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BROADBAND INTERNET ACCESS AND HEALTH OUTCOMES: PATIENT AND PROVIDER RESPONSES IN MEDICARE

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ABSTRACT

High-speed internet has increased the amount of information available in health care markets. Online information may improve health outcomes if it reduces information frictions and helps patients choose higher quality providers or causes providers to improve quality. We examine how health outcomes for common procedures in Medicare changed after broadband internet rolled out across ZIP Codes from 1999 to 2008. Estimates imply that broadband expansion improved health outcomes by 5%. Broadband access primarily helped patients choose higher-quality providers; we find less evidence that broadband improved provider quality. We use a simple structural model to decompose the improvements in patient outcomes over time. Counterfactual simulations imply that broadband roll-out was responsible for about 12% of the improvement in outcomes by the end of the period.

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1 Introduction

Widespread use of high-speed internet has drastically changed the amount of information available in many markets. Online information may be particularly important in health care markets given that limited information is a defining feature (Arrow 1963). Patients may use the internet to research their medical conditions and to make more informed choices about providers, improving health outcomes and increasing competition on quality. Yet, there is mixed evidence on whether individual sources of information about provider quality, such as physician ratings, affect patient demand and outcomes (e.g. Dranove and Sfekas 2008; Chou et al. 2014; Bundorf et al. 2009). However, much of the information on the internet is dispersed. High-speed internet allows patients to access a variety of information sources, communicate with other patients or providers, and aggregate information. Therefore, the general availability of high-speed internet may affect patient decision-making more than any one individual source.

Information from the internet may also lead to changes in hospital quality. If information from the internet makes patients more sensitive to quality, this could incentivize hospitals to increase quality. This may be particularly important in concentrated hospital markets with limited quality competition (Kessler and McClellan 2000; Gaynor et al. 2015). In addition, there is also growing evidence that the internet increases productivity in a number of industries, in part by increasing collaboration and fostering greater diffusion of best practices.[1] Providers often treat similar patients differently, generating unwarranted variation in outcomes across patients (Van Parys 2016; Currie et al. 2016; Currie and MacLeod 2017; Chan 2021). High-speed internet, however, has the potential to reduce unwarranted variation in provider practice styles if providers consult similar sources of online information.

In this paper, we ask how access to high-speed internet affects patient demand and provider quality. We focus on Medicare patients where prices are set administratively. We link geographic variation in the number of high-speed broadband internet providers with Medicare claims to determine whether broadband internet expansion improved patient outcomes. We use Federal Communication Commission (FCC) data on the roll-out of broadband internet and the number of broadband providers within each ZIP code from 1999 to 2008. There is evidence that broadband users are more likely than non-users to research

[1] For instance, see Grimes et al. (2012), Hjort and Poulsen (2019), Czernich et al. (2011), Atif et al. (2012), Kolko (2012), and Bhuller et al. (2019).

medical conditions and pharmaceutical drugs.[2] In our data, we confirm that the roll-out of broadband internet increased internet use in the Medicare population. We are not aware of work using this data to show how broadband expansion has affected patients' health care decision-making or hospital quality.

We match the broadband data to Traditional Medicare claims from 1999 to 2008 for patients seeking elective hip or knee replacements (i.e., total joint replacements). We focus on these procedures because they are very common among Medicare patients, with almost 2 million procedures over the sample period. Moreover, patients plan ahead to receive joint replacements; patients can consult with different surgeons, research hospitals, and schedule their procedures at the most opportune times. Joint replacements also have well-defined outcomes: 30-day all-cause readmission rates and 30-day all-cause mortality rates. We use readmission rates, mortality rates, and a combination of readmission and mortality rates as indicators of poor health outcomes following joint replacement.

To motivate our analysis, we start by showing that risk-adjusted health outcomes for hip and knee replacements improved from 1999 to 2008. The improvement in outcomes over the period is substantial. Readmission rates improved by about 20%, while mortality rates remained unchanged. We then show that the average number of broadband providers available per ZIP Code increased from 1999 to 2008. Internet use by the Medicare population triples over this period. Importantly, there is considerable variation in the timing in which broadband providers entered ZIP Codes. We then show that health outcomes for patients living in ZIP codes with no broadband providers in 1999 converged to health outcomes for patients in ZIP Codes with some broadband providers in 1999, as broadband expanded into more areas. This convergence provides initial evidence that broadband expansion is associated with better outcomes.

We employ a difference-in-difference model that exploits the staggered expansion of broadband within ZIP Codes over time. Our approach is motivated by previous research showing that consumer broadband availability and speed increases monotonically with the number of broadband providers in an area (Kolko 2012; Molnar and Savage 2017). We estimate the effect of broadband expansion on patient visit-level outcomes controlling for ZIP Code fixed effects, geographic-market-specific year fixed effects, and detailed patient characteristics. We estimate the same set of models using provider quality as the outcome variable

[2] Kolko (2010) finds that 59% of broadband users in 2006 researched medical conditions and 45% researched pharmaceutical drugs. Kolko (2010) finds evidence that broadband adoption increases research into medical conditions and drugs.

to examine whether patients received care at higher quality hospitals as broadband internet access expanded. Finally, we add hospital fixed effects to our models, and we add a measure of broadband penetration in the hospital's ZIP Code. We do this to test whether broadband availability in the hospital's ZIP Code also affected health outcomes, after conditioning on the patient's choice of hospital.

To supplement this analysis, we explore broadband's effects on health outcomes for other major medical conditions. First, we show how broadband availability in patient ZIP Codes affected 30-day hospitalization and mortality rates following colonoscopies. Colonoscopies are another common medical procedure in the Medicare population where patients choose their provider. Though rare, colonoscopies can result in complications such as hospitalization, so we examine how broadband roll-out affects hospitalization following a routine colonoscopy. Second, we construct a "placebo" sample for analysis, which focuses on emergency heart attacks (acute myocardial infarction (AMI)) and strokes. We consider emergency AMI and stroke as a placebo sample because these hospitalizations are unplanned by definition; therefore, patient access to broadband may have little impact on the patient's hospital choice or outcomes.

We find that increasing the number of broadband providers in a patient's ZIP Code decreases the readmission probability for joint replacement. The readmission probability is 5.7% lower when a patient goes from no broadband access to 4 or more broadband providers. These results are driven in large part by concentrated hospital markets where quality information is likely particularly valuable to patients. We find diminishing marginal returns to the number of broadband providers available in a patient's ZIP Code. The greatest improvements in health outcomes arise when a ZIP Code gains broadband internet providers after initially having no providers. Beyond four broadband providers, there are minimal improvements in health outcomes. We find similar effects of broadband expansion for colonoscopies, where there is also scope for patient choice. However, broadband expansion has no statistically significant effect on patient outcomes following hospitalizations for AMI and stroke, where there is less scope for patient choice.

Much of the relationship between patient outcomes and broadband expansion can be explained by a shift in patient demand to higher quality providers. Patients living in ZIP Codes when broadband access expands are less likely to receive care at hospitals with high risk-adjusted lagged readmission or mortality rates for joint replacement. In addition to these demand-side effects, hospitals marginally improve their quality as broadband internet expands; conditional on a patient's choice of hospital and access to broadband, readmission plus mortality probabilities decrease when broadband providers enter hospital ZIP Codes, but the result lacks statistical significance in our main sample.

Our results are robust to three alternative identification strategies: an IV approach, the Callaway and Sant'Anna (2021) approach to dealing with staggered difference-in-difference designs with two-way fixed effects, and a within-patient fixed effects approach. In addition, our results are even stronger when we extend our sample period to 2014.

Finally, we use a simple structural model to decompose the total change in joint replacement outcomes from 1999 to 2008 into the share due to broadband expansion. The model allows broadband access to affect both patient demand and the supply-side of health care markets. For the demand-side, we estimate a discrete choice model in which patient demand is a function of broadband access. We also allow demand to be a function of distance and allow for heterogeneous preferences. Estimation leverages the same variation generated by the roll-out of broadband internet providers. The results imply that broadband access increases the elasticity of demand with respect to quality. Combining these results with the reduced-form estimates on how broadband access affects the provision of hospital quality, we simulate outcomes in the absence of broadband expansion. Estimates imply that 12% of the reduction in the rate of readmission and mortality over the period was due to broadband expansion. We find that broadband's effect on patient outcomes is largely driven by improvements in patient choice of hospital, with smaller improvements in hospital quality.

2 Literature Review

Our paper connects three active research areas. First, we contribute to the literature examining the effects of high-speed internet access, where research has shown that internet access has increased price competition in many markets (Morton et al. 2001; Brown and Goolsbee 2002; Aker 2008). We are not aware of literature examining how consumer internet access affects quality competition among health care providers. A related literature, however, focuses on how high-speed internet affects firm productivity and economic growth (e.g., Grimes et al. 2012; Hjort and Poulsen 2019). More broadly, there is evidence that broadband penetration affects overall economic growth and labor markets (Czernich et al. 2011; Atif et al. 2012;

Kolko 2012; Bhuller et al. 2019).[3]

Second, we contribute to the literature on how information about health care provider quality affects patient choice. This literature has generally focused on information sources such as quality report cards. There is evidence that information from report cards or quality grade cards can affect demand (e.g., Jin and Leslie 2003; Bundorf et al. 2009). However, Dranove and Sfekas (2008) and Kolstad (2013) find little evidence that provider report cards affect health care demand in their settings. Rather, Kolstad (2013) finds that report cards affect the intrinsic motivation of surgeons. Chou et al. (2014) find evidence that heart surgery report cards increase hospitals' resource use and quality in competitive markets. There is also a literature examining how the lack of information in other health care settings affects patients. Information frictions in health insurance choice have been well documented and research has shown that information about cost or quality can improve choice (e.g., Dafny and Dranove 2008; Abaluck and Gruber 2011; Kling et al. 2012; Handel and Kolstad 2015; Brown and Jeon 2020). Information about health care prices can also affect demand for providers and provider prices (Lieber 2017; Brown 2019b).

While the literature on health care demand has generally focused on specific sources of quality information, much of the information on the internet is dispersed across many individual sources.[4] There is very limited work examining how the internet has affected health care markets.[5] One exception is Amaral-Garcia et al. (2022), who find that internet expansion in the UK increased patient demand for C-sections, particularly among lower-income women.

Finally, we contribute to the broader literature on how patient demand for quality and competition affect the provision of health care quality. The literature shows that hospitals provide different quality to otherwise similar patients, implying significant scope for some hospitals to increase quality (Doyle et al. 2019; Chandra and Staiger 2020; Cooper et al. 2022). Choice-based reforms, such as those that expand choice of hospitals, can make patients more responsive to quality (Cooper et al. 2011; Gaynor et al. 2016). There is mixed evidence about how changes in market structure affect hospital quality (Gaynor et al. (2015) provide

[3]Previous studies have examined the relationship between internet access and education choice (Dettling et al. 2018), electronic tax filing (Gunter 2019), and property markets (Ahlfeldt et al. 2017).

[4]Websites in the U.S. providing reviews of physicians and other health providers are numerous, including Google Maps, Yelp, Healthgrades, CareDash, RateMDs, U.S. News, Hospital Safety Grades, WebMD, and ZocDoc.

[5]There is research that has examined the internet's effect on health behaviors, and it has found that the internet affects sleep (Billari et al. 2018) and obesity (DiNardi et al. 2019).

a review). A contribution of our paper is that we estimate a demand system for hospitals where we allow broadband access to change patient responsiveness to hospital quality. This allows us to examine counterfactual outcomes in the absence of broadband expansion.

The remainder of the paper proceeds as follows: Section 3 describes the FCC and Medicare data. Section 4 describes our empirical methods. Section 5 presents results from our estimation strategy and robustness tests. Section 6 describes our structural model of patient demand and discusses the results of our counterfactual simulations in a world without broadband expansion. Section 7 discusses the implications and limitations of our results, and suggests directions for future research.

3 Data and Summary Statistics

Our high-speed internet data comes from the Federal Communications Commission (FCC) form 477. To measure broadband penetration, we use the FCC's number of broadband providers available per ZIP Code from 1999 to 2008. We focus on that time period for two reasons. One, it was the period in which broadband access increased the fastest in the United States. Two, the FCC did not collect broadband data prior to 1999 and the FCC changed its data collection methods after 2008.[6] Broadband providers are counted in the data if they provide broadband service, at 200 kbps download speed or faster, to at least one residential customer in the ZIP Code-year. Given that all residents in a ZIP do not necessarily have access to all of the broadband providers identified by the FCC in the ZIP Code, the results should be interpreted carefully. We also address this issue by using an instrumental variables method in our robustness section.

Over the sample period, there was a large increase in broadband access for Medicare enrollees. The average Medicare enrollee gained access to 10 broadband providers in their ZIP Code from 1999 to 2008. Panel A in Figure 1 shows that the fraction of the Medicare population with four or more broadband providers in their ZIP Code increased from about 20% in 1999 to nearly 100% in 2008. We also use data from the Medicare Current Beneficiary Survey (MCBS) to examine internet usage among the Medicare population. Panel B in

[6]The FCC began collecting data at the Census tract level in 2009. The FCC will not release the broadband provider identifiers (even after a FOIA request), so we can not map the number of broadband providers available by Census tract to the number available by ZIP Code to create a longer panel of FCC data. However, in robustness tests, we use a data set produced by Julia Tanberk at Broadband Now, which contains the number of broadband providers by ZIP Code in 2015 and 2020 (`https://github.com/BroadbandNow/Open-Data`). We then linearly interpolate the number of broadband providers available per ZIP Code from 2008 to 2015 to fill in the intervening years. In our Appendix, we show results utilizing this longer panel of data.

Figure 1 shows that internet usage among Medicare beneficiaries increased by 40 percentage points from 1999 to 2008. The increase was nearly linear over the period.

Figure 2 shows changes in the weighted average number of broadband providers per ZIP Code from 1999 to 2008 across hospital referral regions (HRRs). Every HRR experienced an increase in the number of broadband providers from 1999 to 2008, but some HRRs experienced greater increases than others. For example, HRRs near South Florida, Denver, Washington D.C., and NYC had the most significant growth in the number of broadband providers.

Using the MCBS sample, we examine how the entry of broadband providers affected internet use among the Medicare population. Table 1 presents these first stage results. The MCBS sample is smaller than our primary sample, but we still find a significant relationship between broadband provider availability and internet use. We also find a significant relationship between broadband availability and whether the individual has a computer or whether the individual uses the Medicare website. For example, Medicare beneficiaries living in ZIP Codes with broadband internet access are 9% ($\frac{-0.0365}{0.402}$) more likely to use a computer, 9% ($\frac{-0.036}{0.384}$) more likely to use the internet, and 18% ($\frac{-0.0149}{0.083}$) more likely to use the Medicare website compared to beneficiaries without broadband internet in their ZIP Code.

Our health care data comes from the Center for Medicare and Medicaid Services (CMS). We obtained a data use agreement to use Medicare claims from 1996 to 2014, including 100% samples of MedPar, inpatient, and MBSF files, and 20% samples of Carrier claims. We focus on Traditional Medicare patients who are hospitalized for elective hip or knee replacements, hospitalized for emergency heart attacks or ischemic strokes (AMI/ST sample), or who have outpatient claims for colonoscopies. We focus on elective hospitalizations for joint replacement because (1) they are some of the most commonly reimbursed claims for Medicare enrollees and we observe the universe of procedures, (2) they are planned medical events, (3) they must occur in hospital settings, and (4) the health outcomes are well-defined.[7] We focus on colonoscopies for similar reasons, however, unlike joint replacements, colonoscopies are performed in outpatient settings. We use the AMI and stroke sample as a "placebo" group for our analysis, given that patients are less likely to make active choices when faced

[7]For example, the 2014 Medicare bundled payments programs incentivize hospitals to reduce readmission rates for joint replacement patients. We examine joint replacement patient choices and outcomes prior to the Medicare bundled payments programs. This is important because the bundled payments program has affected patient outcomes (Finkelstein et al. 2018; Smith 2021), so we view our results as showcasing the role of "low-cost" information on health outcomes in the absence of payment reform.

with an emergency health event.[8] Our health outcomes include 30-day all-cause readmission and 30-day all-cause mortality. The top panel of Figure 3 shows that the risk-adjusted joint replacement readmission rate decreased from about 6% in 1999 to 5% in 2008. Mortality rates remained flat, but mortality is a very rare event following an elective joint replacement procedure (<0.8% of the sample dies within 30 days). We risk-adjust these outcomes using patient procedure (hip or knee replacement) interacted with patient age (5-year bins), sex, race, disability status, chronic conditions, and the percent of Medicare beneficiaries enrolled in Medicare Advantage in the ZIP Code-year. Then we smooth the rates by taking 3-year equally-weighted moving averages.

The next two panels of Figure 3 show outcomes also improved for AMI, stroke, and colonoscopy. Mortality rates for AMI and stroke decreased from about 16% in 1999 to 14% in 2008. 30-day readmission rates decreased from 15.5% in 1999 to less than 14% in 2008. Mortality rates for colonoscopy are very low, but still decline over the time period. Hospitalization rates following outpatient colonoscopy start around 7% in 1999 and decline to 5% in 2008. Therefore, health outcomes for AMI, stroke, and colonoscopies improved through the 2000s, similar to the improvements we noted for joint replacement patients.

Though health outcomes improved through the early 2000s for all conditions that we study, it is unclear whether broadband availability was responsible for those improvements. To descriptively examine broadband's role in improving patient health outcomes, we examine how health outcomes changed over time for patients living in ZIP Codes without broadband access in 1999 (0 broadband providers) compared to patients living in ZIP Codes with some broadband access in 1999 (one or more broadband providers). If broadband access improves health outcomes, then we might expect to see convergence in health outcomes between ZIP Codes that start the period with no broadband access, but gain it by 2008, compared to ZIP Codes that started the period with some broadband access. Figure 4 shows these results graphically for each condition. We add 30-day readmission rates to 30-day mortality rates for each condition to create a composite "poor" health outcome. Figure 4 shows that joint replacement patients living in ZIP Codes without broadband access start the time period with worse health outcomes, but end the time period with the same or slightly better health outcomes compared to those living in ZIP Codes that had broadband access in 1999. Similarly, colonoscopy patients living in ZIP Codes without broadband access start the time period with worse health outcomes, but end the time period with the same health outcomes

[8] We specified these patient cohorts in a pilot grant and in our DUA application.

as patients living in ZIP Codes with broadband access in 1999. These results suggest that the roll-out of broadband internet in ZIP Codes that initially lacked broadband may have differentially improved joint replacement outcomes in these areas. However, we see less evidence of convergence for AMI and stroke patients, suggesting that general technological improvements may be more important for these procedures.

To inform our empirical strategy, we consider how patient characteristics differ across ZIP Codes with and without broadband access in 1999. Table 2 presents these summary statistics from the FCC and Medicare data. We divide the sample of ZIP Codes into three groups – ZIP Codes with zero broadband providers in 1999 ($N = 13,509$), ZIP Codes with 1-3 broadband providers in 1999 ($N = 14,807$), and ZIP Codes with 4 or more broadband providers in 1999 ($N = 3,023$).[9] An important source of variation during our sample period comes from ZIP Codes that switch from zero to 1-3 providers, and from 1-3 providers to 4 or more providers. Therefore, we examine how ZIP Codes with no internet, some internet (1-3), and a lot of internet providers (4+) differed in the "pre-period" from 1996 to 1999. We weight the means in Table 2 by the average number of Medicare enrollees in the ZIP Code from 1996 to 1999 to make them comparable to the means calculated in Figures 1-4.

There are meaningful differences across ZIP Codes with broadband internet access in 1999 compared to those without, starting with the fact that ZIP Codes with early broadband have more Medicare enrollees. ZIP Codes with early broadband also have more Medicare beneficiaries enrolled in Medicare Advantage from 1996 to 1999. We find that Traditional Medicare enrollees in ZIP Codes with early broadband access have fewer chronic conditions on average, despite the fact that they are older, on average. Part of this is explained by the lower disability incidence in ZIP Codes with broadband internet in 1999. Enrollees in ZIP Codes with broadband in 1999 are also more likely to be female and less likely to be white. Given these differences, we control for patient age, sex, race, disability status, and chronic conditions in all of our models. We also control for time-varying differences across ZIP Codes in their Medicare populations (e.g., total enrollment, % enrolled in Medicare Advantage, average annual spending per enrollee).

[9]The FCC data does not differentiate between ZIP Codes with one, two, or three providers because it does not want to reveal the identities of providers.

4 Methods

Our paper aims to show how high-speed internet access affects patient demand for hospitals and the quality-of-care that hospitals deliver. Our empirical approach proceeds in three steps. First, we estimate difference-in-difference models relating the number of broadband providers in patients' residential ZIP Codes to their 30-day readmission and mortality probabilities. Second, we calculate risk-adjusted hospital quality based on each hospital's lagged 30-day readmission and mortality rates. We re-estimate our difference-in-difference models where the outcome variable is the lagged hospital quality of each patient's chosen hospital. These results show how patient broadband access affects patient demand for hospitals. Third, we examine the effect of *hospital* broadband access on patient health outcomes, after controlling for patient broadband access and the patient's choice of hospital. These specifications allow us to condition on patients' choices to investigate whether health outcomes improved when hospitals gained broadband access. We also discuss potential identification concerns and robustness exercises, including concerns about bias in staggered difference-in-difference models. In Section 6 we use the difference-in-difference estimates in combination with a simple structural model of demand to examine counterfactual health outcomes in the absence of broadband expansion.

4.1 Difference-in-Difference Model

The goal of our estimation strategy is to examine how outcomes change for patients living in ZIP Codes that start with little to no broadband access in 1999 and switch to having significant broadband access by 2008. We start by focusing on the overall effect on health outcomes, which may be due to either changes in demand or supply. Our "control" groups in this analysis include patients living in ZIP Codes that do not experience significant changes in broadband access (e.g., the "never" treated, the "always" treated, the "not yet" treated, and the "already" treated). To that end, we estimate the following linear probability model:

$$\begin{aligned} P(Y_{izht} = 1) &= \alpha + \beta_1 Broadband1to3_{zt} + \beta_2 Broadband4up_{zt} + \delta_z + \tau_{ht} \\ &+ \sum_{r=1}^{r=7} \rho_r \times age_{r,izht} + \Theta \boldsymbol{C_{izht}} + \Psi \boldsymbol{X_{zht}} + \epsilon_{izht} \end{aligned} \qquad (1)$$

where $Pr(Y_{izht} = 1)$ is the probability that patient i living in ZIP Code z in hospital referral region (HRR) h in year $t \in [1999, 2008]$ was readmitted to any hospital or died within 30-days of their joint replacement admission date. We estimate the model separately for three different samples—the joint replacement cohort, the AMI and stroke cohort, and the colonoscopy cohort. We assign ZIP Codes to three binary categories that can change categories over time: $Broadband0_{zt} = 1$ when ZIP Codes have no broadband internet in year t (omitted category), $Broadband1to3_{zt} = 1$ when ZIP Codes have 1–3 broadband internet providers in year t, and $Broadband4up_{zt} = 1$ when ZIP Codes have 4 or more broadband internet providers in year t. β_1 captures the difference in the readmission probability across patients living in ZIP Code-years with some broadband access compared to patients living in ZIP Code-years without broadband access. In this specification, the estimated change in patient outcomes may be due to patients choosing higher-quality hospitals or due to hospitals improving their quality, holding patient choices fixed.

The model includes ZIP Code fixed effects, δ_z, which control for time-invariant factors that may be correlated with broadband access and health outcomes. The model also includes HRR-year fixed effects, τ_{ht}, which control for time-varying factors at the HRR-level that may be correlated with changes in health outcomes at the HRR-level over time (e.g., hospital market power). Therefore, our model is identified from within-HRR-year variation in broadband access across ZIP Codes. Our model also includes a large number of time-varying controls to account for time-varying differences in Medicare enrollee characteristics across ZIP Codes; for example, $\boldsymbol{X_{zht}}$ includes the natural log of the total number of Medicare beneficiaries in the ZIP Code (including Medicare Advantage enrollees), the percentage of total Medicare beneficiaries in the ZIP Code enrolled in Medicare Advantage, and the natural log of Traditional Medicare spending per beneficiary in the ZIP Code. We also control for patient-level characteristics. We flexibly control for patient age in five-year bins, starting with ages 65-69 years and ending with ages older than 90. We control for the patient's sex (female), race (white, black, other), disability status (yes or no), and 27 chronic condition indicators for conditions such as anemia and hyperlipidemia ($\boldsymbol{C_{izht}}$). Finally, we cluster our standard errors at the HRR× year-level.

4.2 Measuring Hospital Quality

Next we explore the relationship between broadband access and the quality of hospitals that patients choose. The outcome of interest is the lagged risk-adjusted, moving average of health outcomes, measured at the hospital-year-level. This provides insight into whether broadband access affects patient demand for quality.

To construct risk-adjusted hospital quality, we estimate models where health outcomes are a function of patient characteristics interacted with the type of acute care they receive (hip or knee replacement) and hospital ID×year fixed effects.

For example, we estimate the following linear probability model for hip and knee replacements, pooling data from 1996 to 2014:

$$P(Y_{iht} = 1) \quad = \quad \alpha + \Phi \boldsymbol{K}_{iht} + \Omega \boldsymbol{H}_{iht} + \gamma_{ht} + u_{iht} \tag{2}$$

where $P(Y_{iht} = 1)$ is the probability that patient i who receives care at hospital h in year t was readmitted to any hospital within 30 days of their joint replacement discharge date. The matrix K_{iht} includes interactions between patient characteristics (age, sex, race, disability, chronic conditions, % Medicare Advantage in ZIP Code) and an indicator for receiving a knee replacement. The matrix H_{iht} contains the same set of interactions, but for patients receiving hip replacements.

The hospital-year fixed effects in this model (γ_{ht}) give us risk-adjusted hospital quality that varies each year. Then we construct lagged 3-year moving averages of quality for each hospital. For example, hospital h's quality in 2008 is an equal weighted average of its quality in 2005, 2006, and 2007. Then we use lagged hospital quality as the outcome variable in the difference-in-difference model described in Section 4.1. The goal is to determine whether patients received care from higher quality hospitals as broadband access expanded in their ZIP Codes.

4.3 Patient Broadband Access vs. Hospital Broadband Access

Finally, we examine whether broadband access in the hospital's ZIP Code plays a role in improving patient health outcomes. We re-estimate model (1), but we add an indicator for four or more broadband providers in the hospital's ZIP Code and we include hospital fixed effects.[10] The goal is to determine whether broadband access in the patient's or the hospital's ZIP Code is significant once we shut down the channel of patient choice of facility. A significant, negative coefficient on broadband access in the hospital's ZIP Code would suggest that providers use the internet to improve quality. A significant, negative coefficient on broadband access in the patient's ZIP Code would suggest that patients use the internet

[10] We only compare hospitals located in ZIP Codes with a lot of broadband providers (4+) to those located in ZIP Codes with 0–3 broadband providers because it is extremely rare for providers to be located in ZIP Codes without any broadband access during the time period.

to improve their health in a way other than choosing higher quality hospitals (e.g., choosing higher quality surgeons within a hospital).

4.4 Identification Concerns and Robustness

A key assumption of the difference-in-difference approach is that trends in health outcomes across ZIP Codes that gain broadband providers at different points in time would be the same in the absence of broadband expansion. The primary concern is that unobservable selection of patients may cause the parallel trends assumption to fail. While it is common to examine parallel trends prior to treatment to provide evidence in support of this assumption, we lack data in the pre-period for most ZIP Codes. Therefore, we take two approaches to addressing this concern. First, we test whether the timing of broadband roll-out is correlated with the rates or composition of medical procedures (joint replacement, colonoscopy, AMI/stroke) at the ZIP-Code level. Second, we test the robustness of our results in a subsample of patients who receive multiple total joint replacements or colonoscopies over time and we include patient fixed effects. Therefore, we compare readmission probabilities for a given patient when the patient's access to broadband changes over time. We discuss these results in Section 5.4.

A related issue is that the staggered nature of broadband expansion can generate biased estimates in difference-in-difference (DiD) models with two-way fixed effects. To address these issues, we test the robustness of our results to the approach from Callaway and Sant'Anna (2021). By identifying appropriate comparison units for each treated ZIP Code, this approach addresses issues caused by the presence of heterogeneous treatment effects. These results are also presented in Section 5.4.

5 Results

We now present results from our models that utilize variation in the number of broadband providers available in ZIP Codes over time. In Section 3, we showed that readmission rates decreased for patients receiving elective total joint replacements from 1999 to 2008. In this section, we show that health outcomes improved relatively faster in patient ZIP Codes where broadband access expanded, and that patients were more likely to choose higher quality hospitals as broadband access expanded in their ZIP Codes.

5.1 Patient Broadband Access and Health Outcomes

Table 3 shows how joint replacement patients in ZIP Codes that gained broadband providers fared in terms of 30-day readmission probability, 30-day mortality probability, or either outcome. Column (1) shows the probability of a 30-day readmission is 0.0033 lower for a joint replacement patient living in a ZIP Code with 4+ broadband providers compared to a patient living in a ZIP Code with no broadband access. The mean probability of readmission is 0.058, so the likelihood of being readmitted decreases by 5.7% ($\frac{0.0033}{0.058} = 0.057 \times 100\%$), moving from a ZIP Code with no broadband access to a ZIP Code with four or more providers. Column (2) shows that broadband expansion has no significant effect on the probability of 30-day mortality. This is consistent with the fact that mortality is relatively uncommon after elective joint replacement procedures. Column (3) combines the results from columns (1) and (2) to show that the number of broadband providers in a patient's ZIP Code is negatively correlated with the probability that the patient suffers a poor health outcome, defined as a 30-day readmission or 30-day mortality following the procedure.

Next, we examine whether changes in health outcomes are due in part to changes in patient demand for quality. Column (4) of Table 3 shows that patients choose higher quality hospitals for their joint replacement procedures after their ZIP Codes gain broadband internet access. The outcome in column (4) is the risk-adjusted, 3-year lagged moving average of each hospital's readmission plus mortality rate. In other words, each patient in our sample receives their chosen hospital's historical readmission plus mortality rate as their outcome in column (4). The results show that patients living in ZIP Codes with 4+ broadband providers choose hospitals with 0.0013 lower readmission plus mortality rates compared to patients living in ZIP Codes without broadband internet. Patients living in ZIP Codes with 1–3 broadband providers also choose hospitals with lower readmission plus mortality rates. Both results are statistically significant.

5.2 Hospital Broadband Access and Health Outcomes

Column (5) of Table 3 shows the effects of patient broadband access versus hospital broadband access, after conditioning on the patient's choice of hospital for their elective joint replacement procedure. The estimates show that the relationship between patient broadband access and the probability of having a poor health outcome (readmission or mortality) are still negative (relative to no broadband access), but now lack statistical significance. Therefore, our results suggest that broadband access in the patient's ZIP Code primarily affects patient health outcomes by making patient demand more responsive to quality. Turning to the effect of broadband access in the hospital ZIP Code, we compare patient outcomes in hospitals in ZIP Codes with 4+ broadband providers to outcomes in hospitals in ZIP Codes with fewer than 4 broadband providers. The goal of this specification is to determine whether broadband access at the hospital-level affects patient outcomes, after controlling for the patient's broadband access and their choice of hospital. We find that broadband access in the hospital's ZIP Code reduces the probability that patients at the hospital experience negative health outcomes, but the result lacks statistical significance.

5.3 Hospital Market Power and the Effects of Patient Broadband Access

Given the notable consolidation in hospital markets since the 1990s (Gaynor et al. 2015), we examine the heterogeneous effects of patient broadband access in markets with more versus less hospital competition. There is evidence that less competitive hospital markets may deliver lower quality-of-care for Medicare patients (e.g. Kessler and McClellan 2000), so online information may be particularly important for patients in less competitive markets. We examine the effect of broadband access separately by hospital competition, where competition is defined by the hospital referral regions's (HRR) Herfindahl-Hirschmann Index (HHI) for joint replacement procedures in 1999 (i.e., first year of the sample).

Table 4 shows that broadband access primarily affects readmission rates in HRRs with below-average hospital competition. The results show that patients living in ZIP Codes with 1–3 broadband providers choose hospitals with 0.0034 lower readmission rates compared to patients living in ZIP Codes without broadband internet. Patients living in ZIP Codes with 4+ broadband providers choose hospitals with 0.0038 lower readmission rates. Both of these results are statistically significant. The estimates for patients living in HRRs with more hospital competition are small and insignificant. Our results in this section are consistent with the idea that online information is particularly valuable when hospital markets are concentrated. This result is also consistent with other settings in which health information has a larger effect in concentrated markets (Brown 2019a).

5.4 Robustness

In this section, we show the robustness of our results to different identification strategies and to different time periods.

First, we consider the critiques to difference-in-difference designs with two-way fixed effects and staggered treatment timing (Goodman-Bacon 2021). In our context, broadband access expands over time. ZIP Codes gain broadband providers at different rates, but ultimately 92% of ZIP Codes (99.4% of patients) have some broadband access by the end of 2008. Therefore, we test the robustness of our estimates to the approach described in Callaway and Sant'Anna (2021). To do so, we collapse our data to the ZIP Code-year-level and define a binary treatment outcome that equals 1 when the ZIP Code-year has >0 broadband providers and equals 0 when the ZIP Code-year has 0 broadband providers. Then we estimate difference-in-difference models using the untreated groups as the controls, i.e., ZIP Codes that do not yet have broadband internet access.

Overall, the results using the Callaway and Sant'Anna (2021) approach are similar to our baseline results. Table 5 shows that broadband access results in lower readmission probabilities (column 1). Patients are also more less likely to choose hospitals with high readmission rates for joint replacement patients (column 2). These results are significant at the 5% level. There is no relationship between patient broadband access and the probability the patient dies within 30-day of their procedure (column 3), similar to our results in Table 3. There is, however, a negative relationship between the patient's broadband access and choosing a hospital where more joint replacement patients die following their procedures (column 4). Column (5) combines the readmission and mortality probabilities, and shows that patients with broadband access are less likely to suffer these poor health outcomes. Column (6) combines the hospital's readmission and mortality rates, and shows that patients are less likely to choose hospitals where joint replacement patients suffer poor health outcomes.

A second concern is potential measurement error in our measure of broadband access. In our main results, we used the number of broadband providers in a patient's ZIP Code to proxy for their access to broadband internet. However, broadband providers are not required to service all households within a ZIP Code. Therefore, our broadband measurements may be overstating true broadband availability at the patient-level. To address this issue, we instrument for the number of broadband providers available in the patient's ZIP Code using the average number of broadband providers in the neighboring five closest ZIP Codes. Column (1) in Table 6 shows that as the average number of broadband providers in neighboring

ZIP Codes increases by 1, the number of broadband providers in the focal ZIP Code increases by 0.64. This first stage result is very statistically significant. Next we estimate instrumental variable models using the average number of broadband providers in neighboring ZIP Codes as the instrument for the number of broadband providers in patient's ZIP Code. To model diminishing marginal returns to broadband access, we instrument for the square of the number of broadband providers in the patient's ZIP Code using the squared average number of providers in the neighboring five ZIP Codes. The even columns of Table 6 show the OLS results and the odd columns of Table 6 show the IV results. We consistently find that as the number of broadband providers increases in the patient ZIP Code, the readmission probability decreases at an decreasing rate. The IV results are larger in magnitude than the OLS results, suggesting that measurement error in the number of broadband providers available in the patient ZIP Code biases our estimates toward zero. As in our previous results, we find that patients increasingly avoid lower quality hospitals as the number of broadband providers increases in their ZIP Code. The result holds in both our OLS and IV models, and is statistically significant.

Third, we consider whether our main results—which show that broadband access improves patient outcomes—could be driven by changes in the patient sample over time. In particular, we test whether the timing of broadband roll-out is correlated with rates of total joint replacement in the Medicare population or characteristics of the individuals receiving joint replacements. Table 7 examines these hypotheses.[11] First we show there is no relationship between broadband access and the number of joint replacements per 100 Medicare beneficiaries at the ZIP Code level. Second, we show there is no relationship between broadband access and the average age of patients undergoing joint replacements in the ZIP Code. We further show there is no relationship between broadband access and rates of colonoscopy or AMI/stroke per 100 Medicare beneficiaries at the ZIP Code-level, nor is there a relationship between broadband access and the average ages of patients in those samples. Therefore, it seems unlikely that our main results are driven by changes in the composition of the patient samples over time. However, we explore this concern in more detail with a patient fixed effects model described below.

While our main sample covers 1999 to 2008, it is useful to extend the panel to 2014.

[11]Unlike most results in this paper, these models were estimated at the ZIP Code-year level where a ZIP Code-year is included in the sample if at least one Medicare enrollee resides there. Our control variables in this model are similar to those in our main specification (i.e., HRR-year fixed effects, ZIP Code fixed effects, time-varying ZIP Code-level characteristics of the Medicare population).

The FCC's broadband data, measured at the ZIP Code-level, ends in 2008, but we employ a similar data set measuring the number of broadband providers at the ZIP Code-level in 2015. We connect the data sets by linearly interpolating the number of broadband providers per ZIP Code between 2008 and 2015 to fill in the missing values of broadband providers in the panel. Then we convert the number of broadband providers into three categories as before: ZIP Codes with 0 broadband providers, ZIP Codes with 1–3 broadband providers, and ZIP Codes with 4+ broadband providers. Figure 1 shows that approximately 95% of Medicare beneficiaries lived in ZIP Codes with 4 or more broadband providers by 2008; therefore, most ZIP Codes transitioned across these categories prior to 2008. By constructing the longer panel, we are primarily extending the time period in which we measure the long-run treatment effects of broadband access. Therefore, these new estimates may better capture the long-term benefits of high-speed internet as more people use it and network effects are realized.

Results for the relationship between patient broadband access and joint replacement health outcomes using the longer panel are shown in Table A-1. Here we find even stronger evidence that health outcomes improve as patients gain access to broadband internet, and that patients choose higher quality hospitals.

The longer panel also allows us to focus on the sub-sample of patients who receive multiple procedures and estimate a model that includes patient fixed effects. This addresses concerns that our previous estimates could have been biased if broadband expansion is correlated with time-varying unobservable characteristics of Medicare beneficiaries at the ZIP Code level. For instance, broadband internet could cause migration into or out of a ZIP Code, affecting the composition of patients seeking elective joint replacements.

A typical procedure for an elective total joint replacement replaces one joint at a time, so a patient could be hospitalized for up to four elective joint replacement procedures in their lifetime (assuming none of the procedures has to be redone). We find that 38% of joint replacement patients in our sample receive more than one elective joint replacement procedure from 1999 to 2014.[12] Given low mortality rates following joint replacement procedures, we focus on how 30-day readmission rates change within patients over procedures as they gain broadband access.

Table A-2 shows the results from these specifications with patient fixed effects.[13] The

[12]Here we do not restrict to Medicare beneficiaries ages 65 and older; we keep disabled beneficiaries who are younger in an effort to increase the sample size. However, we flexibly control for patient age.

[13]Our specification replaces ZIP Code fixed effects with patient fixed effects. We still control for HRR×Year

probability of readmission decreases by 0.0107 as patients switch from having no broadband access to 4+ broadband providers in their ZIP Codes. The mean readmission rate is lower for this sub-sample of patients than in the full sample (0.045), so the percent change in the readmission probability is even larger than before (23.7%=$\frac{0.0107}{0.045} \times 100\%$). As in our previous results, we also find that patients are less likely to choose low quality hospitals as they gain broadband access. Here our results are very close to what we estimate for the full sample from 1999 to 2014 (Table A-1).

5.5 Additional Results: Scheduled Colonoscopy, Emergency AMI and Stroke

We now examine the effects of patient broadband access on health outcomes for other conditions: 30-day hospitalizations and mortality following routine colonoscopies and 30-day readmission and mortality following emergency heart attacks (AMI) and strokes. Routine colonoscopies are very common procedures in the Medicare population. They take place in outpatient settings. Though rare, complications can occur with colonoscopies resulting in hospitalization, and even rarer, death.

Given the elective and scheduled nature of colonoscopies, we expect the relationship between patient broadband access and health outcomes following colonoscopies to mirror the results we found for elective joint replacement patients. Indeed, Table 8 shows that patients living in ZIP Codes with 4+ broadband providers have 6.4% ($= \frac{0.0037}{0.058} \times 100\%$) lower 30-day hospitalization probabilities than patients living in ZIP Codes without broadband access (column 1). There's no statistically significant relationship between patient broadband access and 30-day mortality following colonoscopy (column 2), which likely reflects the fact that it is such a rare event. Nevertheless, the overall results show that patients with broadband access are less likely to experience a poor health outcome following colonoscopy (column 3), and they are less likely to receive colonoscopies from physician groups that have more patients experiencing poor health outcomes (column 4). As in our results for joint replacements, there is no statistically significant effect of patient broadband access or provider broadband access on patient health outcomes following colonoscopy once we condition on the physician group that the patient chose for the procedure, implying that the results are largely driven by the demand-side.

The last two columns of Appendix Table A-2 show how broadband access affects colonoscopy

fixed effects, time-varying characteristics of Medicare enrollees in the patient's ZIP Code, and the patient's time-varying characteristics (e.g., age, disability status, and chronic conditions).

outcomes within patients over time. These models use patient fixed effects and take advantage of the fact that patients are recommended to receive colonoscopies at least once every 10 years. The probability of hospitalization following colonoscopy decreases by 0.0079 as patients switch from having no broadband access to 4+ broadband providers in their ZIP Codes. The mean hospitalization rate is lower for this sub-sample of patients than in the full sample (0.054), so the percent change in readmission probability is larger than in Table 8 (14.6%=$\frac{0.0079}{0.054} \times 100\%$). As in our previous results, we find that patients are less likely to choose low quality physician groups as they gain broadband access.

Next we consider the effects of patient and provider broadband access on patient health outcomes following emergency hospitalizations for AMI (heart attacks) or ischemic stroke. In contrast to elective joint replacements and colonoscopies, emergency AMIs and strokes are two conditions that require prompt medical care. Here we expect the relationship between patient broadband access and health outcomes to differ. AMI and stroke patients do not necessarily have time to consider their hospital choice. In many instances, ambulances choose hospitals for patients with these conditions (Doyle Jr et al. 2015). Therefore, we expect patient access to broadband to play a smaller role in explaining changes in 30-day readmission and mortality probabilities for these patients.

Our results for AMI and stroke patients appear in Table 9. As the number of broadband providers increases in patient ZIP Codes, there is no change in the patients' 30-day readmission or 30-day mortality probability (columns 1 & 2). AMI/stroke patients living in ZIP Codes with 4+ broadband providers are slightly less likely to go to hospitals with poor patient outcomes for AMI/stroke (0.37%=$\frac{0.0011}{0.296} \times 100\%$) compared to patients living in ZIP Codes without broadband access, but the result is not economically significant, and it is only marginally statistically significant.

Unlike our results for joint replacement and colonoscopy patients, our results for AMI and stroke patients show that broadband access in the hospital's ZIP Code affects patients' health outcomes. Column (5) of Table 9 shows that when AMI/stroke patients go to hospitals in ZIP Codes with 4+ broadband providers (compared to hospitals with fewer than 4 broadband providers), their probability of experiencing a poor outcome (30-day readmission or mortality) decreases by 1% (= $\frac{0.0032}{0.297} \times 100\%$). Though the effect is small, it is statistically significant. These results suggest that broadband access affected provider practice styles for treating AMI/stroke patients.

6 Patient Demand and Counterfactual Simulations

Our difference-in-difference analysis shows evidence that broadband expansion preimarily affected patient demand for hospitals. However, results also suggest some supply-side changes that affected the provision of quality. We now ask how much of the improvement in joint replacement outcomes in Figure 3 is due to the expansion of broadband.

To examine counterfactual health outcomes, we start by estimating a simple demand model that that allows access to broadband internet to affect patient sensitivity to quality. The model accounts for both changes in the set of hospitals available to patients over time and changes in the demographics of patients in each location. The estimation of the demand model leverages similar variation in broadband access as the difference-in-difference analysis. We then combine the demand model estimates with difference-in-difference estimates on the supply-side to decompose broadband's total effect on health outcomes into the share due to changes in patients' hospital choices versus the share due to changes in hospital quality.

6.1 Demand Model

When choosing a hospital, patients trade off distance, perceived clinical quality, and unobserved non-clinical quality or amenities. Patients that require a procedure choose one hospital in their HRR or the outside option, a hospital outside their HRR. Indirect utility of hospital h for individual i in year t and market m is given by

$$\mathbb{E}[u_{ihmt}] = \underbrace{\beta\mathbb{E}[q_{ht}] + \alpha d_{ih}\boldsymbol{X_{mt}} + \xi_h + \theta_m}_{\delta_{ijmt}} + \epsilon_{ihmt} \tag{3}$$

where d_{ij} is distance from individual i to hospital h which is interacted with patient demographics, $\boldsymbol{X_{mt}}$. This includes the same patient demographics used in Section 4.1, namely chronic conditions, age categories, race, disability status, procedure type, and ZIP code characteristics. Hospital quality q_{ht} is measured by the risk-adjusted rate of readmission or mortality as described in Section 4.2. Other unobserved hospital quality (e.g., amenities) is captured by hospital fixed effects, ξ_h. Market fixed effects, θ_m, allow the value of the outside option to differ across markets. The idiosyncratic preference shock is given by ϵ_{ijmt} which is assumed to follow an EV1 distribution. Finally, the representative utility of the outside option is normalized to zero.

We assume that individuals believe quality to be the weighted average of true risk-adjusted outcomes and average outcomes across all hospitals, $\bar{q}_t$. The weight, $w_{mt}(b_{mt})$, is determined by access to the internet, b_{mt}. In particular

$$\mathbb{E}[q_{ht}] = (1 - w_{mt}(b_{mt}))\bar{q}_t + w_{mt}(b_{mt})q_{ht}. \tag{4}$$

Noting that $\bar{q}_t$ is the same for all options in the choice set, representative utility can simply be expressed as

$$\delta_{ihmt} = \beta q_{ht} b_{mt} + \alpha d_{ih} \boldsymbol{X_{mt}} + \xi_h + \theta_m \tag{5}$$

We parameterize b_{mt} in the same way as in Section 4.1 by constructing indicators for no broadband access, 1 to 3 broadband providers, and more than 4 broadband providers. The coefficients on the interactions between health outcomes and broadband categories, β, are the key parameters that capture how individuals respond to risk-adjusted hospital outcomes. To the extent that individuals are less likely to choose a hospital with poor health outcomes when they have access to the internet, we expect β to be negative when broadband access is high. To the extent that individuals respond to quality regardless of internet access, this will be captured by hospital fixed effects ξ_h.

Let $\hat{s}_{hmt}$ denote observed shares of hospital h in market m in year t. Applying the standard inversion from Berry (1994), this implies

$$\log \hat{s}_{mt} - \log \hat{s}_0 = \beta q_{ht} b_{mt} + \alpha d_{ih} \boldsymbol{X_{mt}} + \xi_h + \theta_m \tag{6}$$

The outside option, $\hat{s}_0$, is defined as the share of individuals not choosing a provider in the choice set. Given that demand is not a function of price, and therefore there is no price endogeneity, Equation 6 can be estimated using OLS. Identification of the broadband effect leverages variation over time due to the roll-out of broadband internet, similar to the difference-in-difference identification in the prior section.

6.2 Demand Estimates and Results

A challenge for estimation is that there are over 40,000 ZIP codes, making it infeasible to define a market as a patient ZIP code-year.[14] We aggregate by defining a market by HRR, broadband provider categories, and procedure (i.e., hip versus knee). We average over dis-

[14] It is well known that small market sizes cause error in shares, leading to significant problems when using the approach of Berry (1994) and Berry et al. (1995). See, for example, Gandhi et al. (2023).

tance from each patient ZIP code to provider. The choice set is defined as all providers that performed the procedure in the HRR in a given year.

Table 10 presents the results for the demand model. As expected, individuals receive disutility from distance on average; however, there is significant heterogeneity. For instance, older patients are somewhat more sensitive to distance and choose closer providers. The key parameters are the coefficients on the interaction between indicators for broadband internet accessibility and risk-adjusted health outcomes. The coefficient is more negative for patients with more broadband providers, implying that broadband internet makes individuals less likely to choose a provider with worse risk-adjusted outcomes. The coefficient for readmission/mortality rate interacted with 1-3 broadband providers is large in magnitude compared to the omitted category, no broadband providers. The coefficient on 4 or more providers is even larger in magnitude. The finding that broadband internet makes individuals more sensitive to provider quality is broadly consistent with the results in Section 5.

We use the estimates to simulate counterfactual outcomes when turning off the demand-side effect of internet and the supply-side effect of internet. In particular, simulated shares when shutting-down the demand-side effect of broadband internet are given by

$$\hat{s}^{d}_{hmt} = \frac{\exp[\beta \hat{q}_{ht} b^{1999}_{mt} + \alpha d_{ih} \boldsymbol{X_{mt}} + \xi_h + \theta_m]}{1 + \sum_k \exp[\beta \hat{q}_{kt} b^{1999}_{mt} + \alpha d_{ik} \boldsymbol{X_{mt}} + \xi_k + \theta_m]} \tag{7}$$

where b^{1999}_{mt} is the number of internet providers in 1999.

Both the demand-side and supply-side effects are simulated by considering shares given by

$$\hat{s}^{sd}_{hmt} = \frac{\exp[\beta \hat{q}^{1999}_{ht} b^{1999}_{mt} + \alpha d_{ih} \boldsymbol{X_{mt}} + \xi_h + \theta_m]}{1 + \sum_k \exp[\beta \hat{q}^{1999}_{kt} b^{1999}_{mt} + \alpha d_{ik} \boldsymbol{X_{mt}} + \xi_k + \theta_m]} \tag{8}$$

where $\hat{q}^{1999}_{ht}$ is the predicted risk-adjusted outcome of hospitals if the number of internet providers is held fixed at 1999 broadband levels. There may have been many productivity changes over the time period even in the absence of broadband expansion; therefore, one cannot assume that provider quality would have remained unchanged over the period without broadband expansion. Rather than model the factors that determine quality, we predict $\hat{q}^{1999}_{ht}$ using the difference-in-difference estimates as in the hospital outcomes reported in Table 3. Broadband levels for both patients and the hospital are fixed at 1999 levels and then Equation 1 is used to predict hospital outcomes.

Given shares, the counterfactual health outcomes in year t is the weighted average over markets using the counterfactual shares. For example, $(\sum_m N_{mt})^{-1} \sum_m \sum_h N_{mt} q_{ht} \hat{s}_{hmt}$ is the weighted average outcome for year t given a counterfactual market share $\hat{s}_{hmt}$ and market size N_{mt}. We focus on the risk-adjusted readmission or mortality rate as the main outcome of interest in counterfactual simulations.

The counterfactual simulations for joint replacement outcomes are summarized in Figure 5. First, the baseline predictions of the model are similar to the actual risk-adjusted readmission or mortality rate shown in the top panel of Figure 3, providing evidence on model fit.

Examining the demand-side effect if broadband internet had not been expanded since 1999 (i.e. holding hospital quality fixed at the baseline level), Figure 5 indicates that risk-adjusted health outcomes would have been slightly higher in the early 2000s. Then the gap grows over time as broadband access expands. Allowing the supply-side to adjust by predicting hospital quality given 1999 broadband levels and re-simulating demand shows a similar effect, indicating that the change in health outcomes is largely driven by the demand-side. At the end of the sample period, the simulations imply that broadband expansion was responsible for 12% of the reduction in the readmission/mortality rate.

7 Discussion

In this paper we show that patients had better health outcomes and visited higher quality providers when they gained access to broadband internet. Our results imply that internet access makes patient demand more elastic with respect to quality. This mechanism is particularly important in hospital markets that are highly concentrated. We also examine supply-side effects and whether hospitals changed their provision of quality. Overall, counterfactual simulations imply that broadband expansion was responsible for 12% of the total reduction in poor health outcomes for joint replacements from 1999 to 2008, largely due to changes in demand.

The results have implications for policy regarding health care competition and broadband access. Previous work has documented that high quality hospitals gain market share over time (Chandra et al. 2016). Our results imply that access to broadband is important for facilitating hospital competition on quality. The results also provide evidence on the magnitude of externalities generated by broadband access in one important setting (health care), suggesting that policies that increase access to high-speed internet may have positive spillover effects on health.

There are some important limitations to our analysis. First, our data is historical, given that the aim of our study is to show how the roll-out of high-speed internet affected patient outcomes. High-speed internet is now ubiquitous in many countries; people have access to it from home, from work, and on mobile devices. Content on the internet, including medical resources, is constantly expanding and today's internet is a bigger place than the internet of 2008. Future research could explore how the modern internet affects patient demand and hospital competition. Second, we have broadband data at the ZIP Code level rather than at the individual level. We cannot say whether the patients in our sample used the internet to search for health-related information or whether providers used the internet as a communication tool. Future work should examine the causal effect of individuals and healthcare providers using the internet, ideally using variation in internet access that addresses concerns about time-varying unobservable characteristics. Finally, we note that there is more scope for understanding what specific information sources can best facilitate competition in health care markets.

References

Abaluck, Jason and Jonathan Gruber, "Choice inconsistencies among the elderly: evidence from plan choice in the Medicare Part D program," *American Economic Review*, 2011, *101* (4), 1180–1210.

Ahlfeldt, Gabriel, Pantelis Koutroumpis, and Tommaso Valletti, "Speed 2.0: Evaluating access to universal digital highways," *Journal of the European Economic Association*, 2017, *15* (3), 586–625.

Aker, Jenny C, "Does digital divide or provide? The impact of cell phones on grain markets in Niger," *Center for Global Development working paper*, 2008, (154).

Amaral-Garcia, Sofia, Mattia Nardotto, Carol Propper, and Tommaso Valletti, "Mums Go Online: Is the Internet Changing the Demand for Health Care?," *Review of Economics and Statistics*, 2022, *104* (6), 1157–1173.

Arrow, Kenneth J, "Uncertainty and the Welfare Economics of Medical Care," *The American economic review*, 1963, *53* (5), 941–973.

Atif, Syed Muhammad, James Endres, and James Macdonald, "Broadband infrastructure and economic growth: A panel data analysis of OECD countries," *Available at SSRN 2166167*, 2012.

Berry, Steven, James Levinsohn, and Ariel Pakes, "Automobile prices in market equilibrium," *Econometrica: Journal of the Econometric Society*, 1995, pp. 841–890.

Berry, Steven T, "Estimating discrete-choice models of product differentiation," *The RAND Journal of Economics*, 1994, pp. 242–262.

Bhuller, Manudeep, Andreas Kostol, and Trond Vigtel, "How Broadband Internet Affects Labor Market Matching," *IZA Working Paper*, 2019.

Billari, Francesco C, Osea Giuntella, and Luca Stella, "Broadband internet, digital temptations, and sleep," *Journal of Economic Behavior & Organization*, 2018, *153*, 58–76.

Brown, Jeffrey R and Austan Goolsbee, "Does the Internet make markets more competitive? Evidence from the life insurance industry," *Journal of political economy*, 2002, *110* (3), 481–507.

Brown, Zach Y., "An Empirical Model of Price Transparency and Markups in Health Care," Working Paper 2019.

Brown, Zach Y, "Equilibrium effects of health care price information," *Review of Economics and Statistics*, 2019, *101* (4), 699–712.

Brown, Zach Y. and Jihye Jeon, "Endogenous Information and Simplifying Insurance Choice," Working Paper 2020.

Bundorf, M Kate, Natalie Chun, Gopi Shah Goda, and Daniel P Kessler, "Do markets respond to quality information? The case of fertility clinics," *Journal of health economics*, 2009, *28* (3), 718–727.

Callaway, Brantly and Pedro HC Sant'Anna, "Difference-in-differences with multiple time periods," *Journal of Econometrics*, 2021, *225* (2), 200–230.

Chan, David C, "Influence and information in team decisions: evidence from medical residency," *American Economic Journal: Economic Policy*, 2021, *13* (1), 106–37.

Chandra, Amitabh, Amy Finkelstein, Adam Sacarny, and Chad Syverson, "Health care exceptionalism? Performance and allocation in the US health care sector," *American Economic Review*, 2016, *106* (8), 2110–44.

_ **and Douglas O Staiger**, "Identifying Sources of Inefficiency in Healthcare," *Quarterly Journal of Economics*, 2020, *135* (2), 785–843.

Chou, Shin-Yi, Mary E Deily, Suhui Li, and Yi Lu, "Competition and the impact of online hospital report cards," *Journal of Health Economics*, 2014, *34*, 42–58.

Cooper, Zack, Joseph Doyle, John Graves, and Jonathan Gruber, "Do higher-priced hospitals deliver higher-quality care?," *NBER Working Paper 29809*, 2022.

__ , Stephen Gibbons, Simon Jones, and Alistair McGuire, "Does hospital competition save lives? Evidence from the English NHS patient choice reforms," *The Economic Journal*, 2011, *121* (554), F228–F260.

Currie, Janet and W Bentley MacLeod, "Diagnosing expertise: Human capital, decision making, and performance among physicians," *Journal of labor economics*, 2017, *35* (1), 1–43.

__ , __ , and Jessica Van Parys, "Provider practice style and patient health outcomes: The case of heart attacks," *Journal of health economics*, 2016, *47*, 64–80.

Czernich, Nina, Oliver Falck, Tobias Kretschmer, and Ludger Woessmann, "Broadband infrastructure and economic growth," *The Economic Journal*, 2011, *121* (552), 505–532.

Dafny, Leemore and David Dranove, "Do report cards tell consumers anything they don't already know? The case of Medicare HMOs," *The Rand journal of economics*, 2008, *39* (3), 790–821.

Dettling, Lisa J, Sarena Goodman, and Jonathan Smith, "Every little bit counts: The impact of high-speed internet on the transition to college," *Review of Economics and Statistics*, 2018, *100* (2), 260–273.

DiNardi, Michael, Melanie Guldi, and David Simon, "Body weight and Internet access: evidence from the rollout of broadband providers," *Journal of Population Economics*, 2019, *32* (3), 877–913.

Doyle, Joseph, John Graves, and Jonathan Gruber, "Evaluating measures of hospital quality: Evidence from ambulance referral patterns," *Review of Economics and Statistics*, 2019, *101* (5), 841–852.

Dranove, David and Andrew Sfekas, "Start spreading the news: a structural estimate of the effects of New York hospital report cards," *Journal of health economics*, 2008, *27* (5), 1201–1207.

Finkelstein, Amy, Yunan Ji, Neale Mahoney, and Jonathan Skinner, "Mandatory Medicare bundled payment program for lower extremity joint replacement and discharge to institutional postacute care: interim analysis of the first year of a 5-year randomized trial," *Jama*, 2018, *320* (9), 892–900.

Gandhi, Amit, Zhentong Lu, and Xiaoxia Shi, "Estimating demand for differentiated products with zeroes in market share data," *Quantitative Economics*, 2023, *14* (2), 381–418.

Gaynor, Martin, Carol Propper, and Stephan Seiler, "Free to choose? Reform, choice, and consideration sets in the English National Health Service," *American Economic Review*, 2016, *106* (11), 3521–3557.

__ , Kate Ho, and Robert J Town, "The industrial organization of health-care markets," *Journal of Economic Literature*, 2015, *53* (2), 235–284.

Goodman-Bacon, Andrew, "Difference-in-differences with variation in treatment timing," *Journal of Econometrics*, 2021, *225* (2), 254–277.

Grimes, Arthur, Cleo Ren, and Philip Stevens, "The need for speed: impacts of internet connectivity on firm productivity," *Journal of Productivity Analysis*, 2012, *37* (2), 187–201.

Gunter, Samara, "Your biggest refund, guaranteed? Internet access, tax filing method, and reported tax liability," *International Tax and Public Finance*, 2019, *26*, 536–570.

Handel, Benjamin R and Jonathan T Kolstad, "Health insurance for humans: Information frictions, plan choice, and consumer welfare," *American Economic Review*, 2015, *105* (8), 2449–2500.

Hjort, Jonas and Jonas Poulsen, "The arrival of fast internet and employment in Africa," *American Economic Review*, 2019, *109* (3), 1032–79.

Jin, Ginger Zhe and Phillip Leslie, "The effect of information on product quality: Evidence from restaurant hygiene grade cards," *The Quarterly Journal of Economics*, 2003, *118* (2), 409–451.

Jr, Joseph J Doyle, John A Graves, Jonathan Gruber, and Samuel A Kleiner, "Measuring returns to hospital care: Evidence from ambulance referral patterns," *Journal of Political Economy*, 2015, *123* (1), 170–214.

Kessler, Daniel P and Mark B McClellan, "Is hospital competition socially wasteful?," *The Quarterly Journal of Economics*, 2000, *115* (2), 577–615.

Kling, Jeffrey R, Sendhil Mullainathan, Eldar Shafir, Lee C Vermeulen, and Marian V Wrobel, "Comparison friction: Experimental evidence from Medicare drug plans," *The Quarterly Journal of Economics*, 2012, *127* (1), 199–235.

Kolko, Jed, "How broadband changes online and offline behaviors," *Information Economics and Policy*, 2010, *22*, 144–152.

—, "Broadband and local growth," *Journal of Urban Economics*, 2012, *71* (1), 100–113.

Kolstad, Jonathan T, "Information and quality when motivation is intrinsic: Evidence from surgeon report cards," *American Economic Review*, 2013, *103* (7), 2875–2910.

Lieber, Ethan MJ, "Does It Pay to Know Prices in Health Care?," *American Economic Journal: Economic Policy*, 2017, *9* (1), 154–179.

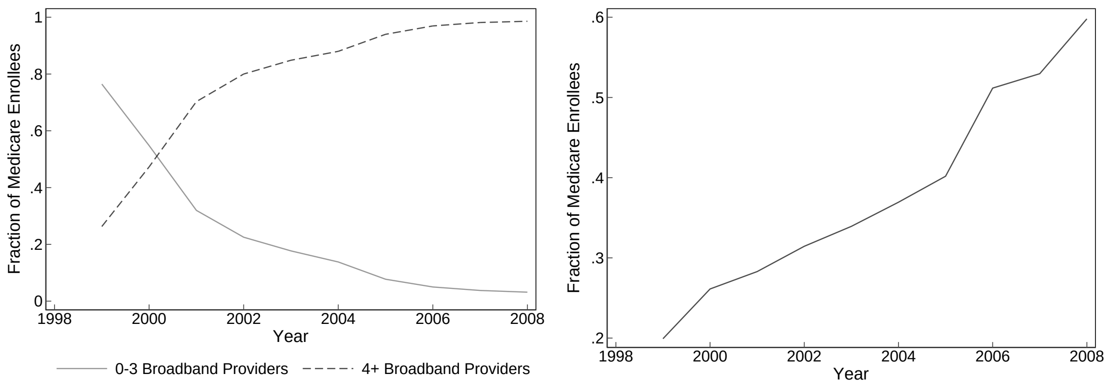
Molnar, Gabor and Scott J Savage, "Market structure and broadband internet quality," *The Journal of Industrial Economics*, 2017, *65* (1), 73–104.

Morton, Fiona Scott, Florian Zettelmeyer, and Jorge Silva-Risso, "Internet car retailing," *The Journal of Industrial Economics*, 2001, *49* (4), 501–519.

Parys, Jessica Van, "Variation in Physician Practice Styles Within and Across Emergency Departments," *PLoS ONE*, 2016, *11* (8), 1–19.

Smith, Brad, "CMS Innovation Center at 10 Years—Progress and Lessons Learned," 2021.

Figure 1
Broadband Internet Availability and Internet Use
in the Medicare Population

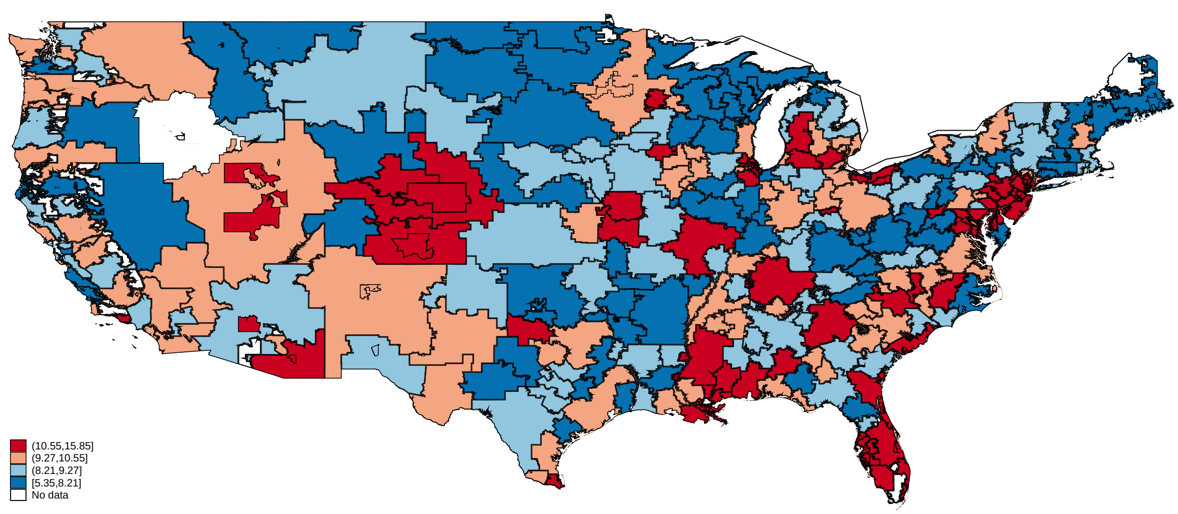


a. Broadband Availability

b. Internet Use by Medicare Population

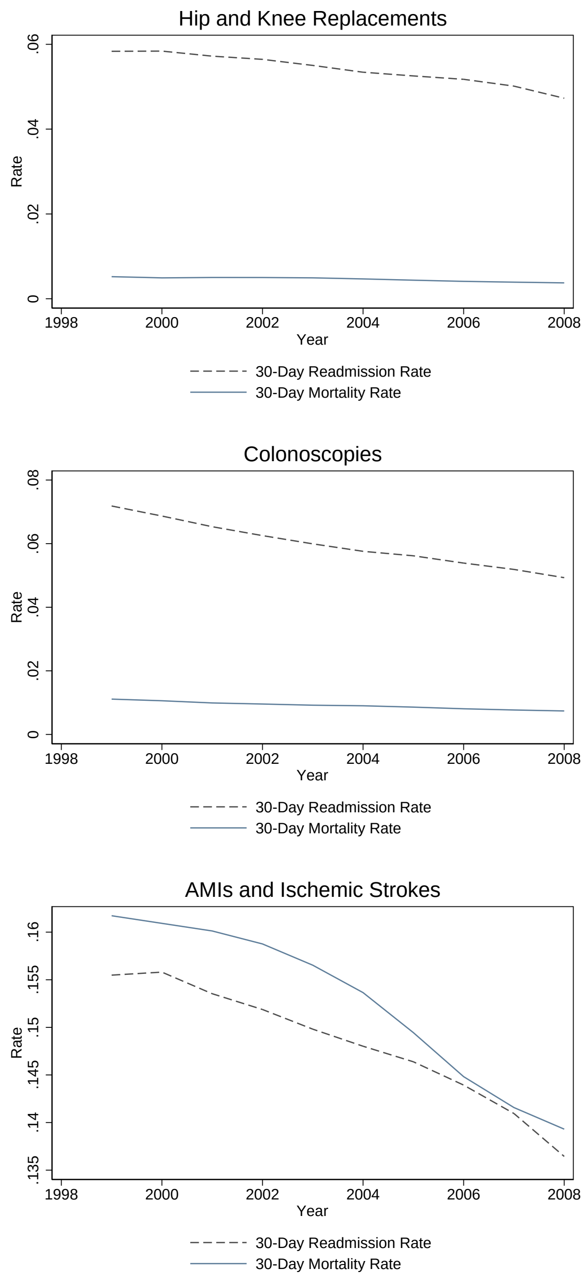
Notes: Panel (a) shows the number of broadband providers available to the average Medicare patient in the sample. Panel (b) shows average internet use among Medicare beneficiaries from the Medicare Current Beneficiary Survey.

Figure 2
Weighted Average Change in the Number of Broadband Providers
Per ZIP Code, 1999-2008



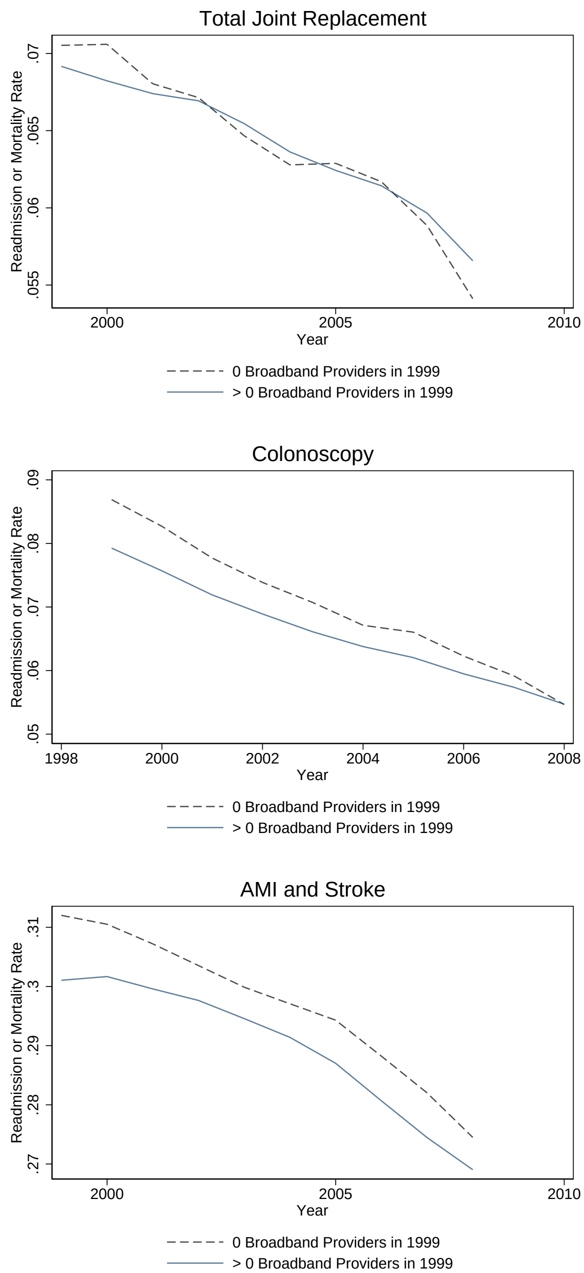
Notes: Map shows Hospital Referral Region (HRR) boundaries in the U.S. For each Zip Code, we calculate the change in broadband providers from 1999 to 2008. Then we calculate the weighted average change in the number of broadband providers across ZIP Codes within HRRs, where the weights equal the number of Medicare beneficiaries living in the ZIP Code in 1999.

Figure 3
Changes in Risk-Adjusted Health Outcomes
After Acute Care Episodes



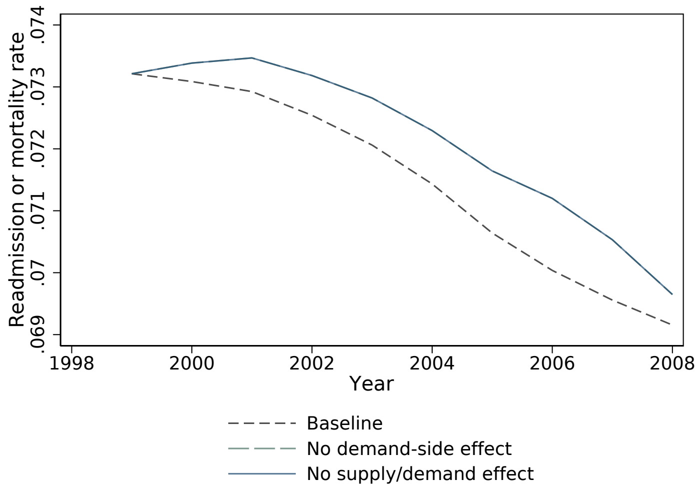
Notes: Figures show changes in all-cause 30-day readmission rates (dotted lines) and 30-day mortality rates (solid lines) following hospitalizations for elective hip or knee replacements, outpatient visits for colonoscopies, and hospitalizations for emergent AMIs or strokes. Rates are risk-adjusted using patient age (5-year bins), sex, race, disability status, chronic conditions, and %Medicare Advantage enrollees in the ZIP Code. Rates are smoothed as 3-year moving averages. Sample includes Traditional Medicare patients ages 65+ receiving acute care in hospitals or outpatient locations from 1999–2008.

Figure 4
Changes in Health Outcomes Across ZIP Codes with Different Numbers of Broadband Providers in 1999



Notes: These figures show changes in the average 30-day readmission rate plus mortality rate following hip and knee replacement, colonoscopy, and AMI and stroke. The black dotted lines show the rates of poor health outcomes for patients living in ZIP Codes that had 0 broadband internet providers in 1999. The solid line shows the rates for patients living in ZIP Codes with >0 broadband providers in 1999. Rates are risk-adjusted using patient age (5-year bins), sex, race, disability status, chronic conditions, and %Medicare Advantage enrollees in the ZIP Code. Rates are smoothed as equally-weighted 3-year moving averages. Sample includes Traditional Medicare patients ages 65+ receiving acute care in hospitals or outpatient settings from 1999–2008.

Figure 5
Counterfactual Readmission Rate for Total Joint Replacement with Broadband Providers Set at 1999 Level



Notes: Figure shows the simulated baseline readmission/mortality rate predicted from the demand model under actual broadband internet, counterfactual readmission rate predicted from simulated demand under broadband internet at 1999 levels (demand-side), and counterfactual readmission/mortality rate predicted from simulated demand and supply under broadband internet at 1999 levels (demand and supply-side).

Table 1
First Stage Effects of Broadband Providers on Internet Use Among Medicare Enrollees

	Has Computer	Uses Internet	Uses Medicare Website	Has Computer	Uses Internet	Uses Medicare Website
Number broadband providers	0.0318***	0.0399***	0.0326**			
	(0.0094)	(0.0101)	(0.0147)			
Number broadband providers squared	−0.0009**	−0.0012**	−0.0010			
	(0.0004)	(0.0005)	(0.0006)			
No Internet				−0.1558***	−0.1606**	−0.3461**
				(0.0528)	(0.0667)	(0.1474)
State Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Medicare Current Beneficiary Survey Characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Marginal Effect: Broadband providers	0.0041***	0.0049***	0.0008**			
	(0.0015)	(0.0016)	(0.0004)			
Marginal Effect: No Internet				−0.0365***	−0.0360**	−0.0149**
				(0.0123)	(0.0149)	(0.0063)
Observations	119,790	119,787	119,768	119,790	119,787	119,768
Outcome Mean	0.402	0.384	0.083	0.402	0.384	0.083

Notes: Sample includes Medicare patients in the Medicare Current Beneficiary Survey from 1999–2008. Estimates from logit model. Number of broadband providers vary by enrollee ZIP Code and year. All specifications control for age, sex, race, disability status, income, marriage status, and education. Marginal effects at the mean shown in lower panel. Standard errors are clustered at the state level and appear in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 2
Pre-Period Summary Statistics: 1996-1999

	Number of Broadband Providers in 1999		
	None	1 to 3	4 or more
Change in # Broadband Providers	6.77	9.87	11.26
# Medicare Enrollees	821.51	3632.15	5280.74
# FFS Enrollees	778.26	3449.31	4947.49
Share in Medicare Advantage	0.06	0.12	0.23
Share Female Enrollees	0.54	0.57	0.58
Share White Ernollees	0.88	0.86	0.83
Share Black Enrollees	0.08	0.09	0.09
Share Disabled Enrollees	0.15	0.13	0.11
Average Age of FFS Enrollees	71.39	71.78	72.33
Average Total FFS Spending	4790.12	4727.93	4800.44
Average # Chronic Conditions	2.08	2.00	1.79
Average Overall Yearly Death Rate	0.05	0.05	0.05
Hip Replacements Per 1K Enrollees	3.02	2.67	2.34
Average Age of Patients	76.59	76.35	76.44
30-Day Readmission Rate	0.08	0.07	0.06
30-Day Mortality Rate	0.02	0.02	0.02
Knee Replacements Per 1K Enrollees	4.65	4.03	3.11
Average Age of Patients	73.82	74.05	74.47
30-Day Readmission Rate	0.05	0.05	0.05
30-Day Mortality Rate	0.00	0.00	0.00
AMIs Per 1K Enrollees	4.86	5.65	5.52
Average Age of Patients	76.81	77.14	77.83
30-Day Readmission Rate	0.16	0.16	0.16
30-Day Mortality Rate	0.19	0.18	0.17
Ischemic Strokes Per 1K Enrollees	4.31	5.76	5.86
Average Age of Patients	76.81	77.14	77.83
30-Day Readmission Rate	0.16	0.16	0.16
30-Day Mortality Rate	0.19	0.18	0.17
Colonoscopies Per 1K Enrollees	6.87	6.92	6.37
Average Age of Patients	74.51	74.77	75.25
30-Day Readmission Rate	0.09	0.08	0.07
30-Day Mortality Rate	0.01	0.01	0.01
Total observations = # Zip Codes	13,509	14,807	3,023

Notes: Table includes summary statistics for Medicare beneficiaries from 1996–1999. Column (1) shows summary statistics for Medicare beneficiaries living in ZIP Codes with zero broadband internet providers in 1999. Column (2) shows summary statistics for patients living in ZIP Codes that had 1–3 broadband providers in 1999. Column (3) shows summary statistics for patients living in ZIP Codes that had four or more broadband providers in 1999.

Table 3
Effects of Patient and Provider Broadband Access on Hip and Knee Replacement Outcomes

	Readmission	Mortality	Readmission or Mortality		
	Patient	Patient	Patient	Hospital	Patient
1-3 broadband providers (in patient ZIP)	−0.0017	0.0004	−0.0014	−0.0007**	−0.0009
	(0.0012)	(0.0005)	(0.0013)	(0.0003)	(0.0013)
4+ broadband providers (in patient ZIP)	−0.0033**	0.0003	−0.0027*	−0.0013***	−0.0017
	(0.0014)	(0.0006)	(0.0014)	(0.0003)	(0.0014)
4+ broadband providers (in provider ZIP)					−0.0015
					(0.0010)
Zip Code Fixed Effects	Yes	Yes	Yes	Yes	Yes
HRR×Year Fixed Effects	Yes	Yes	Yes	Yes	Yes
ZIP Code-level Medicare Population Characteristics	Yes	Yes	Yes	Yes	Yes
Patient Age, Sex, Race, Disability, & Chronic Conditions	Yes	Yes	Yes	Yes	Yes
Observations	3,006,240	3,006,240	3,006,240	2,839,595	3,006,143
R-squared	0.055	0.047	0.065	0.647	0.069
Outcome Mean	0.058	0.008	0.064	0.076	0.064
Outcome Variance	0.054	0.008	0.060	0.002	0.060

Notes: Sample includes all Traditional Medicare patients hospitalized for elective hip or knee replacements from 1999–2008. The number of broadband providers in each patient's residential ZIP Code varies by year. The omitted category is patients with no broadband access in their residential ZIP Codes. The columns labeled "Patient" report results from models where the outcome variable is measured at the patient-level. The column labeled "Hospital" reports results from a model where the outcome is the risk-adjusted, 3-year lagged moving average of joint replacement 30-day readmission rates plus 30-day mortality rates at the patient's chosen hospital. All specifications control for patient chronic conditions, age (5-year bins), sex, race, disability status, procedure type (hip or knee replacement), ZIP code characteristics (log(#Medicare enrollees), %Medicare Advantage, log(Average FFS total spending)), ZIP Code fixed effects, and HRR×year fixed effects. Standard errors are clustered at the HRR×year level and appear in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 4
Effects of Patient and Provider Broadband Access on Hip and Knee Replacement Outcomes
by Hospital Competition

	Readmission		Mortality		Readmission or Mortality	
	High Competition	Low Competition	High Competition	Low Competition	High Competition	Low Competition
1-3 broadband providers (in patient ZIP)	0.0009	−0.0034**	0.0001	0.0005	0.0006	−0.0027*
	(0.0021)	(0.0015)	(0.0010)	(0.0006)	(0.0021)	(0.0016)
4+ broadband providers (in patient ZIP)	−0.0019	−0.0038**	−0.0000	0.0008	−0.0021	−0.0026
	(0.0022)	(0.0017)	(0.0010)	(0.0007)	(0.0023)	(0.0018)
Zip Code Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
HRR×Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
ZIP Code-level Medicare Population Characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Patient Age, Sex, Race, Disability, & Chronic Conditions	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,497,255	1,508,106	1,497,255	1,508,106	1,497,255	1,508,106
R-squared	0.061	0.054	0.058	0.044	0.073	0.063
Outcome Mean	0.062	0.054	0.010	0.006	0.070	0.059
Outcome Variance	0.058	0.051	0.009	0.006	0.065	0.055

Notes: Competition is defined by whether a hospital in a market with above or below median HHI. HHI is defined using the first year of the sample based on market shares within an HRR. Results from models where the outcome variable is measured at the patient-level. Sample follows Table 3 and all specifications control for patient chronic conditions, age (5-year bins), sex, race, disability status, procedure type (hip or knee replacement), ZIP code characteristics (log(#Medicare enrollees), %Medicare Advantage, log(Average FFS total spending)), ZIP Code fixed effects, and HRR×year fixed effects. Standard errors are clustered at the HRR×year level and appear in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 5
Effects of Patient Broadband Access on Hip and Knee Replacement Outcomes
Robustness to Callaway and Sant'anna (2021) Approach

	Readmission Rate		Mortality Rate		Bad Outcome	
	Patient	Hospital	Patient	Hospital	Patient	Hospital
Has internet (ATT)	-0.0130^{**}	-0.0079^{***}	0.0039	-0.0029^{**}	-0.0076	-0.0100^{***}
	(0.0066)	(0.0028)	(0.0040)	(0.0011)	(0.0067)	(0.0036)
Zip Code Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
HRR×Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
ZIP Code-level Medicare Population Characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Patient Sex, Race, Disability, & Chronic Conditions	Yes	Yes	Yes	Yes	Yes	Yes
Observations	104,426	99,814	104,426	99,814	104,426	99,814
Outcome Mean	0.056	0.064	0.009	0.015	0.064	0.077
Outcome Variance	0.028	0.001	0.005	0.000	0.032	0.001

Notes: Summarizes average treatment effect for all groups across all periods using approach from Callaway and Sant'Anna (2021) which addresses issues due to variation in treatment timing. We focus on the effect of the patient "having internet " (vs. not), given that Callaway and Sant'Anna (2021) assumes a binary treatment. We aggregate to the ZIP Code–year level and weight by number of patients receiving joint replacement procedures in the ZIP Code–year. The sample follows the baseline specification in Table 3, except the estimation procedure requires a balanced panel, so ZIP Codes without outcomes in all years are dropped. All specifications control for average demographics in the ZIP Code-year where demographics follow those in the baseline specification. Standard errors following Callaway and Sant'Anna (2021) appear in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 6
Effects of Broadband Access on Hip and Knee Replacement Outcomes, OLS & IV Results

	# Broadband	Readmission		Mortality		Readmission or Mortality			
	Providers	Patient	Patient	Patient	Patient	Patient	Patient	Hospital	Hospital
Avg # broadband providers (in 5 closest ZIPs)	0.6393^{***}								
	(0.0082)								
# broadband providers (in patient ZIP)		-0.0005^{***}	-0.0015^{***}	-0.0000	0.0001	-0.0005^{**}	-0.0013^{***}	-0.0002^{***}	-0.0003^{*}
		(0.0002)	(0.0004)	(0.0001)	(0.0002)	(0.0002)	(0.0004)	(0.0001)	(0.0002)
# broadband providers-squared (in patient ZIP)		0.0000^{**}	0.0001^{***}	-0.0000	-0.0000	0.0000^{*}	0.0001^{***}	0.0000^{***}	0.0000^{***}
		(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Model	First Stage	OLS	IV	OLS	IV	OLS	IV	OLS	IV
Zip Code Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HRR×Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ZIP Code-level Medicare Population Characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Patient Age, Sex, Race, Disability, & Chronic Conditions	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,904,796	3,007,022	2,904,798	3,007,022	2,904,798	3,007,022	2,904,798	2,840,434	2,740,377
R-squared	0.840	0.041	N/A	0.034	N/A	0.051	N/A	0.615	N/A
Outcome Mean	7.743	0.058	0.058	0.008	0.008	0.064	0.064	0.076	0.076
Outcome Variance	21.053	0.054	0.054	0.008	0.008	0.059	0.059	0.001	0.001

Notes: Sample includes all Traditional Medicare patients hospitalized for elective hip or knee replacements from 1999–2008. The number of broadband providers in each patient's residential ZIP Code varies by year. The omitted category is patients with no broadband access in their residential ZIP Codes. The columns labeled "Patient" report results from models where the outcome variable is measured at the patient-level. The column labeled "Hospital" reports results from a model where the outcome is the risk-adjusted, 3-year lagged moving average of joint replacement 30-day readmission rates plus 30-day mortality rates at the patient's chosen hospital. All specifications control for patient chronic conditions, age (5-year bins), sex, race, disability status, procedure type (hip or knee replacement), ZIP code characteristics (log(#Medicare enrollees), %Medicare Advantage, log(Average FFS total spending)), ZIP Code fixed effects, and HRR×year fixed effects. Standard errors are clustered at the HRR×year level and appear in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 7
Broadband Access, Procedure Rates, and Patient Composition

	Joint Replacement		Colonoscopy		AMI and Stroke	
	Rate	Patient Age	Rate	Patient Age	Rate	Patient Age
1-3 broadband providers (in patient ZIP)	−0.0081	−0.0367	−0.0013	0.0070	0.0126	−0.0231
	(0.0105)	(0.0477)	(0.0104)	(0.0417)	(0.0089)	(0.0602)
4+ broadband providers (in patient ZIP)	−0.0039	−0.0756	0.0207	−0.0606	0.0055	−0.0187
	(0.0134)	(0.0576)	(0.0136)	(0.0490)	(0.0115)	(0.0735)
Zip Code Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
HRR×Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
ZIP Code-level Medicare Population Characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Observations	323,321	259,379	323,321	272,005	323,321	243,189
R-squared	0.242	0.242	0.285	0.275	0.312	0.259
Outcome Mean	0.873	74.566	1.265	73.965	0.760	78.568
Outcome Variance	1.341	14.609	1.513	12.528	1.059	21.878

Notes: Sample includes all ZIP Code-years with at least 1 Medicare enrollee from 1999–2008 ($N = 323,321$). The number of broadband providers per ZIP Code varies by year. The omitted category is ZIP Codes with no broadband access. Procedure rates equal the number of patients in the ZIP Code-year receiving the procedure divided by the total number of Medicare enrollees in the ZIP Code-year, multiplied by 100 (rate per 100 people). Patient age is the average age of patients undergoing the procedure in the ZIP Code-year. All specifications control for ZIP Code fixed effects, HRR×year fixed effects, and time-varying average characteristics of Medicare enrollees at the ZIP Code-level (log(#Medicare enrollees), %Medicare Advantage, log(Average total spending), share female, share white, share Black, share disabled). Standard errors are clustered at the HRR×year level and appear in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 8
Effects of Patient and Provider Broadband Access on Colonoscopy Outcomes

	Hospitalization	Mortality	Hospitalization or Mortality		
	Patient	Patient	Patient	Physician Group	Patient
1-3 broadband providers (in patient ZIP)	−0.0026**	0.0002	−0.0024**	−0.0018***	−0.0015
	(0.0012)	(0.0005)	(0.0012)	(0.0005)	(0.0012)
4+ broadband providers (in patient ZIP)	−0.0037***	0.0001	−0.0036***	−0.0020***	−0.0020
	(0.0013)	(0.0006)	(0.0013)	(0.0006)	(0.0013)
4+ broadband providers (in provider ZIP)					−0.0002
					(0.0008)
Zip Code Fixed Effects	Yes	Yes	Yes	Yes	Yes
HRR×Year Fixed Effects	Yes	Yes	Yes	Yes	Yes
ZIP Code-level Medicare Population Characteristics	Yes	Yes	Yes	Yes	Yes
Patient Age, Sex, Race, Disability, & Chronic Conditions	Yes	Yes	Yes	Yes	Yes
Observations	4,959,821	4,959,821	4,959,821	4,738,636	4,838,689
R-squared	0.091	0.037	0.104	0.127	0.117
Outcome Mean	0.058	0.009	0.065	0.068	0.065
Outcome Variance	0.055	0.009	0.061	0.002	0.060

Notes: Sample includes a random 20% of Traditional Medicare patients receiving colonoscopies in outpatient facilities from 1999–2008. The number of broadband providers in each patient's residential ZIP Code varies by year. The omitted category is patients with no broadband access in their residential ZIP Codes. The columns labeled "Patient" report results from models where the outcome variable is measured at the patient-level. The column labeled "Physician Group" reports results from a model where the outcome is the risk-adjusted, 1-year lagged moving average of 30-day colonoscopy hospitalization rates plus 30-day mortality rates at the patient's chosen physician group. Physician groups are identified using tax numbers. All specifications control for patient chronic conditions, age (5-year bins), sex, race, disability status, ZIP code characteristics (log(#Medicare enrollees), %Medicare Advantage, log(Average FFS total spending)), ZIP Code fixed effects, and HRR×year fixed effects. Standard errors are clustered at the HRR×year level and appear in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 9
Effects of Patient and Provider Broadband Access on AMI and Stroke Outcomes

	Readmission	Mortality	Readmission or Mortality		
	Patient	Patient	Patient	Hospital	Patient
1-3 broadband providers (in patient ZIP)	0.0024	−0.0001	0.0021	−0.0003	0.0027
	(0.0018)	(0.0018)	(0.0023)	(0.0005)	(0.0023)
4+ broadband providers (in patient ZIP)	0.0015	0.0002	0.0013	−0.0011*	0.0028
	(0.0019)	(0.0020)	(0.0026)	(0.0006)	(0.0026)
4+ broadband providers (in provider ZIP)					−0.0032**
					(0.0013)
Zip Code Fixed Effects	Yes	Yes	Yes	Yes	Yes
HRR×Year Fixed Effects	Yes	Yes	Yes	Yes	Yes
ZIP Code-level Medicare Population Characteristics	Yes	Yes	Yes	Yes	Yes
Patient Age, Sex, Race, Disability, & Chronic Conditions	Yes	Yes	Yes	Yes	Yes
Observations	3,704,946	3,704,946	3,704,946	3,532,839	3,704,688
R-squared	0.060	0.121	0.088	0.536	0.091
Outcome Mean	0.153	0.157	0.297	0.296	0.297
Outcome Variance	0.129	0.132	0.209	0.004	0.209

Notes: Sample includes all Traditional Medicare patients hospitalized for emergency acute myocardial infarction (AMI) or ischemic stroke from 1999–2008. The number of broadband providers in each patient's residential ZIP Code varies by year. The omitted category is patients with no broadband access in their residential ZIP Codes. The columns labeled "Patient" report results from models where the outcome variable is measured at the patient-level. The column labeled "Hospital" reports results from a model where the outcome is the risk-adjusted, 3-year lagged moving average of AMI and stroke 30-day readmission rates plus 30-day mortality rates at the patient's chosen hospital. All specifications control for patient chronic conditions, age (5-year bins), sex, race, disability status, procedure type (hip or knee replacement), ZIP code characteristics (log(#Medicare enrollees), %Medicare Advantage, log(Average FFS total spending)), ZIP Code fixed effects, and HRR×year fixed effects. Standard errors are clustered at the HRR×year level and appear in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 10
Demand Model Estimates

	Estimate	Standard Error
Distance (miles)		
Constant	0.0490**	(0.0193)
Dist × Medicare Advantage	−0.0006***	(0.0000)
Dist × Age	−0.0005*	(0.0003)
Dist × Female	−0.0069	(0.0045)
Dist × White	−0.0193***	(0.0034)
Dist × Black	−0.0940***	(0.0081)
Dist × Disabled	0.0441	(0.0312)
Risk-adjusted hospital outcomes		
Readmission/mortality × 1-3 broadband	−1.861***	(0.313)
Readmission/mortality × 4+ broadband	−2.259***	(0.289)
Observations	130,596	

Notes: The unit of observation is a hospital in a market, where market is defined by a HRR-Broadband Providers-Year-Procedure. Specification includes hospital fixed effects and market fixed effects. Estimates from OLS regression. Interactions between distance and comorbidities not shown. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Online Appendix

Table A-1
Effects of Patient and Provider Broadband Access on Hip and Knee Replacement Outcomes, 1999–2014

	Readmission	Mortality	Readmission or Mortality		
	Patient	Patient	Patient	Hospital	Patient
1-3 broadband providers (in patient ZIP)	−0.0016	0.0003	−0.0013	−0.0005**	−0.0008
	(0.0011)	(0.0005)	(0.0011)	(0.0002)	(0.0011)
4-5 broadband providers (in patient ZIP)	−0.0036***	0.0003	−0.0031***	−0.0011***	−0.0019
	(0.0011)	(0.0005)	(0.0012)	(0.0003)	(0.0012)
6+ broadband providers (in patient ZIP)	−0.0038***	0.0003	−0.0032**	−0.0013***	−0.0018
	(0.0012)	(0.0005)	(0.0013)	(0.0003)	(0.0013)
4+ broadband providers (in provider ZIP)					−0.0023**
					(0.0090)
Zip Code Fixed Effects	Yes	Yes	Yes	Yes	Yes
HRR×Year Fixed Effects	Yes	Yes	Yes	Yes	Yes
ZIP Code-level Medicare Population Characteristics	Yes	Yes	Yes	Yes	Yes
Patient Age, Sex, Race, Disability, & Chronic Conditions	Yes	Yes	Yes	Yes	Yes
Observations	5,118,352	5,118,352	5,118,352	4,911,090	5,118,266
R-squared	0.049	0.038	0.058	0.629	0.061
Outcome Mean	0.052	0.006	0.058	0.071	0.058
Outcome Variance	0.050	0.006	0.054	0.001	0.054

Notes: Sample includes all Traditional Medicare patients hospitalized for elective hip or knee replacements from 1999–2014. The number of broadband providers in each patient's residential ZIP Code varies by year. The omitted category is patients with no broadband access in their residential ZIP Codes. The columns labeled "Patient" report results from models where the outcome variable is measured at the patient-level. The column labeled "Hospital" reports results from a model where the outcome is the risk-adjusted, 3-year lagged moving average of joint replacement 30-day readmission rates plus 30-day mortality rates at the patient's chosen hospital. All specifications control for patient chronic conditions, age (5-year bins), sex, race, disability status, procedure type (hip or knee replacement), ZIP code characteristics (log(#Medicare enrollees), %Medicare Advantage, log(Average FFS total spending)), ZIP Code fixed effects, and HRR×year fixed effects. Standard errors are clustered at the HRR×year level and appear in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A-2
Within-Patient Effects of Broadband Access on Health Outcomes, 1999-2014

	Hip & Knee Replacements		Colonoscopies	
	Patient Readmission	Hospital Poor Outcome	Patient Hospitalization	Physician Group Poor Outcome
1-3 broadband providers (in patient ZIP)	-0.0077^{***}	-0.0002	-0.0048^{***}	-0.0024^{***}
	(0.0026)	(0.0004)	(0.0015)	(0.0005)
4+ broadband providers (in patient ZIP)	-0.0107^{***}	-0.0011^{***}	-0.0079^{***}	-0.0041^{***}
	(0.0028)	(0.0004)	(0.0016)	(0.0006)
Patient Fixed Effects	Yes	Yes	Yes	Yes
HRR×Year Fixed Effects	Yes	Yes	Yes	Yes
ZIP Code-level Medicare Population Characteristics	Yes	Yes	Yes	Yes
Patient Age & Chronic Conditions	Yes	Yes	Yes	Yes
Observations	1,960,355	1,847,895	4,524,980	4,283,200
R-squared	0.506	0.872	0.437	0.489
Outcome Mean	0.045	0.069	0.054	0.062
Outcome Variance	0.043	0.001	0.051	0.002

Notes: The first two columns include hip and knee replacement patients and the second two columns include colonoscopy patients, all from 1999–2014. The number of broadband providers in each patient's residential ZIP Code varies by year. The omitted category is patients with no broadband access in their residential ZIP Codes. The odd columns include health outcomes measured at the patient-level. The even columns include health outcomes measured at the health care provider-level. For joint replacements, providers are hospitals. For colonoscopies, providers are physician groups. All specifications control for patient chronic conditions, age (5-year bins), disability status, procedure type (hip or knee replacement), ZIP code characteristics (log(#Medicare enrollees), %Medicare Advantage, log(Average FFS total spending)), patient fixed effects, and year fixed effects. Standard errors are clustered at the HRR×year level and appear in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.