}	{-14,665, -2,526}	{-7,107, 580.4}	{-9,145, -249.7}	{-11,942, -1,282}	{-9,712, -938.0}	{-10,405, 589.8}	{-8,581, -228.3}	{-11,629, -905.8}
Mean Dep. $\mid$ Minimally Invasive = 0	17,333	17,022	17,458	16,356	18,269	17,162	17,589	16,474	20,840	16,830	17,813
% Relative to Control Mean	-30.43%	-42.28%	-26.10%	-52.55%	-17.86%	-27.37%	-37.59%	-32.32%	-23.55%	-26.17%	-35.19%
Panel B. Medical Spending											
Coefficient	-4,553	-6,302	-3,904	-7,645	-2,692	-4,103	-5,532	-4,647	-4,043	-3,821	-5,378
Std. Error	(2,129)	(2,477)	(2,011)	(2,800)	(1,780)	(2,054)	(2,472)	(2,046)	(2,479)	(1,951)	(2,453)
p-value	[0.033]	[0.011]	[0.053]	[0.006]	[0.131]	[0.046]	[0.025]	[0.023]	[0.103]	[0.050]	[0.029]
95% CI	{-8,726, -380.8}	{-11,157, -1,447}	{-7,846, 38.56}	{-13,133, -2,156}	{-6,180, 796.5}	{-8,129, -76.26}	{-10,376, -687.3}	{-8,658, -636.6}	{-8,903, 816.6}	{-7,644, 3.029}	{-10,186, -570.3}
Mean Dep. $\mid$ Minimally Invasive = 0	16,613	16,266	16,753	15,601	17,583	16,373	16,974	15,873	19,634	16,138	17,067
% Relative to Control Mean	-27.41%	-38.74%	-23.30%	-49.00%	-15.31%	-25.06%	-32.59%	-29.28%	-20.59%	-23.67%	-31.51%
Panel C. Prescription Drug Spending											
Coefficient	-720.3	-895.4	-653.1	-951.1	-571.1	-594.9	-1,080	-677.9	-864.6	-583.9	-889.4
Std. Error	(283.7)	(361.3)	(260.2)	(401.5)	(226.0)	(274.0)	(342.8)	(248.1)	(422.7)	(233.9)	(360.8)
p-value	[0.011]	[0.013]	[0.012]	[0.018]	[0.012]	[0.030]	[0.002]	[0.006]	[0.041]	[0.013]	[0.014]
95% CI	{-1,276, -164.2}	{-1,604, -187.2}	{-1,163, -143.1}	{-1,738, -164.1}	{-1,014, -128.3}	{-1,132, -57.97}	{-1,752, -408.2}	{-1,164, -191.6}	{-1,693, -36.23}	{-1,042, -125.5}	{-1,597, -182.2}
Mean Dep. $\mid$ Minimally Invasive = 0	719.7	755.9	705.1	755.0	685.8	789.4	614.7	600.5	1,207	692.1	746.1
% Relative to Control Mean	-100.08%	-118.46%	-92.63%	-125.96%	-83.28%	-75.36%	-175.70%	-112.89%	-71.66%	-84.37%	-119.21%
Panel D. Total Cash Benefits Paid											
Coefficient	-3,981	-2,719	-4,470	-5,254	-3,170	-4,173	-3,335	-3,949	-4,044	-3,979	-4,066
Std. Error	(1,750)	(1,799)	(1,821)	(2,104)	(1,708)	(1,703)	(2,138)	(1,694)	(2,176)	(1,698)	(1,998)
p-value	[0.023]	[0.131]	[0.014]	[0.013]	[0.064]	[0.014]	[0.119]	[0.020]	[0.063]	[0.019]	[0.042]
95% CI	{-7,411, -550.8}	{-6,245, 806.3}	{-8,039, -901.0}	{-9,378, -1,130}	{-6,517, 177.4}	{-7,510, -836.1}	{-7,524, 855.2}	{-7,269, -628.8}	{-8,309, 220.7}	{-7,307, -650.6}	{-7,983, -149.6}
Mean Dep. $\mid$ Minimally Invasive = 0	15,926	12,171	17,440	14,656	17,144	15,854	16,035	15,091	19,340	15,539	16,296
% Relative to Control Mean	-25.00%	-22.34%	-25.63%	-35.85%	-18.49%	-26.32%	-20.80%	-26.17%	-20.91%	-25.61%	-24.95%
Panel E. Days of Temporary Income Benefits											
Coefficient	-37.12	-41.78	-35.73	-51.35	-28.61	-35.82	-41.02	-37.28	-37.00	-36.96	-38.08
Std. Error	(12.93)	(15.61)	(12.70)	(18.39)	(10.94)	(12.74)	(15.88)	(13.02)	(14.70)	(13.25)	(14.51)
p-value	[0.004]	[0.008]	[0.005]	[0.005]	[0.009]	[0.005]	[0.010]	[0.004]	[0.012]	[0.005]	[0.009]
95% CI	{-62.47, -11.78}	{-72.36, -11.19}	{-60.62, -10.85}	{-87.39, -15.31}	{-50.04, -7.168}	{-60.79, -10.86}	{-72.14, -9.900}	{-62.79, -11.77}	{-65.81, -8.189}	{-62.92, -11.00}	{-66.51, -9.647}
Mean Dep. $\mid$ Minimally Invasive = 0	127.4	117.4	131.5	121.6	133.1	126.5	128.8	119.7	159.0	124.3	130.5
% Relative to Control Mean	-29.13%	-35.60%	-27.17%	-42.24%	-21.50%	-28.31%	-31.85%	-31.14%	-23.28%	-29.74%	-29.19%
Panel F. Impairment Income Benefits Paid											
Coefficient	-1,371	-786.0	-1,582	-1,834	-1,069	-1,398	-1,265	-1,229	-1,805	-1,266	-1,499
Std. Error	(610.8)	(639.5)	(639.4)	(700.6)	(622.1)	(611.6)	(741.5)	(611.1)	(727.8)	(679.6)	(626.1)
p-value	[0.025]	[0.219]	[0.014]	[0.009]	[0.086]	[0.022]	[0.088]	[0.045]	[0.013]	[0.063]	[0.017]
95% CI	{-2,568, -173.9}	{-2,039, 467.3}	{-2,835, -328.3}	{-3,208, -461.2}	{-2,289, 150.0}	{-2,597, -199.4}	{-2,718, 188.6}	{-2,427, -31.22}	{-3,232, -378.7}	{-2,598, 66.04}	{-2,726, -271.7}
Mean Dep. $\mid$ Minimally Invasive = 0	5,276	4,338	5,655	4,518	6,004	5,239	5,333	5,017	6,338	5,131	5,415
% Relative to Control Mean	-25.99%	-18.12%	-27.97%	-40.60%	-17.81%	-26.69%	-23.71%	-24.50%	-28.48%	-24.67%	-27.68%
Panel G. Total Workers' Compensation Costs											
Coefficient	-9,255	-9,917	-9,027	-13,850	-6,433	-8,871	-9,946	-9,274	-8,952	-8,384	-10,334
Std. Error	(3,284)	(3,711)	(3,206)	(4,474)	(2,735)	(3,155)	(3,956)	(3,217)	(3,757)	(3,063)	(3,885)
p-value	[0.005]	[0.008]	[0.005]	[0.002]	[0.019]	[0.005]	[0.012]	[0.004]	[0.017]	[0.006]	[0.008]
95% CI	{-15,690, -2,819}	{-17,190, -2,644}	{-15,310, -2,744}	{-22,618, -5,081}	{-11,794, -1,072}	{-15,055, -2,687}	{-17,700, -2,192}	{-15,579, -2,969}	{-16,315, -1,589}	{-14,388, -2,379}	{-17,949, -2,719}
Mean Dep. $\mid$ Minimally Invasive = 0	33,259	29,192	34,898	31,012	35,413	33,016	33,623	31,565	40,180	32,370	34,109
% Relative to Control Mean	-27.83%	-33.97%	-25.87%	-44.66%	-18.16%	-26.87%	-29.58%	-29.38%	-22.28%	-25.90%	-30.30%

Notes: This table reports estimated coefficients on the indicator for minimally invasive surgery from the IV specification outlined in Equations (1) and (2), estimated separately for each subgroup denoted in the column headers. The dependent variables, measured over the two years following surgery, are indicated in each panel. Column (1) reports the baseline estimates for reference. Robust standard errors clustered at the doctor level are reported in parentheses, p-values in brackets, and 95% confidence intervals in braces. Post-surgery control means are calculated among patients who received open surgery within each subgroup. These estimates are visually presented in Figure 7.

Table A4: Heterogeneity Analysis by Patient Characteristics: Supplemental Table

	Gender	Age	1(First Treatment of Injury at ED)	1(Any Opioid Prescription)	First Day Health Care Spending
	(1)	(2)	(3)	(4)	(5)
Panel A. Total Health Care Spending					
Difference	-2,641	-5,333	1,914	-417.3	1,863
	(1,099)	(1,477)	(1,129)	(1,053)	(1,173)
	[0.016]	[< 0.001]	[0.090]	[0.692]	[0.112]
Panel B. Medical Spending					
Difference	-2,398	-4,953	1,429	-604.1	1,558
	(989.3)	(1,334)	(1,054)	(924.0)	(1,045)
	[0.016]	[< 0.001]	[0.175]	[0.513]	[0.136]
Panel C. Prescription Drug Spending					
Difference	-242.3	-379.9	485.1	186.7	305.5
	(164.0)	(232.5)	(169.9)	(227.1)	(186.6)
	[0.140]	[0.103]	[0.004]	[0.411]	[0.102]
Panel D. Total Cash Benefits Paid					
Difference	1,751	-2,084	-838.7	95.11	87.23
	(1,127)	(1,387)	(1,233)	(1,287)	(1,120)
	[0.121]	[0.133]	[0.496]	[0.941]	[0.938]
Panel E. Days of Temporary Income Benefits					
Difference	-6.046	-22.74	5.194	-0.277	1.120
	(9.627)	(12.26)	(10.86)	(9.783)	(9.884)
	[0.530]	[0.064]	[0.633]	[0.977]	[0.910]
Panel F. Impairment Income Benefits Paid					
Difference	795.6	-765.1	-133.3	576.2	232.8
	(432.9)	(481.1)	(472.4)	(501.0)	(410.8)
	[0.066]	[0.112]	[0.778]	[0.250]	[0.571]
Panel G. Total Workers' Compensation Costs					
Difference	-889.8	-7,417	1,075	-322.2	1,950
	(1,663)	(2,539)	(2,030)	(1,841)	(2,006)
	[0.593]	[0.004]	[0.596]	[0.861]	[0.331]

NOTES: This table supplements Appendix Table A3. Each column corresponds to one category and reports differences in the IV estimates between the two subgroups in that category, estimated as the former subgroup (e.g., female) minus the latter subgroup (e.g., male) in Appendix Table A3. Robust standard errors clustered at the doctor level are reported in parentheses, and p-values are reported in brackets.

Table A5: Trends in Minimally Invasive Surgery Shares by Surgery Type

	Number	Share Minimally Invasive		Change in	
		2008–2009	2019–2020	Level	Percent
	(1)	(2)	(3)	(4)	(5)
Knee meniscectomy	26,884	0.999	0.999	0.001	0.06%
Shoulder rotator cuff repair	17,646	0.469	0.783	0.314	67.04%
Knee ACL/PCL reconstruction	6,623	0.942	0.896	-0.047	-4.95%
Shoulder subacromial decompression	5,093	0.941	0.938	-0.003	-0.37%
Wrist/forearm fracture fixation	4,520	0.164	0.033	-0.130	-79.66%
Shoulder biceps tenodesis	3,658	0.120	0.237	0.117	97.30%
Wrist/forearm carpal tunnel release	2,774	0.266	0.488	0.222	83.38%
Spine discectomy	2,198	0.000	0.000	0.000	N/A
Hand phalangeal shaft fracture fixation	2,174	0.385	0.370	-0.015	-3.80%
Hand distal phalangeal fracture fixation	2,167	0.203	0.176	-0.027	-13.15%
Shoulder loose/foreign body removal	2,091	1.000	1.000	0.000	0.00%
Knee synovectomy	2,041	0.995	0.978	-0.017	-1.73%
Shoulder distal clavicle resection	1,910	0.455	0.780	0.325	71.44%
Shoulder SLAP lesion repair	1,901	0.997	1.000	0.003	0.27%
Hand metacarpal fracture fixation	1,440	0.215	0.226	0.011	5.22%
Shoulder capsulorrhaphy	1,434	0.784	0.928	0.144	18.36%
Wrist/forearm TFCC repair or debridement	1,219	0.973	0.927	-0.046	-4.69%
Knee meniscus repair	858	0.952	0.977	0.025	2.67%
Foot metatarsal fracture fixation	829	0.108	0.078	-0.029	-27.18%
Knuckle ulnar collateral ligament repair	683	0.000	0.000	0.000	N/A
Ankle loose/foreign body removal	677	0.910	0.974	0.063	6.97%
Elbow loose/foreign body removal	520	0.243	0.523	0.280	115.20%
Foot calcaneal fracture fixation	498	0.015	0.015	0.000	-2.94%
Tibia plateau fracture treatment	459	0.079	0.169	0.090	114.61%
Leg tibial shaft fracture fixation	457	0.017	0.000	-0.017	-100.00%

NOTES: This table reports changes in the shares that are minimally invasive between 2008 and 2020 for the 25 most common target surgeries in the analysis sample. Column (1) reports the number of surgeries for each surgery type. Columns (2) and (3) report the mean shares that are minimally invasive in the first two years (2008–2009) and in the last two years (2019–2020) of the sample period, respectively. Columns (4) and (5) report the changes in these shares between the two periods, in absolute levels and percentage terms, respectively. These trends are visually presented in Appendix Figure A6.

Table A6: Diffusion Analysis

	Aggregated Impact of Diffusion on Outcomes (1)	(2)	Overall Change in Outcomes (3)	Share Explained by Diffusion (%) (4)	With 20% Faster Diffusion (5)
Panel A. Health Care Outcomes					
Total Spending					
Total Health Care Spending	-324.3	-1.87%	-2,161	15.01%	-389.2
Medical Spending	-280.0	-1.69%	-1,664	16.82%	-336.0
Prescription Drug Spending	-44.30	-6.16%	-497.0	8.91%	-53.16
Other Outcomes					
Office Visits	-0.314	-3.91%	0.739	-42.42%	-0.376
Office Visit Spending	-31.08	-3.37%	335.2	-9.27%	-37.30
Physical Therapy Visits	-0.097	-0.45%	0.345	-28.09%	-0.116
Physical Therapy Spending	-83.23	-1.95%	4.734	-1758.23%	-99.88
1(Any Opioid Prescription)	-0.001	-0.20%	-0.203	0.64%	-0.002
Opioid Days Supplied	-2.515	-5.25%	-34.90	7.21%	-3.018
Opioid Prescriptions	-0.085	-2.39%	-2.810	3.01%	-0.102
1(Any ED Visit)	-0.001	-0.44%	0.084	-0.63%	-0.001
ED Visit Spending	0.548	0.57%	74.71	0.73%	0.658
Subsequent Musculoskeletal Surgeries on Same Body Part					
1(Subsequent Surgery)	-0.005	-2.70%	0.011	-41.97%	-0.006
Number of subsequent surgeries	-0.006	-3.05%	0.013	-45.59%	-0.007
Spending on subsequent surgeries	-24.89	-3.86%	-75.01	33.19%	-29.87
Panel B. Disability and Benefit Outcomes					
Total Cash Benefits Paid	-244.8	-1.54%	2,108	-11.61%	-293.8
1(Any Cash Benefit)	-0.001	-0.15%	0.004	-31.49%	-0.002
Temporary Income Benefits Paid	-160.5	-1.51%	2,483	-6.46%	-192.6
1(Any Temporary Income Benefit)	-0.003	-0.39%	0.016	-19.70%	-0.004
Days of Temporary Income Benefits	-2.283	-1.79%	16.47	-13.86%	-2.740
Impairment Income Benefits Paid	-84.32	-1.60%	-375.3	22.47%	-101.2
1(Any Impairment Income Benefit)	-0.005	-0.73%	-0.063	7.49%	-0.006
Impairment Severity Rating	-0.065	-1.87%	-0.520	12.53%	-0.078
Total Workers' Compensation Costs	-569.2	-1.71%	-53.40	1065.79%	-683.0

NOTES: This table summarizes the impact of the diffusion of minimally invasive techniques, drawing upon the baseline IV estimates and the observed change in the share that is minimally invasive between 2008 and 2020. Column (1) reports the aggregated diffusion impacts, obtained by multiplying the baseline IV estimates by the overall growth rate in adoption (6.15 p.p.). Column (2) reports the estimated diffusion impacts in percentage terms relative to the control means reported in column (1) of Table 3. Column (3) reports mean changes in the indicated outcomes—net of surgery type fixed effects—between patients who had surgery in the first two years (2008–2009) and in the last two years (2019–2020) of the sample period. Column (4) reports the shares of these changes explained by diffusion (i.e., column (1) over column (3)). Column (5) reports the expected diffusion impacts if diffusion were counterfactually 20 % faster than observed.