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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 also find some evidence that broadband improved provider quality. We use a structural model to decompose the improvements in patient outcomes over time. Counterfactual simulations imply that broadband roll-out was responsible for 16% 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; Bundorf et al. 2009; Chou et al. 2014). 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. It also may allow patients to more easily communicate with their physician, improving outcomes.

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 medical

[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).

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 other research that uses Medicare 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). These procedures provide an ideal setting since they are very common among Medicare patients, with about 3 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 usage among 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-differences 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 by year fixed effects, and detailed patient characteristics. We estimate the same set of models using provider quality as the outcome

[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.

variable to determine whether patients received care at higher quality hospitals as broadband internet access expanded. Finally, we add hospital-by-physician 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 affected health outcomes via changes the in the supply-side, i.e. after conditioning on the patient's choice of hospital and surgeon.

To supplement this analysis, we explore broadband's effects on health outcomes for other major medical conditions. First, we show how broadband availability affected 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 decreases by 5.7% when a patient's ZIP Code changes from having zero broadband providers to 4 or more broadband providers. These results are driven by concentrated hospital markets where quality information may be particularly valuable to patients. Next, 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.

Our results suggest that 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, there is some evidence that hospitals improve their quality as broadband internet expands. Conditional on a patient's choice of hospital and physician, as well as their own access to broadband, the probability of a readmission or death following a joint replacement procedure decreases as broadband providers enter hospital ZIP Codes; however, the result is imprecise in our main sample. Focusing on hospitals in markets with less competition, we find larger supply-side effects that are statistically significant.

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-differences 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 the weight that individuals place on hospital quality depends on access to broadband internet. 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 hospital quality, we simulate outcomes in the absence of broadband expansion. Estimates imply that 16% of the reduction in the rate of readmission and/or 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 (10%), with smaller improvements due to changes in hospital quality (6%).

The remainder of the paper proceeds as follows: Section 2 reviews the literature. 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.

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 and ratings. There is evidence that this information can affect demand (e.g., Jin and Leslie 2003; Bundorf et al. 2009; Chartock 2023). 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 2023). 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

[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

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 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.

3 Data and Summary Statistics

Broadband internet technology allows individuals to continuously access high-speed internet, replacing "dial-up" internet access which was generally slow and required connecting at the start of each session. Between 1999 and 2008, the use of home broadband increased from 1% of the population to over 50%.[6] Our data on the geographic roll-out of broadband internet 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.[7] 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. The FCC groups 1–3 broadband providers in a ZIP Code, otherwise reports the

internet affects sleep (Billari et al. 2018) and obesity (DiNardi et al. 2019).

[6] See Pew Research, "Internet/Broadband Fact Sheet."

[7] 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.

exact number of broadband providers. 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 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% ($\frac{-0.0365}{0.402} \times 100\%$) more likely to use a computer, 9% ($\frac{-0.036}{0.384} \times 100\%$) more likely to use the internet, and 18% ($\frac{-0.0149}{0.083} \times 100\%$) 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.[8] 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 with an emergency health event.[9] 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 colonoscopy, AMI, and stroke. Hospitalization rates following outpatient colonoscopy start around 7% in 1999 and decline to 5% in 2008. Mortality rates for colonoscopy are very low, but still decline over the time period. Mortality rates for AMI and stroke decreased from about 16.5% in 1999 to 14.25% in 2008. 30-day readmission rates decreased from 16% in 1999 to 14.5% in 2008. Therefore, health outcomes for colonoscopy, AMI, and stroke 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 ac-

[8]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.

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

cess 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. For each patient, we create a binary "poor" health outcome variable that equals 1 if the patient was readmitted and/or died within 30-days of their procedure. We then risk-adjust these outcomes as in Figure 3.[10] 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 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 improved joint replacement outcomes in these areas. In contrast, we do not observe evidence of convergence for AMI and stroke patients, suggesting that other technological improvements, rather than broadband access, may have been more important for these patients' outcomes.

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 ($N = 3,023$).[11] 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

[10] Note that the mean of the "readmission or mortality rate" outcome does not exactly equal the mean of the readmission rate plus the mortality rate in Figure 3 because some patients are both readmitted and die within 30-days.

[11] 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.

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).

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-differences 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-differences 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 and physician. These specifications allow us to condition on the 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-differences 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-Differences 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:

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

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 at the ZIP Code-level 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

Isolating whether changes in health outcomes are due to changes in patient choice or changes in the supply-side is challenging. First, we seek to provide evidence on whether there are demand-side changes by exploring 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.

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 or died 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 equally weighted average of its quality in 2005, 2006, and 2007. Then we use lagged hospital quality as the outcome variable in the difference-in-differences 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 potential supply-side effects of broadband access, including 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-physician fixed effects.[12] 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 provider. A negative coefficient on hospital broadband access, after controlling for demand-side factors, would imply that there are factors that increase quality other than patient choice. Examples include better communication between the patient and their provider, better dissemination of best-practices among providers, or increased investments in hospital quality due to broadband making patients more responsive to quality.

4.4 Identification Concerns and Robustness

A key assumption of the difference-in-differences 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-differences 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

[12]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 hospitals to be located in ZIP Codes without any broadband access during the time period.

(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. In Columns (1)–(3), the outcome of interest is measured at the patient-level. These patient-level outcomes may be affected by broadband access due to either patients choosing higher-quality providers or improvements in provider quality (i.e., demand or supply-side responses). 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 a relatively uncommon event 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. These results could be driven by patients choosing better providers (patient demand); however, it is possible that the results are driven by improvements in health outcomes even if individuals do not choose different providers. Health outcomes could improve, for example, if patient broadband access facilitates better communication with doctors, improvements in information gathering in general, or other supply-side factors.

Next, we ask whether changes in health outcomes are due in part to changes in patient demand for quality. Column (4) of Table 3 shows evidence 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 "poor outcome rate," defined as the rate of patient readmission or mortality. In other words, each patient in our sample receives their chosen hospital's historical rate of readmission and mortality as their outcome in column (4). The results imply that patients living in ZIP Codes with 4+ broadband providers choose hospitals with 0.0013 lower poor outcome 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 poor outcome rates. Both results are statistically significant. These results assume that our HRR by year fixed effects fully capture the extent to which providers increase their quality over the time period for reasons unrelated to broadband roll-out.[13]

5.2 Hospital Broadband Access and Health Outcomes

Columns (5) and (6) of Table 3 show the effects of hospital broadband access, after conditioning on the patient's choice of hospital and physician for their elective joint replacement procedure by including hospital-physician fixed effects. We interpret the coefficient on broadband access as reflecting the supply-side effect.

In column (5), 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 to determine whether broadband access at the hospital-level affects patient outcomes. We find that broadband access in the hospital's ZIP Code reduces the probability that patients at the hospital experience poor health outcomes by 2.9% ($= \frac{-0.0018}{0.063} \times 100\%$) in column (5). In column (6) we include indicators for broadband availability in the patient's ZIP Code. The coefficient on hospital broadband is similar, but lacks statistical significance in this specification.[14] However, we find significant effects of hospital broadband when we extend the panel

[13] Another caveat is that even after controlling for HRR by year fixed effects, there is a correlation between patient and hospital broadband. In that case, the coefficient on patient broadband could still partially reflect supply-side factors.

[14] This may be due, in part, to the degree of collinearity between the number of broadband providers in the patient's ZIP Code and the number of broadband providers in the hospital's ZIP Code. The correlation coefficient

to 2014 in section 5.4, and we find significant effects in markets with less hospital competition in section 5.3. Together, these results provide evidence of a supply-side effect, although it is smaller than the demand-side effect for elective TJR patients.

One concern with interpreting the results as the supply-side effect is whether controlling for hospital-physician fixed effects completely shuts down demand-side factors. To address concerns that quality of a hospital-physician pair may change over time, we also estimate a version with hospital-year fixed effects and find similar point estimates, albeit with larger standard errors.[15]

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 (bottom panel). Column (1) implies that patients living in ZIP Codes with 1–3 broadband providers have 0.0034 lower readmission probabilities compared to patients living in ZIP Codes without broadband internet. Patients living in ZIP Codes with 4+ broadband providers have 0.0038 lower readmission probabilities compared to patients in ZIP Codes without broadband internet. 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. These results are also consistent with research in other settings, which shows that health information has a larger effect in concentrated markets (Brown 2019a).

Columns (5) and (6) of Table 4 show that the supply-side effect is also concentrated in

between 4+ broadband providers in the patient's ZIP Code and 4+ broadband providers in the hospital's ZIP Code is 0.56.

[15] We thank an anonymous referee for this suggestion.

markets with low hospital competition. In low competition markets, 4+ broadband providers in the hospital's ZIP Code decreases poor health outcomes by 4.7% ($= \frac{-0.0027}{0.058} \times 100\%$). In high competition markets the effect is smaller in magnitude and not statistically significant.

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), and we use ZIP codes that are not yet treated as the control group. While this approach addresses issues that arise with staggered treatment timing, it also introduces other limitations as it requires a binary treatment variable and does not allow for the HRR-year fixed effects, which control for time-varying factors at the HRR-level.

Overall, the results using the Callaway and Sant'Anna (2021) approach are qualitatively similar to our baseline results. Table 5 shows that patient broadband access reduces readmission probabilities, although this result is not statistically significant (column 1). The results imply that patient broadband access also reduces mortality (column 2). This result is significant at the 10% level. Column (3) combines the readmission and mortality probabilities, and shows that patients with broadband access are less likely to suffer these poor health outcomes. Column (4) shows that patients are less likely to choose hospitals where joint replacement patients suffer poor health outcomes. This result is even larger in magnitude than the baseline results and is significant at the 1% level.

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 serve 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.[16] Col-

[16] When the FCC data indicates that there are between 1–3 broadband providers in a ZIP Code, we say the ZIP

umn (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.[17] First we show that 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 that 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

Code has 2 broadband providers.

[17]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).

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. 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 four categories to model diminishing marginal returns to broadband: ZIP Codes with 0 broadband providers, ZIP Codes with 1–3 broadband providers, ZIP Codes with 4-5 broadband providers, and ZIP Codes with 6+ 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. We also continue to find some evidence that patient health outcomes improve as the number of broadband providers in the hospital's ZIP Code increases (e.g., a supply-side effect).

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.[18] Given low mortality rates following joint replacement procedures,

[18]Here we do not restrict to Medicare beneficiaries ages 65 and older; we keep disabled beneficiaries who are

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.[19] The 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). We find a negative, but statistically insignificant effect of 4+ broadband providers in the physician's ZIP Code on colonoscopy

younger in an effort to increase the sample size. However, we flexibly control for patient age.

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

patient health outcomes (columns (5) and (6)). Our results imply that broadband access primarily improves colonoscopy patient outcomes through the demand-side channel.

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

Like 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 is negatively correlated with poor patient outcomes, but it lacks statistical significance. Column (5) of Table 9 shows that when hospitals gain 4+ broadband providers (compared to fewer than 4 broadband providers), the probability that their AMI/stroke patients experience a poor outcome (30-day readmission or mortality) decreases by 0.5% ($= \frac{-0.0014}{0.297} \times 100\%$). Column

(6) shows a similar result. We also find, counter-intuitively, that the number of broadband providers in the patient's ZIP Code is positively correlated with poor outcomes following AMI and stroke when we condition on hospital×physician fixed effects in column (6). We believe this is a spurious result as it does not hold up when we only consider mortality as the outcome instead of readmission or mortality (results available upon request). Overall our results from the AMI and stroke sample imply that broadband access in neither the patient nor hospital ZIP Code significantly determined health outcomes following AMIs/strokes from 1999-2008.

6 Patient Demand and Counterfactual Simulations

Our difference-in-differences analysis shows evidence that broadband expansion affected patient demand for hospitals. 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 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-differences analysis. We then combine the demand model estimates with difference-in-differences estimates on the supply-side to decompose broadband's total effect on health outcomes into the share due to changes in patients' provider 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, sex, race, disability status, procedure type, and ZIP code characteristics. Individuals care about the expected quality of a hospital, $\mathbb{E}[q_{ht}]$. 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.

Given the reduced-form results in Section 5, we hypothesize that patients have more information about quality when they have access to broadband internet, implying they effectively put more weight on quality. We model this by assuming 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-differences identification in the prior section.

6.2 Demand Estimates

We define the choice set as all hospitals in a patient's HRR. The outside option is defined as any hospital outside of the patient's HRR. A key issue is that variation in broadband availability is largely across ZIP Codes within an HRR. For this reason, we calculate market shares for each year by HRR, broadband provider categories, and procedure (i.e., hip versus knee) for the purposes of demand estimation.[20] We average over distance from each patient ZIP code to provider.

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 slightly larger in magnitude. The finding that broadband internet makes individuals more sensitive to provider quality is broadly consistent with the results in Section 5.

[20] An alternative approach would be to compute shares for each of the roughly 40,000 ZIP Codes, however it is well known that small market sizes cause error in shares, causing issues for demand estimation (Gandhi et al. 2023).

6.3 Counterfactual Results

We use the estimates to simulate counterfactual outcomes when turning off the demand-side and supply-side effect of internet expansion since 1999. 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.

We find some evidence that hospital quality changed in response to hospitals getting broadband, as seen in Column 5 and 6 of Table 3 using the difference-in-differences approach presented in Equation 1. While modeling factors that determine hospital quality is beyond the scope of this paper, we capture these supply-side effects in the counterfactual simulation by directly using the reduced-form estimates. In particular, we use the estimate in column 5 of Table 3 to predict $\hat{q}^{1999}_{ht}$, the quality of hospitals holding broadband providers fixed at 1999 levels. It is important to note that the same assumptions discussed in Section 5.2 apply.

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 better starting around 2001. The gap grows larger over time as broadband access expands. By the end of the period, the rate of poor health outcomes would have been 0.0018 higher if broadband had not expanded given the demand-side effects. Overall, changes in demand due to broadband account for 9.7% of the reduction in poor health outcomes over the period.

Allowing the supply-side to adjust by predicting hospital quality given 1999 broadband levels and re-simulating demand shows a larger effect. At the end of the sample period, the simulations imply that broadband expansion was responsible for 0.0029 reduction in the readmission/mortality rate. The demand-side and supply-side effects of broadband together explain 15.8% of the reduction in negative health outcomes over the period. In other words, our model estimates imply roughly two-thirds of the change in health outcomes at the end of the period is due to demand-side effects while the remaining change is a result of supply-side effects.

The presence of positive spillovers due to broadband access motivates policies aimed at increasing the speed of broadband roll-out. Over the period, there were large subsidies aimed at increasing broadband availability. In order to examine the implications of faster broadband roll-out, we examine a counterfactual in which broadband expands half as fast over the period starting in 1999. The results are shown in Figure 6. Compared to the baseline case, the changes in demand would result in a meaningful increase in the readmission/mortality rate of 0.0008 by the end of the period. The supply-side effects are more modest under this counterfactual.

Finally, we examine the robustness of the main counterfactual under alternative demand specifications in Appendix Figure A-1. In panel (a) we include hospital quality alone in utility in addition to the interaction with broadband providers and hospital fixed effects. This allows for quality changes over time to affect demand for hospitals independently of broadband access. In panel (b) we include the number of broadband providers alone. Under both specifications, counterfactual health outcomes are quite similar.

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 16% of the total reduction in poor health outcomes for joint replacements from 1999 to 2008. While demand-side effects are especially important, changes on the supply-side also play a role.

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 a significant factor 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 can have positive spillovers by facilitating choice and improving health outcomes.

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.

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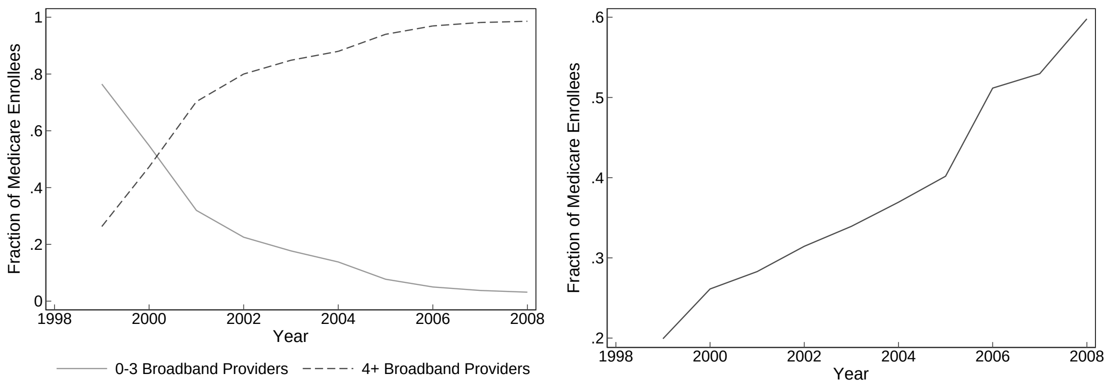
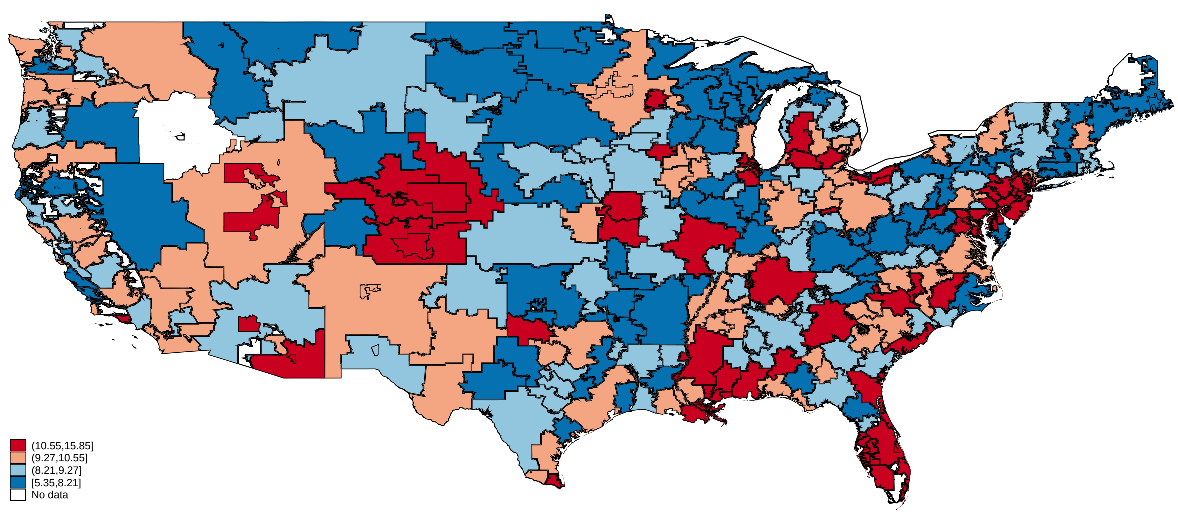
Figure 1
Broadband Internet Availability and Internet Use
in the Medicare Population



a. Broadband Availability b. Internet Use by Medicare Population

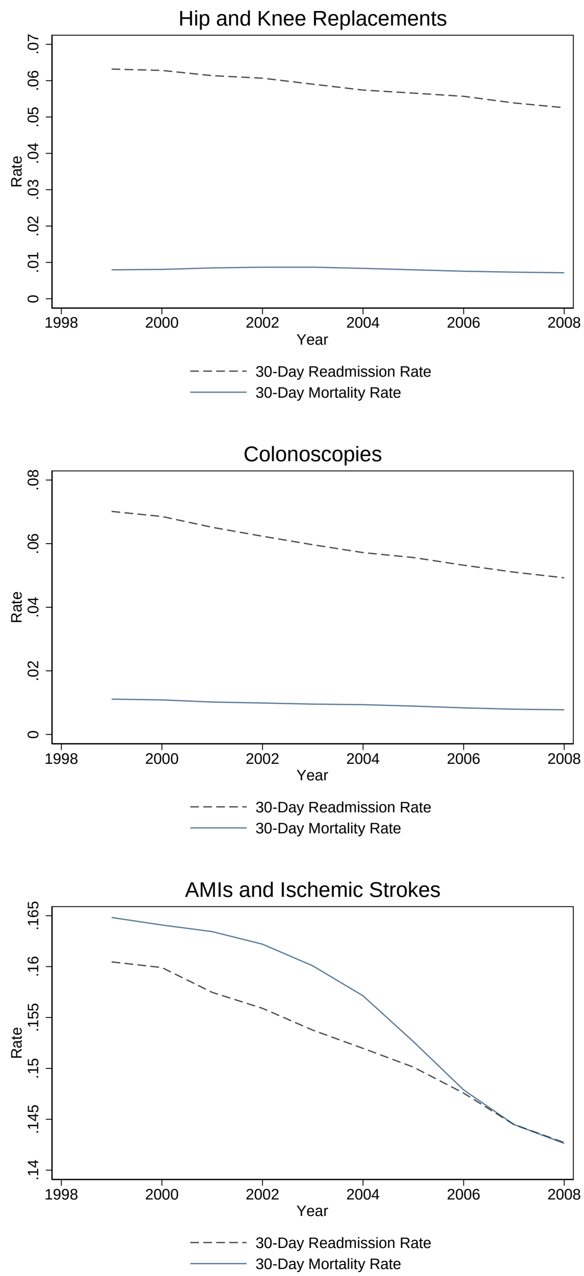
Notes: Panel (a) shows the number of broadband providers available to the average Medicare patient in the sample. Panel (b) shows average internet use among Medicare beneficiaries from the Medicare Current Beneficiary Survey.

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



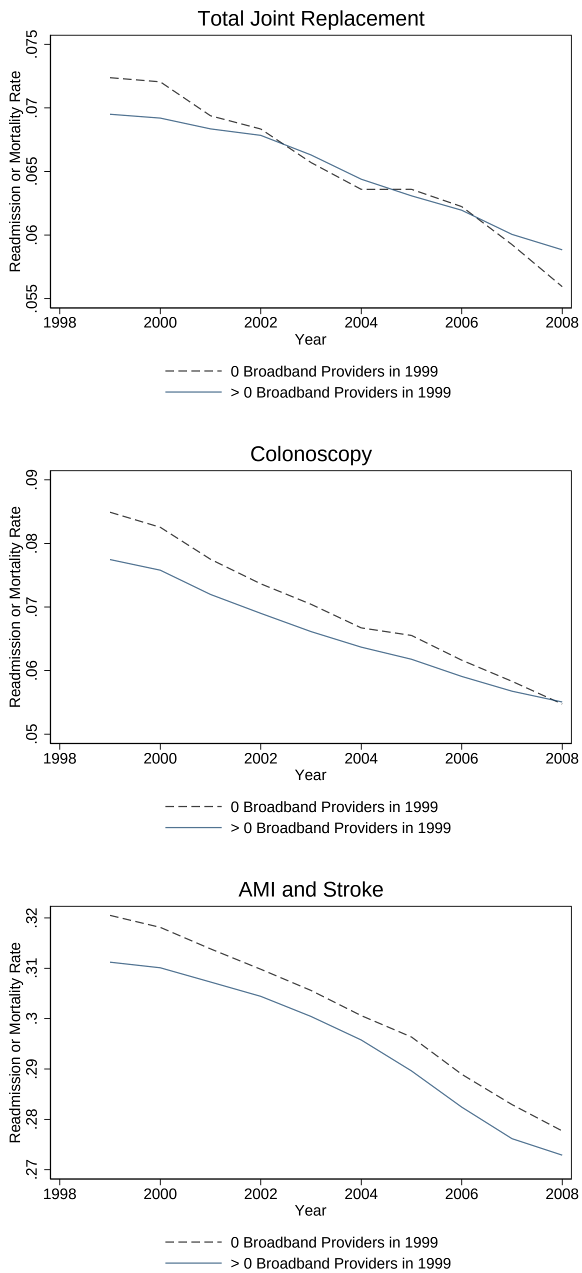
Notes: Map shows Hospital Referral Region (HRR) boundaries in the U.S. For each Zip Code, we calculate the change in broadband providers from 1999 to 2008. Then we calculate the weighted average change in the number of broadband providers across ZIP Codes within HRRs, where the weights equal the number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

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



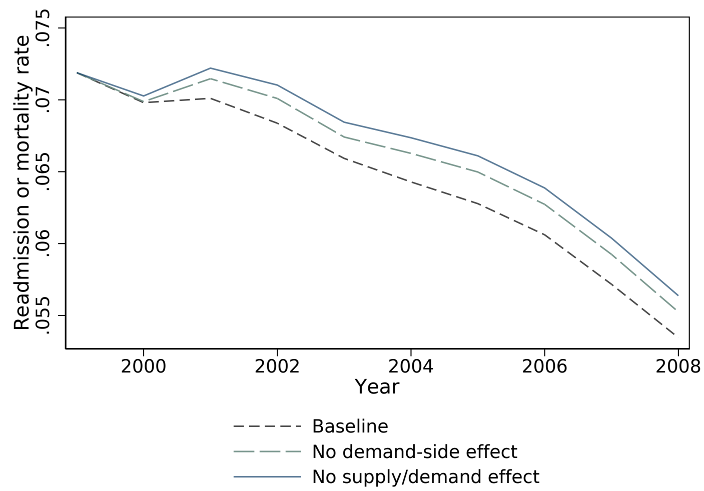
Notes: Figures show changes in all-cause 30-day readmission rates (dotted lines) and 30-day mortality rates (solid lines) following hospitalizations for elective hip or knee replacements, outpatient visits for colonoscopies, and hospitalizations for emergent AMIs or strokes. Rates are risk-adjusted using 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



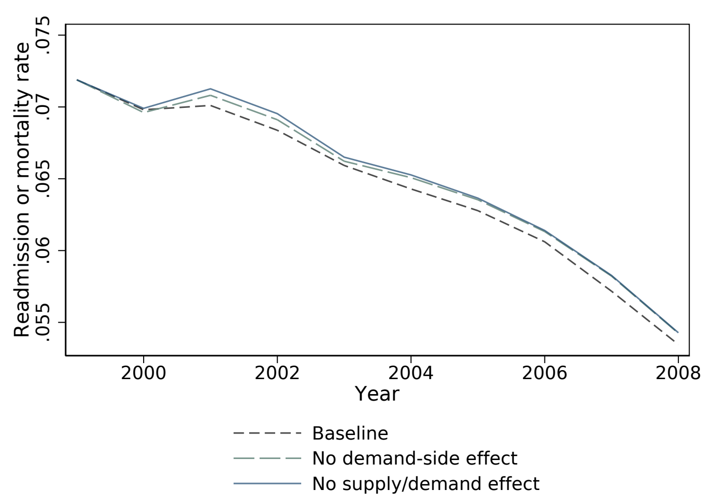
Notes: These figures show changes in the average 30-day readmission rate plus mortality rate following hip and knee replacement, colonoscopy, and AMI and stroke. The black dotted lines show the rates of poor health outcomes for patients living in ZIP Codes that had 0 broadband internet providers in 1999. 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/Mortality Rate for Hip and Knee 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).

Figure 6
Counterfactual Readmission/Mortality Rate for Hip and Knee Replacement with Slow Broadband Rollout



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 if broadband roll-out happened half as fast (demand-side), and counterfactual readmission/mortality rate predicted from simulated demand and supply if broadband roll-out happened half as fast (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			
	Overall			Demand-side	Supply-side	
	Patient	Patient	Patient	Hospital	Patient	Patient
1-3 broadband providers (in patient ZIP)	−0.0017	0.0004	−0.0014	−0.0007**		−0.0003
	(0.0012)	(0.0005)	(0.0013)	(0.0003)		(0.0013)
4+ broadband providers (in patient ZIP)	−0.0033**	0.0003	−0.0027*	−0.0013***		−0.0010
	(0.0014)	(0.0006)	(0.0014)	(0.0003)		(0.0015)
4+ broadband providers (in hospital ZIP)					−0.0018*	−0.0016
					(0.0010)	(0.0010)
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
Physician-Hospital Fixed Effects	No	No	No	No	Yes	Yes
Observations	3,006,240	3,006,240	3,006,240	2,839,595	2,962,371	2,962,371
R-squared	0.055	0.047	0.065	0.647	0.099	0.099
Outcome Mean	0.058	0.008	0.064	0.076	0.063	0.063
Outcome Variance	0.054	0.008	0.060	0.002	0.059	0.059

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. The last two columns include physician×hospital 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			
	Patient	Patient	Patient	Hospital	Patient	Patient
	High Competition Markets					
1-3 broadband providers (in patient ZIP)	0.0009	0.0001	0.0006	−0.0005		0.0018
	(0.0021)	(0.0010)	(0.0021)	(0.0005)		(0.0022)
4+ broadband providers (in patient ZIP)	−0.0019	−0.0000	−0.0021	−0.0014**		−0.0001
	(0.0022)	(0.0010)	(0.0023)	(0.0006)		(0.0024)
4+ broadband providers (in hospital ZIP)					−0.0017	−0.0013
					(0.0014)	(0.0015)
Observations	1,497,255	1,497,255	1,497,255	1,418,196	1,462,311	1,462,311
R-squared	0.061	0.058	0.073	0.639	0.120	0.120
Outcome Mean	0.062	0.010	0.070	0.084	0.068	0.068
Outcome Variance	0.058	0.009	0.065	0.002	0.063	0.063
	Low Competition Markets					
1-3 broadband providers (in patient ZIP)	−0.0034**	0.0005	−0.0027*	−0.0007**		−0.0020
	(0.0015)	(0.0006)	(0.0016)	(0.0003)		(0.0016)
4+ broadband providers (in patient ZIP)	−0.0038**	0.0008	−0.0026	−0.0010***		−0.0018
	(0.0017)	(0.0007)	(0.0018)	(0.0004)		(0.0019)
4+ broadband providers (in hospital ZIP)					−0.0027**	−0.0027**
					(0.0013)	(0.0013)
Observations	1,508,106	1,508,106	1,508,106	1,420,462	1,487,271	1,487,271
R-squared	0.054	0.044	0.063	0.650	0.093	0.093
Outcome Mean	0.054	0.006	0.059	0.068	0.058	0.058
Outcome Variance	0.051	0.006	0.055	0.001	0.054	0.054

Notes: This table recreates Table 3, but for "high" vs. "low" hospital competition markets. 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. The last two columns include physician×hospital 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	Mortality	Readmission or Mortality	
	Patient	Patient	Patient	Hospital
Has broadband (ATT)	-0.0105 (0.0124)	-0.0087^{*} (0.0050)	-0.0234^{*} (0.0123)	-0.0048^{***} (0.0018)
ZIP Code-level Medicare Population Characteristics	Yes	Yes	Yes	Yes
Patient Sex, Race, Disability, & Chronic Conditions	Yes	Yes	Yes	Yes
Observations	395,103	395,103	395,103	365,154
Outcome Mean	0.057	0.009	0.064	0.077
Outcome Variance	0.054	0.009	0.060	0.002

Notes: Summarizes average treatment effect using approach from Callaway and Sant'Anna (2021) which addresses issues due to variation in treatment timing. We examine the effect of having broadband internet given that Callaway and Sant'Anna (2021) assumes a binary treatment. The sample follows the baseline specification in Table 3, however "always treated" groups are dropped following Callaway and Sant'Anna (2021) which reduces the sample size considerably. 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^{***} (0.0002)	-0.0015^{***} (0.0004)	-0.0000 (0.0001)	0.0001 (0.0002)	-0.0005^{**} (0.0002)	-0.0013^{***} (0.0004)	-0.0002^{***} (0.0001)	-0.0003^{*} (0.0002)
# broadband providers-squared (in patient ZIP)		0.0000^{**} (0.0000)	0.0001^{***} (0.0000)	-0.0000 (0.0000)	-0.0000 (0.0000)	0.0000^{*} (0.0000)	0.0001^{***} (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	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 physician ZIP)					−0.0004	−0.0002
					(0.0008)	(0.0008)
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
Physician-Group Fixed Effects	No	No	No	No	Yes	Yes
Observations	4,959,821	4,959,821	4,959,821	4,738,636	4,838,689	4,838,689
R-squared	0.091	0.037	0.104	0.127	0.117	0.117
Outcome Mean	0.058	0.009	0.065	0.068	0.065	0.065
Outcome Variance	0.055	0.009	0.061	0.002	0.060	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. The last two columns include physician×group 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	Patient
1-3 broadband providers (in patient ZIP)	0.0024	−0.0001	0.0021	−0.0003		0.0048**
	(0.0018)	(0.0018)	(0.0023)	(0.0005)		(0.0024)
4+ broadband providers (in patient ZIP)	0.0015	0.0002	0.0013	−0.0011*		0.0054**
	(0.0019)	(0.0020)	(0.0026)	(0.0006)		(0.0027)
4+ broadband providers (in hospital ZIP)					−0.0014	−0.0017
					(0.0014)	(0.0014)
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
Physician-Hospital Fixed Effects	No	No	No	No	Yes	Yes
Observations	3,704,946	3,704,946	3,704,946	3,532,839	3,618,139	3,618,139
R-squared	0.060	0.121	0.088	0.536	0.152	0.152
Outcome Mean	0.153	0.157	0.297	0.296	0.296	0.296
Outcome Variance	0.129	0.132	0.209	0.004	0.208	0.208

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 models control for patient chronic conditions, age (5-year bins), sex, race, disability status, procedure type (AMI or stroke replacement), ZIP code characteristics (log(#Medicare enrollees), %Medicare Advantage, log(Average FFS total spending)), ZIP Code fixed effects, and HRR×year fixed effects. The last two columns include physician×hospital fixed effects. Standard errors are clustered at the HRR×year level and appear in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

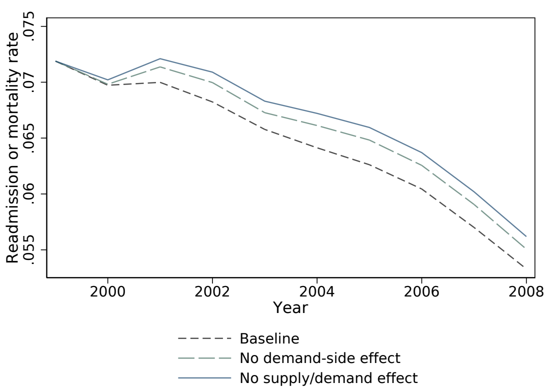
Table 10
Hospital Demand Estimates
Hip and Knee Replacement Patients

	Estimate	Standard Error
Distance (miles)		
Constant	0.0398**	(0.0189)
Dist × Medicare Advantage	−0.0007***	(0.0000)
Dist × Age	−0.0001	(0.0003)
Dist × Female	−0.0122***	(0.0044)
Dist × White	−0.0278***	(0.0034)
Dist × Black	−0.1014***	(0.0079)
Dist × Disabled	0.0452	(0.0315)
Risk-adjusted hospital outcomes		
Readmission/mortality × 1-3 broadband	−1.339***	(0.206)
Readmission/mortality × 4+ broadband	−1.340***	(0.192)
Observations	134,452	

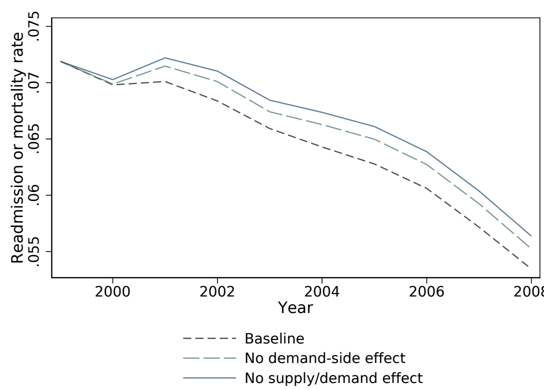
Notes: The unit of observation is a hospital in a market, where market is defined by a HRR-Broadband Providers-Year-Procedure. Specification includes hospital fixed effects and market fixed effects. Estimates from OLS regression. Interactions between distance and comorbidities not shown. * $p < 0.10$,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

Online Appendix

Figure A-1
Counterfactual Readmission/Mortality Rate for Hip and Knee Replacement
Alternative Demand Specifications



a. Alternative Specification 1



b. Alternative Specification 2

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). Specification 1 includes quality alone in utility in addition to interaction between quality and number of broadband providers. Specification 2 includes number of broadband providers alone in addition to interaction between quality and number of broadband providers.

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	Patient
1-3 broadband providers (in patient ZIP)	-0.0016	0.0003	-0.0013	-0.0005^{**}		-0.0004
	(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^{***}		-0.0014
	(0.0011)	(0.0005)	(0.0012)	(0.0003)		(0.0012)
6+ broadband providers (in patient ZIP)	-0.0038^{***}	0.0003	-0.0032^{**}	-0.0013^{***}		-0.0015
	(0.0012)	(0.0005)	(0.0013)	(0.0003)		(0.0013)
4+ broadband providers (in hospital ZIP)					-0.0023^{**}	-0.0020^{**}
					(0.0010)	(0.0010)
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
Physician-Hospital Fixed Effects	No	No	No	No	Yes	Yes
Observations	5,118,352	5,118,352	5,118,352	4,911,090	5,060,037	5,060,037
R-squared	0.049	0.038	0.058	0.629	0.087	0.087
Outcome Mean	0.052	0.006	0.058	0.071	0.057	0.057
Outcome Variance	0.050	0.006	0.054	0.001	0.053	0.053

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. The last two columns include physician×hospital 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. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.