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Abstract

We study the effect of internet diffusion on childbirth procedures performed in England between 2000 and 2011. We exploit an identification strategy based on geographical discontinuities in internet access generated by technological factors. We show that broadband internet access increased Cesarean-sections: mothers living in areas with better internet access are 2.5 percent more likely to have a C-section than mothers living in areas with worse internet access. The effect is driven by first-time mothers who are 6 percent more likely to obtain an elective C-section. The increased C-section rate is not accompanied by changes in health care outcomes of mothers and newborns. Health care costs increased with no corresponding medical benefits for patients. Heterogeneity analysis shows that mothers with low income and low education are those more affected: thanks to the internet, they progressively close the C-section gap with mothers with higher income and education. We show evidence documenting the growing importance of the internet as a source of health related information, and we argue that patient's access to online information is changing the relationship between health care providers and patients.

1 Introduction

In recent years, the diffusion of the internet has reduced informational frictions in several markets, with consumers having access to unprecedented sources of information about the price and quality of products. A high proportion of internet users look online for health information (Fox and Duggan 2013) and, with the spread of the internet, patients have found a new source of information on medical conditions, drugs, and medical procedures.[1] Health care is a market characterized by informational asymmetries between providers and consumers. Access to health information via the web is redefining the roles of 'supplier' and 'consumer', as the flow of information is no longer only from doctor to patient (Hartzband and Groopman 2010).

In principle, having access to broader information should lead to better decisions. Still, the merits of more information in health care are complex (Phelps 1992). There are concerns about the quality of the information provided being difficult to interpret, about the capacity of users to make use of it (Eysenbach et al. 2002), and about patients without internet access (Wagner et al. 2005). As a result, one of the US Healthy People 2010's objectives was devoted to the quality of health information online, recognizing that the potential for harm from inaccurate information can be significant.[2]

The aim of this paper is to assess if access to information via the internet has changed health care treatment. Our setting is the UK in the 2000s and we focus on the impact of the internet on consumer choice of a common health care procedure (C-sections). Examining the impact of internet access on health care treatments is difficult due to potential endogeneity of internet diffusion. Internet subscription is positively correlated with several observable demographic characteristics (such as income and education) that are also positively correlated with health care use and health outcomes. Hence, it is possible that unobservable demographic characteristics may be correlated with both internet access and health outcomes.

We address this issue with an identification strategy based on exogenous discontinuities in internet quality and access. These discontinuities stem from two key elements of the Asymmetric Digital Subscriber Line (ADSL) technology that was, by far, the most important way

[1] See Cline and Haynes (2001) for a review of the literature on health information seeking on the internet.
[2] For example, as shown by the anti-vaccination movement (Chiou and Tucker 2018).

to gain access to the internet in the UK in the years we consider. The first is the decay of the digital signal, which means that the quality of internet connections strongly depends on the distance between the starting node of the connection (the local exchange, LE) and the delivery point (the house). The second is that the areas served by LEs are irregularly shaped because the topology of the network was designed in the 1930s to serve a different purpose (telephone voice communications).

Our strategy works as follows. We use a detailed map of the topology of the internet network to identify adjacent small local areas of around 600 households that are served by different LEs. Because LE catchment areas are irregularly shaped and different in size, contiguous small local areas can be located at very different distances from their respective node of the network and so will experience (potentially large) differences in quality of internet access. By matching data on LE coverage to detailed census and hospital discharge data, we identify a subset of adjacent small areas that are balanced both in terms of aggregate demographics and patient characteristics but differ with respect to the quality and the availability of internet access (discussed in detail below). This identification strategy is possible thanks to the relatively slow (compared to other countries, and notably to the US) development of UK's broadband internet infrastructure which, in the years that we consider, had a average broadband speed of 1-2Mbit/s, mostly based on the upgrade of the pre-existing telephone network.[3]

We apply our research design to the case of childbirth and assess whether internet diffusion affected the choice of childbirth procedure (C-sections) and subsequent health outcomes in the period when the internet was growing dramatically in England. We focus on childbirth for the following reasons. First, childbirth is one of the most commonly performed medical procedures worldwide, meaning that C-sections are one of the most common surgical procedures. The number of these cases not only gives us the statistical power to perform our analysis, but it also means that these cases are quantitatively relevant, particularly as there is widespread concern over the rise in C-sections which has occurred in many health care markets. Second, in the

[3]This identification strategy is close to the one employed by Ahlfeldt et al. (2017), Faber et al. (2015), and Falck et al. (2014), who also exploit discontinuities in distance as an exogenous determinant of internet quality and internet access.

UK the vast majority of mothers deliver in hospitals,[4] which eliminates concerns of a possible selection bias. Third, mothers know their pregnancy status well in advance, giving them time to search for information should they wish to do so. Fourth, childbirth in the UK is tax-financed and free at point of delivery, so all consumers face the same zero price.

A number of empirical studies seek to understand why C-section rates increased over time. The literature emphasizes the role of the supply side and of physicians. The most common explanations are financial incentives for doctors or malpractice pressure (e.g., Currie and MacLeod 2008; Frakes 2013; Amaral-Garcia et al. 2015). In contrast, we consider the role of the demander. Our design shuts-off the role for financial incentives for suppliers. In our setting, hospital staff are salaried and employed by one hospital. Hospitals are paid to provide maternity care through fixed budgets and have no incentive to provide more C-sections (as C-sections are more expensive than vaginal delivery, to the extent that suppliers take costs into account, they actually might have incentives to provide fewer). Further, our design implies that we look at only within-hospital variation as 97.5% of the mothers in our adjacent pairs of small areas use the same set of hospitals. In other words, the hospitals used by mothers in the adjacent small area are almost always the same, and in those hospitals the mothers will be treated by the same staff.[5]

We find that mothers with better, faster access to the internet are 2.5 percent more likely to have a C-section than mothers living in areas with worse internet access. Our effect comes from an increase in *elective* C-sections: we find no effect of the internet on the likelihood of performing an *emergency* C-section (a decision made by the medical supplier and not the demander). We find no effect on either mothers or newborns' health outcomes. Finally, the increase is driven by first-time and low-income mothers, who are 6 percent more likely to have a C-section. By the end of the period, the C-section 'gap' between high- and low-income mothers, that is apparent pre-broadband internet is virtually closed, thanks in large part to the internet.

Overall, the internet has been a non-negligible factor contributing to the observed increase

[4]In England and Wales, only 2.3% of pregnant women give birth at home. http://www.nhs.uk/conditions/pregnancy-and-baby/Pages/where-can-i-give-birth.aspx.

[5]In this with this, we control for hospital fixed effects in all regression models, and we find that adding this control does not change our results. Also, we examine whether there is any impact of the internet on sorting into hospitals with higher C-section rates. We find this not to be the case.

in C-sections in the first decade of 2000s, when the C-section rate increased from 20.7% in 2000 to 24.3% in 2011 (a total increase of 17.4 percent). A back of the envelope calculation of the financial cost associated with the increase in C-sections due to internet diffusion is, at a minimum, around £6.5m per annum with no corresponding medical benefits.

The main limitation of our approach is that we do not have direct evidence of the mechanisms at work. Our data do not report the exact channels by which mothers found information online. We are explicit about this limitation at the outset, and in Section 2.1 we supply complementary evidence suggesting that our findings can be explained by the role of the internet as a new source of diverse information. A number of consistent facts corroborate this conclusion. First, the ongoing discussion on the effects of the internet on health care choice, both in the medical literature and in the press, highlights the rising role of consumers in determining choice of treatment. Second, we document from various sources that the internet quickly became an important source of information on pregnancy and childbirth. Third, we show first-time mothers look more for information than multiple-time mothers, both offline and online.

Our findings support a mechanism of information gathering and joint decisions in a setting where the quality of information is heterogeneous. The internet is a very diverse source of information and one much less controlled by experts than information previously available in print and TV media. Hence, mothers are exposed to a wider range of signals online. First-time mothers have less experience and knowledge about the pros and cons of different delivery methods and thus they are more likely to search for, and to be influenced by, online information. In line with this mechanism, we find that the increase in C-sections is driven by first-time mothers who opt more often for an elective C-section, while we do not find a difference for multiple-time mothers or for emergency C-sections. We also show that the effect we find is not driven by mothers selecting hospitals with high C-section rates or traveling longer distances to find a hospital to have a C-section. This supports the idea that access to information gives mothers the ability to influence the decision of their normal supplier.[6]

[6] From a theoretical standpoint, our findings can be rationalized by a standard model of choice with heterogeneous information. Our results are also consistent with a behavioral model of choice based on anecdotal reasoning (e.g. Spiegler (2006)). The welfare implications of these two classes of models are different. In the behavioral models, decision makers do not know the true expected utility of each product offered in the market and base their decisions on the outcomes of a sample of cases they learn about during a search phase. Suboptimal products are

We contribute to two different literatures. First, to the literature on the effect of increased information in health care markets, where informational asymmetries are a concern. Governments in many countries are seeking ways of providing health information to patients. For example, report cards were introduced in several US states, government websites have been introduced in the US to allow consumers to compare health and nursing care providers, and comparative information on the quality of hospitals is available in the UK and the Netherlands.[7] The literature typically focuses on how measures to increase information might affect health care quality and patients' choice. Evidence on whether these initiatives bring benefits is mixed, pointing to possible unintended consequences and to behavioral responses by both suppliers and consumers. Dranove and Sfekas (2008) find that higher-ranking hospitals did not seem to gain significant market shares due to cardiovascular surgery report cards, a finding in line with Dranove and Jin 2010. The authors also show that when the information provided is different from patients' beliefs, patients respond by moving to higher-quality hospitals. Dranove et al. (2003) find evidence of "cream skimming": hospitals selected less risky patients and performed more cardiac surgeries on healthier patients with negative effects on overall health. Chou et al. (2014) show that online CABG hospital report cards increased hospital's quality competition and health outcomes for Medicare patients in more competitive markets. For the UK, Gaynor et al. (2016) consider how a new information system which provided information on quality to help patients make more informed choices affected patients' hospital choice for CABG surgery. They find that, even for this relatively old and sick group, patients became more responsive to clinical quality and mortality rates decreased by approximately 3%. Gutacker et al. (2016) consider the case of hip replacement surgery and find that patient self-reported outcome measures impact patients' choice of provider. Two papers focus on consumers of a similar demographic to those we examine here. Bundorf et al. (2009) find that patients respond to quality report cards

chosen in equilibrium. In our context, this mechanism can be triggered by the strong presence online of maternity blogs and websites reporting personal experiences and advice that is not always in line with official guidelines (see section 2.1 for a further discussion on mothers' antenatal information search). Our data are not sufficiently rich to disentangle between competing explanations for the documented findings. This is left to further research.

[7]One of the first and most well-known initiative is the New York CABG (coronary artery bypass graft) report card. Currently, many US states have implemented hospital report cards and extended the available information to other types of treatment. For government websites, see for example, https://www.medicare.gov/hospitalcompare/search.html, https://www.medicare.gov/nursinghomecompare/search.html, http://www.cqc.org.uk/, http://www.kiesbeter.nl.

when choosing providers of assisted reproductive therapies, and Price and Simon (2009) find that mothers respond to new medical information on vaginal birth after delivery, with young mothers being more responsive. These age differences are similar to those reported by Goldfarb and Prince (2008) regarding the adoption of new technologies such as the internet.

Secondly, we also contribute to the literature on the impact of internet use and diffusion. Among papers studying the market effects of the internet, Brown and Goolsbee (2002) find that internet use lowers the price of term life insurance by 8 to 15%, and Scott Morton et al. (2003) find that internet consumers pay less for their cars. Among papers studying how the internet changed behavior in other market dimensions, Akerman et al. (2015) study the impact of broadband internet on labour productivity, Falck et al. (2014) show the effect of internet diffusion on political participation and Gavazza et al. (2019) study its effect both on political participation and on the size of the government. Billari et al. (2019) find that broadband access had a positive effect on high educated women's fertility. DiNardi et al. (2019) assess the impact of internet on obesity, finding a small positive effect on white women.

This paper is structured as follows. Section 2 describes the institutional setting of childbirth in England; Section 3 describes the process of internet diffusion; Section 4 discusses the data and identification strategy; Section 5 presents some descriptive evidence; Section 6 analyzes the effect of the internet on childbirth procedures and outcomes; robustness analysis is provided in Section 7; Section 8 discusses potential mechanisms; Section 9 concludes.

2 Childbirth and the health care system in England

As in most health care systems, childbirth is the most common medical reason for admission to hospitals in England.[8] In terms of costs, it represents approximately 2.8% of NHS spending (National Audit Office 2013). There is a trend in many developed countries towards an increasing proportion of deliveries by C-section, much of which is not justified by any change in the risk profiles of mothers, leading to concerns about costs and unnecessary medical intervention

[8]More than 500,000 women give birth each year in England (Hospital Episode Statistics, Admitted Patient Care, England - 2013-14: Procedures and interventions).

(World Health Organization 2015).

In the UK, C-section rates have increased over time, from approximately 20.7% in 2000 to 24.3% in 2011. There are two types of C-section. Elective C-sections have a pre-booked date of delivery and the care pathway is locked-in in advance (Freeman et al. 2017). Emergency C-sections are generally performed when labor has started and when it becomes clear that there might be risks for the mother or baby with a vaginal delivery. This type of delivery cannot be planned in advance. Figure 1 shows both elective and emergency C-sections increased approximately by 1.7 percentage points (from 8.4% and 12.4% in 2000, to 10.1% and 14.1% in 2011, respectively). This corresponds to a 20% increase in elective C-sections and a 14% increase in emergency C-sections. While both types of C-sections have increased, elective C-sections have proportionally increased more. Concerns have been raised about the increase in first-time mothers having C-sections, even though many have not had any problems during their pregnancy.[9]

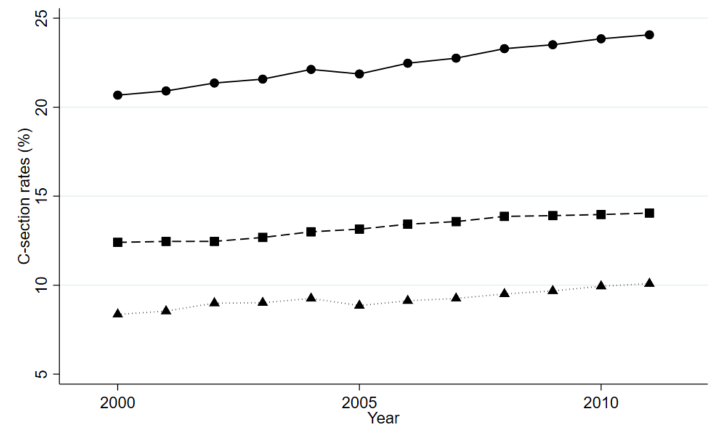

Figure 1: C-section rates over time. Overall C-section rate in circles; emergency C-section in squares; and elective C-section in triangles.

Health care in the UK is tax financed. The vast majority of health care, including maternity care, is provided by the NHS.[10] NHS hospitals are publicly funded and known as NHS Trusts. In order to access maternity care, pregnant women can self-refer to a midwife or go through their General Practitioner (GP), with the vast majority opting for the latter (House of Commons 2003).[11]

[9]https://www.theguardian.com/society/2016/jan/31/caesarean-health-risks-c-section-first-time-mothers.

[10]There is a small private sector which specialises in routine elective care for which there are long waiting lists. Very few mothers give birth in private hospitals.

[11]Patients have a very limited choice of GP and they almost always have to choose a GP located near to where

During the period of our analysis, choice of hospital was constrained for pregnant women and they almost always delivered in a hospital in their area of residence.[12] However, there has been promotion of women's right to be involved in decisions and to have a choice in childbirth. While for other types of health care the meaning of choice was related to the right to choose a hospital, in maternity care the emphasis was put on aspects of the delivery, for example, use of an epidural anaesthetic, or birthing pool (Department of Health 1993; Thomas and Paranjothy 2001). A report from the Royal College of Obstetricians and Gynaecologists (Thomas and Paranjothy 2001) describes that "[o]ne of the priorities of maternity care is to enable women to make informed decisions regarding their care or treatment. To do so, they require access to evidence-based information, to help them in making their decisions". The same report mentions maternal request as a factor that arguably contributes to increases in C-sections.[13]

NHS employees (including midwives and obstetricians) have a fixed salary that does not depend on their performance or results (Freeman et al. 2017) and physicians are generally employed by only one NHS Trust (Gaynor et al. 2016). So while C-sections are more costly than natural deliveries, NHS employees do not benefit financially from performing them. In the period we study, hospitals were funded for maternity care from fixed budgets provided by publicly funded bodies covering specific geographic areas that have the task of buying hospital-based health care from NHS Trusts for their population (Gaynor et al. 2013). This does not provide incentives for hospitals to perform additional surgeries; in fact, this type of funding gives them pressure to reduce costs. Finally, all hospitals are subject to the same rules and incentives, independently of being located in an area with more or less internet diffusion.

2.1 Childbirth information and the internet

The amount of information about childbirth available to pregnant women has increased significantly over the past decades, with the internet being one relevant source of information. We are particularly interested in understanding how internet diffusion influenced the choices made

they live. See Gaynor et al. (2016).

[12]Hospital choice was implemented for elective care in 2006. Maternity care was not included in this reform.

[13]This topic is a long standing part of the medical debate; see, for instance, Paterson-Brown et al. (1998), NICE (2004), NIH (2006).

by mothers and whether certain types of mothers could be more influenced than others. We now consider how internet access might contribute to the formation of mothers' beliefs about childbirth procedures.

Expectant mothers become aware that they will be delivering many months beforehand. This gives them time to search for information if they wish to do so. Evidence shows that internet users search for health information online (Fox and Duggan 2013), and this holds true for pregnant women. Pregnant women are in age groups that are more likely to use the internet. According to the second US nationwide survey collected in 2006 on women's childbearing experiences, 76% of respondents stated they had accessed the internet for information about pregnancy and childbirth (Declercq et al. 2006). In the UK, a national survey of women's experience of maternity care found that 42% of women used non-NHS websites during their pregnancies (Redshaw and Heikkila 2010). We also verified, using google trends (which covers January 2004 onwards), the recurrence of queries such as 'childbirth' or 'C-section'. They all show a rising trend in the interest index, particularly from 2006.[14]

In addition, there is evidence of a sizable difference in the search for information – across all sources – between first- and multiple-time mothers. Redshaw and Heikkila (2010) surveyed a representative sample of women who gave birth in England (Figure 6 in the Appendix). First-time mothers visited more information outlets than multiple-time mothers. On average, 67% of mothers read or consulted the NHS pregnancy book with a predominance of first-time mothers whose share is 79%. Similarly, both the NHS website and other pregnancy websites and blogs attracted more first-time mothers (16% and 49%, respectively) than multiple-time mothers (8% and 39%, respectively).[15] Finally, an important source of antenatal information were pre-natal courses, which were attended mostly by first-time mothers.[16]

The evidence shows that mothers with less experience search more for information, both offline and online. While exactly what women searched for is not known, there is considerable

[14]While this does not distinguish between treated and control groups with respect to internet availability, it does confirm that the internet was used as a source of specific health information in the UK during the period we study, and progressively so. Copies of the google trend graphs are available upon request.

[15]Note that in 2010 broadband internet penetration in the UK was approximately 75% of households.

[16]Differences between first-time and multiple-time mothers with respect to sources of information during pregnancy were also found in the US (Declercq et al. 2006). Moreover, for those mothers using the internet, usage was heavy.

information about the risks and benefits of different modes of childbirth delivery. The most commonly cited benefits of a C-section include greater safety for the baby, less pelvic floor trauma for the mother, avoidance of labor pain, mother's fear of having a vaginal birth, the belief that there is a lower risk of fetal injury/death (Wiklund et al. 2007), preference for having a known date of delivery, and a decreased risk of postpartum hemorrhage (National Institutes of Health 2006). Some of the most common disadvantages are excessive bleeding, increased risk of complications in future pregnancies, and a higher risk of maternal death. Vaginal deliveries tend to have shorter hospital stay and recovery time but may entail a greater risk of obstetric tears and trauma to mothers along with incontinence (Lavender et al. 2012).

Future mothers can gather online information from different sources (e.g., parenting websites, blogs, newspapers, scientific journals). This poses a challenge in terms of the accuracy and interpretation of this information. While scientific articles are more reliable, they are also more difficult to understand and access for the lay reader. On blogs and websites the quality of the information presented is generally not verified. The exception is official medical websites, where there is an effort to update online content so that pregnant women can use it as a source of information. This is the case for the US National Institutes of Health and the UK NHS. However, these efforts only started in 2010. An advantage of blogs and non-governmental websites is that pregnant women can read online about other mothers' experiences during pregnancy and birth and share stories and concerns in an informal way. Internet diffusion spurred the proliferation of blogs and websites supporting both childbirth methods. Those supporting C-sections emphasized the right to have one (not all mothers are aware of the possibility to ask for this procedure) as well as the physical and psychological consequences that may follow from a natural delivery.[17]

During the period we study, the UK media reported many cases of celebrities who chose to have a C-section. This lead to the expression "too posh to push"[18] and may have created the idea that mothers making this choice are wealthier, famous, highly educated, or from a higher

[17] The right to have a C-section seems to be particularly important for tokophobic mothers, i.e., "women who dread and avoid childbirth" (Hofberg and Brockington 2000).

[18] http://content.time.com/time/magazine/article/0,9171,610086-1,00.html. Weaver and Magill-Cuerden (2013) note that the first article using this expression was published in the Daily Mail in 1999.

social class.[19] When analyzing the main UK national newspapers using the expression ”too posh to push”, Weaver and Magill-Cuerden (2013) find that the media contributed to the idea that it is common for mothers to request a C-section, and to an association between the expression and celebrities. Alves and Sheikh (2005) find evidence in favor of the “too posh to push” hypothesis in the UK: mothers from richer areas are more likely to request an elective C-section.

Finally, internet diffusion should not have an impact on physicians' likelihood of performing a C-section. Physicians have expertise from many years of training and know the costs and benefits associated with both delivery methods. They do not need to rely on the internet to obtain this information. However, even if some physicians do use the internet more, our design is such that the mothers we compare give birth in the same hospitals. Thus differential access by providers of care should not affect our results.

3 Internet diffusion in England

The diffusion of broadband internet in England started in the late 1990s and, during the time period considered in this paper, most of the internet access took place through the telephone network (with an aggregate market share of 80%), the only technological alternative being the cable network (accounting for the remaining 20%).[20] Providing internet access over the telephone network required a technological upgrade (from analog to digital), but its broad footprint remained unchanged. The network is made of several nodes, called local exchanges (LEs), connected to each other. Each LE serves a number of houses connected via a fixed line, often called “the last mile”. The ADSL technology, which enables the transmission of digital signals over the telephone network, requires to install special equipment in the LEs and to replace the connections between LEs and the backbone with faster lines. This process of upgrade took several years, both because of the size of the investments and because of the regulatory framework.

The evolution of the broadband market until 2011 can be divided in two parts: an early phase with slow take up, which spanned the years going from the end of the 1990s to the middle of the

[19] http://www.dailymail.co.uk/health/article-1388203/Too-posh-push-Caesareans-common-middle-classes.html.

[20] Mobile and fiber network jointly account for only 1% of internet access over the time period we consider.

2000s, and the second phase of sustained growth, in the second part of the 2000s, when internet access finally took off and became widely diffused. These two phases were the result of two set of factors: institutional and market factors, and technological factors.

The UK internet market, like for other European countries, was initially dominated by large incumbents (usually the former state-owned national champion) which could transfer their dominant position in the telephone market to the new market of internet access, and maintain it thanks to the high entry barriers typical of a network industry. This context, which did not favor the entry of new players in the market, changed when EU member States implemented, through their national authorities, a set of EC directives, the so-called *open-access* regulation.[21] The regulation introduced by the British regulator (Ofcom) consisted of three elements. First, it required British Telecom (BT), the owner of the telephone infrastructure, to functionally separate into two entities: Openreach, which became in charge of the maintenance of the network, and BT Wholesale, which leased the lines to entrant internet operators. This separation followed the repeated claims of entrant operators lamenting the attempts of BT to exclude them from the market, and became effective in 2005. Second, BT was mandated to enable all LEs to host entrant operators, which had the opportunity to make investments in the LEs by installing their own equipment, and so to serve their costumers using the network of BT-Openreach. This technological option is known as *local loop unbundling* (LLU hereafter). It took approximately 3 years (from 2003 until the middle of 2005) to enable the LEs. Third, the wholesale price of leasing an internet line to entrants was regulated and, subsequently, twice revised downwards in 2004 and 2007. These regulatory interventions contributed to increase the competition in the market for broadband internet access. The number of internet service providers grew rapidly and the market share of LLU operators went from only 2.2% at the end of 2005 to 40% at the end of 2009, thus becoming (in aggregate) the most popular choice among internet users. Hence, from a regulatory and market perspective, the moment that marked a significant change in the history of broadband in UK is the end of 2004 and the beginning of 2005.

The technological factors are related to the problem of transmitting data efficiently over the network. The growth in broadband internet penetration required the development, and the roll-

[21] Regulation EC 2887/2000 and Directive 2002/19/EC.

out, of faster technologies for digital data transmission. To create the conditions for a broadband internet era, BT and (later) its competitors, engaged in a roll-out process of newer technologies in the LEs in order to provide faster and more reliable internet connections. The first configuration was ISDN (Integrated Services Digital Network), which cannot be considered broadband due to the very low data transmission speed (128Kbit/s at most under ideal conditions). The second configuration, which was the first significant upgrade, was the first version of ADSL which reached nominal speeds of 2-4Mbit/s, and up to 8 Mbit/s for premium subscriptions. The bulk of the roll-out took place between 2003 and 2005, when 80% of the LEs saw the arrival of at least 1 entrant.[22] The third and next technological configuration was the combination of ADSL technologies and the presence in the LE of investments under LLU. As shown by Nardotto et al. (2015), the main effect of this policy was to promote investments, and thus competition, which increased substantially internet access quality. The change in market environment started in 2004-2005 and continued in the following years, when most of the LEs received (ADSL) LLU investments. Finally, the fourth technological step, allowing nominal speeds up to 24 Mbit/s was the introduction of ADSL2+, which started in 2008 and continued in the following years (again under LLU). Hence, also from a technological perspective, the pivotal years for the transition to broadband internet are the 2004-2005, when finally ADSL becomes widely available to users, and this technological possibility could be converted into actual adoption. In summary, the middle of the 2000s, and in particular the regulatory changes introduced in 2004-2005, profoundly affected the UK's broadband market, leading to sizable investments and, as we discuss next, take up by final users.

The left panel of Figure 2 reports the evolution of broadband internet penetration, and reflects the effect of the two elements just discussed. The change in the pace of the diffusion process is remarkable. In the 5 years between the beginning of 2000 and the end of 2004,

[22]The installation of the necessary equipment to provide internet access followed a preliminary upgrade of the LEs made by BT. This upgrade took place mostly between 1999 and 2003 when 90% of the LE were prepared to host the new technology. During the 4 years between 1999 and the end of 2002 the share of LEs with at least 1 ADSL operator grew to 20% overall. Then, the yearly shares of LEs upgraded in 2003, 2004, and 2005 were 18%, 34%, and 27%, respectively. The main shortcoming of this initial phase, which was later solved by LLU under *open access*, is that all connections were still managed by BT through the *Bitstream* technology, which meant that ISPs had to rely almost entirely on BT to provide access (that technology is often put at the same level as re-selling) and had both a limited scope for cutting on costs (and prices), and no possibility to invest on the quality of the service.

broadband internet penetration rose from zero to 16% of households, whereas in the following 5 years it jumped to 70% and then continued to grow. The right panel of Figure 2 reports

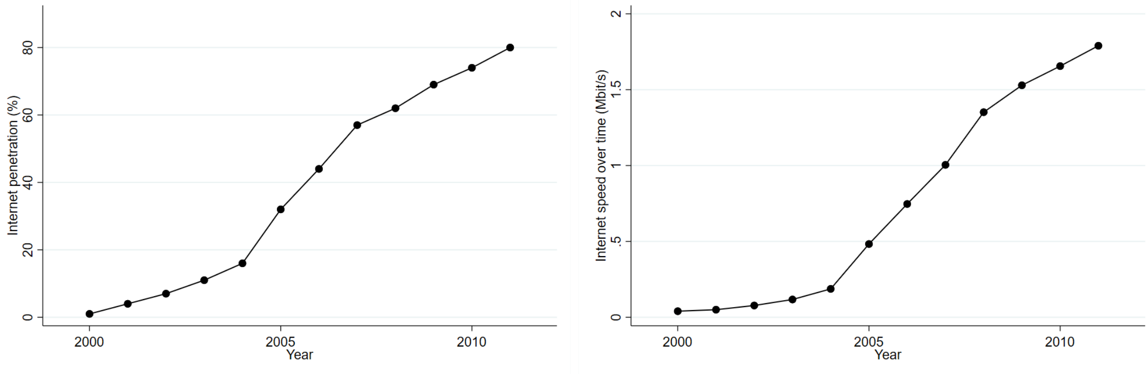

Figure 2: Left panel: Broadband internet penetration between 2000 and 2011. Source: Eurostat. Right panel: average actual speed in Mbit/s between 2000 and 2011, weighted by overall internet penetration.

the evolution of broadband speed. Similarly to what happened to broadband penetration, the growth rate of the average actual speed (as measured by speed tests, see Section 6.1 for more details), also changed after 2005 as a result of the investments made by the incumbent and, more importantly, by the many market entrants which outperformed BT in terms of internet speed.[23]

4 Data and identification

Our empirical analysis seeks to identify the effect of internet diffusion on the health care decisions of expectant mothers and their health care outcomes. For this purpose, we combine several sources of data, as described below.

Internet data: The data on internet diffusion are provided by Ofcom and have been previously used by Nardotto et al. (2015) and Ahlfeldt et al. (2017). The data contains detailed information on the telephone infrastructure. In particular, it reports the exact location of each LE (the geographic coordinates) and all postcodes (7-digits) served by each LE.[24] There are

[23] For more details on the effects of open access regulation see Nardotto et al. (2015). The rest of the broadband market was covered by the (only) cable operator, Virgin Media, which was the only alternative to the ADSL technology in the years we consider (mobile broadband was virtually not available; WiFi is instead included in our dataset). Virgin Media built a completely private network during the 1990s to sell cable-TV. The network deployed by Virgin Media was limited to the most densely populated areas of the country. In total, the market share of Virgin Media was approximately 20%. Virgin Media was not subject to open access regulation and never granted entrant internet providers access to its network.

[24]There are approximately 1.7 million active postcodes in the UK. On average, a postcode covers an area with a

5,587 LEs in the UK, of which 3,832 are in England. The information on the network topology is complemented with data on the technology adopted in each LE/year. This provides us with further variation over time and enables us to estimate the quality (speed) of the broadband connection at the local level (see Section 6.1).[25]

Data on demographic characteristics: Data on socio-demographic characteristics come from the UK Census, available at the small area level we examine. We use information on age structure, employment, and ethnicity. We also use the Index of Multiple Deprivation (IMD) Income Domain and the IMD Education Training and Skills Domain. IMD indices are constructed so that higher values imply higher deprivation.[26]

Childbirth data: We use data from the UK Department of Health's Hospital Episode Statistics (HES) dataset for the financial years 2000 to 2011. The HES is an administrative dataset containing information on every English NHS hospital inpatient admission. The data contain detailed information on patients' conditions at admission to hospital and during their stay and on the medical procedures received by the patient.[27]

Using these data, we start by constructing variables that indicate risk factors such as diabetes, anemia, cardiac and lung conditions, previous abortion, previous C-section, placenta previa, multiple delivery (twins), eclampsia, hypertension, obesity, baby in breech position, fetal distress, and cephalopelvic disproportion. The presence of high-risk factors increases the likelihood of having a C-section (Currie and MacLeod (2008) and Frakes (2013)). We separate multigravida mothers (multiple-time mothers, i.e., those who had at least one previous pregnancy) and primigravida (first-time) mothers. We also examine the utilization of induction of labor and episiotomy during vaginal delivery. Episiotomy utilization is indicated in the presence of certain complications of birth (e.g., abnormal presentation, fetal distress).

radius of 50 meters, but it is often smaller (*i.e.*, a building) in urban areas.

[25]Contrary to Nardotto et al. (2015) and Ahlfeldt et al. (2017), in this paper we do not use information on penetration, as it is not available at the local level of disaggregation we study. Ofcom did not collect detailed information on the evolution of the broadband market prior to 2005. In the US, the FCC also started a detailed data collection only in 2008.

[26]http://webarchive.nationalarchives.gov.uk/20120919132719, and http://www.communities.gov.uk/documents/communities/pdf/131206.pdf.

[27]Patients' conditions are classified according to the ICD-10 codes from the International Classification of Disease. Procedures are classified according to OPCS codes, which is a procedural classification for the coding of procedures, operations and interventions performed in the NHS, and equivalent to the CPT codes in the US.

We examine several measures of health care outcomes of mothers and newborns. With respect to maternal outcomes, we examine co-morbidities, prolonged labor and mothers' trauma during all vaginal deliveries (the last has been used by regulatory authorities as a measure of quality of maternal treatments).[28] For newborns, we examine prematurity, low birth weight, fetal distress, stillbirth, the need for resuscitation measures, and whether the newborn was discharged home or died/stayed in hospital. Finally, the discharge data contains an important variable for our identification strategy: the lower layer super output area (LSOA) of the patient's home.[29] There are approximately 32,000 LSOAs in England.

Identification. Our identification strategy relies on the discontinuities in internet distance between the premises where mothers live and the LE to which they are connected. Such discontinuities are generated by the topology of the telephone network, and are caused by the characteristics of the ADSL technology. We exploit the distance as a source of variation because the main challenge when transmitting a digital signal over the telephone network is the decay in its strength, decay that increases with the distance traveled. The telephone network, being designed to provide (analog) voice services, was entirely made of copper lines, which are unfortunately characterized by a strong decay when used for transmitting digital signals (contrary to optical fiber, which has almost no decay). This forced the deployment of fast (fiber) connections for the backbone connecting the LEs of the telephone network to guarantee that, at least until the LE, the transmission speed was sufficiently high to provide broadband services. After that point though, i.e. between the LE and the house, it was just too costly to employ fiber for the local distribution, and it was much cheaper to upgrade the existing copper lines via ADSL. This meant, however, that the last mile suffered from increasing decay with distance.[30]

In its 2011 annual report, Ofcom stated: *"A characteristic of ADSL broadband is that performance degrades due to signal loss over the length of the telephone line. This means that the*

[28]Traumas are equivalent to Patient Safety Indicators (PSIs) 18 and 19.

[29]See: `http://www.ons.gov.uk/methodology/geography/ukgeographies/censusgeography` for more information on the UK Census geographies. The are approximately 600 households in each LSOA.

[30]The obvious alternative to the telephone network would be the creation of a fully fiber network with all copper connections replaced by fiber ones. This system is referred to as fiber-to-the-home and deployments costs are very high. It is now slowly making progress, again starting with the most densely populated areas. This process started well post 2011 and hence it is not in our sample.

speeds available to different customers vary significantly, with those with shorter line lengths (i.e. who live closer to the exchange) typically able to achieve higher speeds than those with longer line lengths. [...] We found that the average download speed received for 'up to' 20Mbit/s or 24Mbit/s ADSL packages was 6.6Mbit/s, and 37% of customers had average speeds of 4Mbit/s or less". This strong decrease in speed performance indicates the different conditions households had with regard to the quality of their connection depending on location. For many years after the introduction of the first vintages of ADSL, i.e., between 2004 and 2008 when maximum (and advertised) line speed was just 2-4Mbit/s, being located further than 2km away from the LE meant having very poor internet access quality, i.e., a speed just sufficient for very basic internet activities (such as emails).[31]

Furthermore, Geraci et al. (2019) document – using data from the British Household Panel Survey for the same years that we consider in this paper – that distance to the LE also has a negative impact on the decision to buy an internet subscription. Thus, the reduction in quality due to distance produced a twofold effect: it decreased internet use by reducing the quality of the service, and it reduced internet access by inducing households to avoid buying a subscription in the first place.

The interplay between quality decay and the spatial configuration of the telephone network, which results in discontinuities in the distance between the dwellings and the LEs is the core of our identification strategy,[32] which we illustrate in Figure 3, and consists of the following steps. First, we identify pairs of neighboring LSOAs that are served, in a sufficiently large proportion, by different LEs.[33] More precisely, each LSOA must have at least 95% of its postcodes served

[31]To give an idea of the differences in the type of access of users with different internet speed, we can consider the case of moving from 128-256Kbit/s to a speed of 1-2Mbit/s. The FCC sets to 1Mbit/s the threshold for general browsing and email at a reasonable latency (and assuming only 1 connected device) and 3-4MBit/s the streaming of a SD video (see: https://www.fcc.gov/consumers/guides/broadband-speed-guide). Furthermore, the simple loading of the Google home page, requires 5s when connected with a (stable) 256Kbit/s connection, while just 0.6s when connected with a 2Mbit/s connection. Downloading a 20MB video clip takes 10 minutes with a 256Kbit/s connection, while under 1 minute with a 2Mbit/s connection (see Katz and Berry 2014). Also, with a poor connection the user's experience is affected by the longer waiting time, and by a greater likelihood of faults.

[32]The original analog infrastructure was not meant to offer digital services and its roll-out, which took place in the 1930s, and did not take into consideration the problem of signal decay. Thus, LEs are not located in a way that minimizes the average decay suffered by the households they serve. Moreover, these areas can be very heterogeneous in size and shape even in urban areas.

[33]The borders of the catchment areas of LEs do not follow any census or administrative pattern so it is virtually impossible to find LE borders perfectly overlapping LSOA borders.

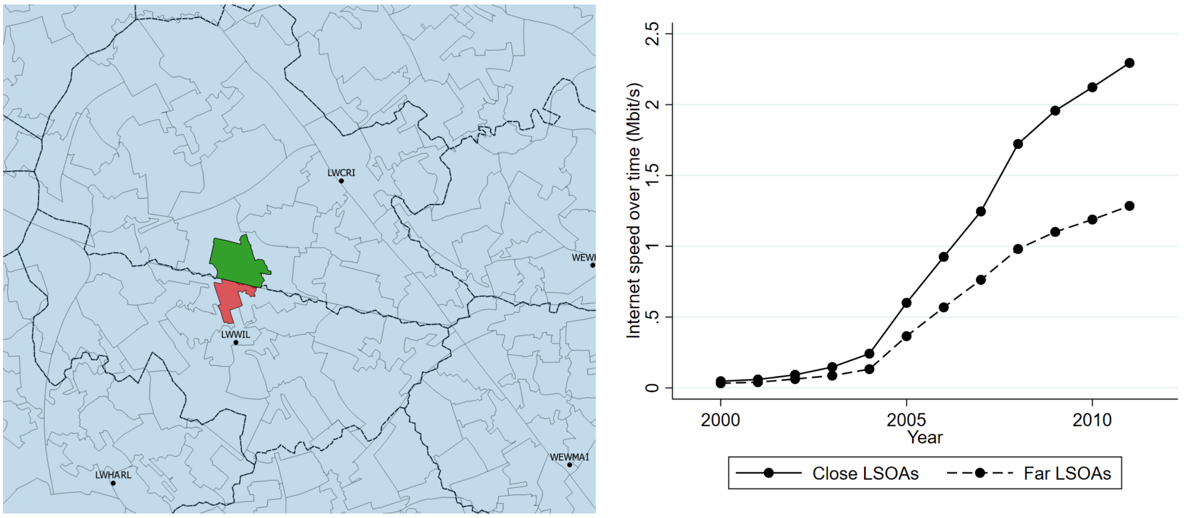

Figure 3: Left panel: The map shows the borders of LEs (bold dashed lines), the locations of the LEs (black dots with LEs' names), and the LSOAs areas (light blue areas delimited by light grey lines). An example of matched LSOAs is given by the pair of LSOAs filled in red and green. They share a border but belong to two different LEs. The LSOA below the border (in red) is connected to a *close* LE labeled `LWWIL` while the LSOA above the border (in green) is connected to a *far* LE labeled `LWCRI`. Right panel: average predicted real internet speed over time, in *close* and *far* LSOA, weighted by overall internet penetration.

by only 1 LE and the two LEs serving the neighboring LSOAs must be different. This reduces substantially the number of LSOAs that we can use but still leaves a sufficient number, as LSOAs cover smaller geographical areas than LE catchment areas. On average, there are 8 LSOAs in each LE. Second, we verify that mothers living in the matched LSOA pairs have balanced demographic characteristics (see Section 5). Third, we compare the health choices of the mothers living in the matched LSOAs, and in our regressions models we also control for a large set of factors, including individual characteristics and locality trends (see Section 6).

We identify 1,209 pairs of LSOAs that we use to estimate the causal impact of internet access on health care choices and outcomes. Each pair of LSOA consists of one *close* LSOA and one *far* LSOA with respect to the distance to their corresponding LE. In the next section, we show that these pairs have balanced demographic and mothers' characteristics. Importantly for the interpretation of our results, we find that 97.5% of mothers in the matched LSOAs deliver in the *same* set of hospitals, which is consistent with the difference in size between the catchment areas of hospitals and of LSOAs, with the former being much larger than the latter (and also larger than the catchment areas of LEs).[34] We also show that the matched LSOAs,

[34]The number of LSOAs, LEs and hospitals in England are approximately 32,000, 3,800 and 400 respectively,

and the mothers living in these LSOAs, are very similar in characteristics when compared with the non-matched LSOAs and with the remaining mothers in the HES data.

The procedure just highlighted gives a sample of mothers who have balanced characteristics, live in the same neighborhood, but differ in their distance to the LE, whose consequence in terms of internet quality can be appreciated in the right panel of Figure 3 which reports the average internet speed for the two groups of mothers.[35] In this figure, as in Figure 2, we can observe the general and rapid improvement in access conditions starting in 2005; however, the gains in internet speed are much larger for those mothers who are located in the *close* LSOAs due to the difference in distance between their houses and the LE to which they are connected.

This identification strategy is similar in spirit to those in Ahlfeldt et al. (2017), Faber et al. (2015), and Falck et al. (2014). The strong decrease in the actual speed of internet connections at greater distances is measured in Ahlfeldt et al. (2017), who find a 65% decline in speed between two houses located at 1km and 3km from the LE and exploit the discontinuities in internet speed to measure the impact of better internet conditions on house prices.[36] Falck et al. (2014) use data from Germany between 2005 and 2008 and focus on a 4km threshold, above which there was virtually no broadband internet availability. They compare municipalities located below and above this threshold to study the role of internet diffusion on electoral turnout.

5 Descriptive evidence

5.1 Summary statistics and trends in childbirth procedures

Panel A of Table 1 reports summary statistics of the demographic variables collected by the Census in 2001 (upper part) and 2011 (lower part) at the level of the LSOA. These are the last

with size of their catchment areas reflecting (inversely) their number.

[35]See Section 6.1 for more details on the calculation of the speed at the local level.

[36]The findings in Ahlfeldt et al. (2017) might raise concerns about a possible bias in the estimated effect of internet quality on childbirths. However, a number of reasons contributes to make a strong case for our identification strategy. Firstly, we find balanced socio-demographic characteristics on either side of the geographical discontinuity (i.e., when we compare *close* and *far* LSOAs). Secondly, the choice of the childbirth procedure (our outcome) is not influenced by any price consideration because the service is provided for free and the availability of information is the main driver of choice. Thirdly, our empirical model includes LSOAs pair FEs interacted with trends to account for time changes in the relative share of high/low income workers in the paired LSOAs.

two waves of the Census, which is collected every 10 years. The left side of Panel A considers the full sample of English LSOAs while the right side of the table considers the subsample of matched LSOAs, *far* and *close*. Panel B of Table 1 reports summary statistics of mothers' characteristics from HES: the full sample of mothers, and those living in the matched LSOAs. The statistics and the tests reported in Table 1 can be read in two ways. The first is to focus on the difference between the means of the variables of the full samples (both in Panel A and in Panel B) and the means of the variables of the matched sample; these means are very close, indicating that the matched LSOAs are very similar in characteristics to the rest of the LSOAs. This suggests that our findings have external validity. The second aspect is the balance in characteristics between *far* and *close* LSOAs (Panel A) and between the mothers living in these areas (Panel B). Panel A shows that LSOAs (*i.e.*, the neighborhood where mothers live) have balanced characteristics, as most of the tests do not reject the null hypothesis of equal means. Importantly, this holds both at the start and at the end of the sample period, indicating that over the years *close* LSOAs did not attract households with different characteristics with respect to *far* LSOAs, indicating that migration in response to different internet penetration does not seem to pose a problem to identification in our case.

The only demographic variable in Panel A for which the test rejects the null hypothesis of equal means is the share of population aged between 20 and 44 years old (p-value is 0.031) in Census 2001. Panel B, which reports summary statistics of mothers' characteristics, also shows good balance between *close* and *far* mothers. Variables' averages are very close and only in two cases we reject the null hypothesis of equal mean: age at delivery and the share of mother with diabetes. The average age of *close* mothers is 29.6 years old while the average age of *far* mothers is 29.3 years old. Despite the difference being small, it is statistically significant due to the large sample size. We address this concern in one of our robustness checks (see Section 9.2 in the Appendix) where we re-balance the samples with respect to age and verify that our results are not affected.

It is important to notice that, despite small imbalances in some variables, we find that the difference in C-section rates in 2000 for *close* and *far* mothers is not statistically significant (C-section rates are 20.87% and 21.1% respectively, as reported in the last row of Table 1).

Table 1: Summary statistics.

A. LSOA Demographic characteristics	**Full sample N=32,482**				**Matched sample N=2,418**		
Variable	Mean	Std.	Min	Max	*Close*	*Far*	P-value
Census 2001							
Population	1512.80	198.67	999	6537	1509.75	1506.16	0.590
Age 20-44 (%)	35.29	8.36	7.55	83.08	35.10	35.81	0.031
Full-time workers (%)	40.74	8.25	4.14	83.83	41.41	41.27	0.663
Part-time workers (%)	11.88	2.70	0.57	26.97	11.73	11.75	0.895
White (%)	90.99	15.00	4.64	100.00	89.94	89.41	0.387
High skill workers (%)	41.54	9.36	11.54	92.04	42.78	42.17	0.112
Number of deliveries (yearly)	15.97	15.01	1	2264	15.59	16.09	0.126
Census 2011							
Population	1614.07	301.29	983	8300	1611.72	1604.70	0.521
Age 20-44 (%)	33.87	9.94	9.90	95.20	33.33	33.84	0.161
Full-time workers (%)	38.61	7.77	3.30	79.10	38.89	38.79	0.737
Part-time workers (%)	13.92	2.74	0.90	27.80	13.84	13.87	0.721
White (%)	86.23	18.72	0.60	100.00	84.65	83.83	0.298
High skill workers (%)	43.35	8.94	7.50	85.50	44.43	43.99	0.237
Number of deliveries (yearly)	19.80	24.84	1	4026	19.68	20.46	0.113
Distance LSOA - LE (km)	2.45	1.40	0.08	12.67	1.71	3.19	0.000
B. Mothers' characteristics	**Full sample N=7,033,942**				**Matched sample N=522,751**		
Variable	Mean	Std.	Min	Max	*Close*	*Far*	P-value
Mean age	29.34	6.05	13	59	29.61	29.32	0.000
Twins (%)	1.57	12.43	0	100	1.6	1.57	0.357
Anemia (%)	4.50	20.74	0	100	5.01	5.1	0.136
Breech position (%)	5.67	23.13	0	100	5.69	5.69	0.959
Cardiac and lung (%)	0.24	4.86	0	100	0.26	0.24	0.189
Cord (%)	2.44	15.44	0	100	0.02	0.02	0.104
Diabetes	2.06	14.22	0	100	2.4	2.46	0.041
Cervix (%)	0.19	4.31	0	100	0.21	0.2	0.443
Hypertens. eclampsia (%)	3.52	18.44	0	100	3.54	3.46	0.128
Previous C-section (%)	7.52	26.36	0	100	7.62	7.64	0.804
C-section in 2000 (%)	20.68	40.50	0	100	20.87	21.10	0.571

Notes: **Panel A**. *Population* is the number of inhabitants in the LSOA. *Age 20-44* is the share of people aged between 20 and 44 years old. *Full-time workers* and *Part-time* workers are the shares of people aged between 16 and 64 years old who are employed with a full-time or part-time job respectively. *White* is the share of whites. *High-skilled* is the share of people aged between 16 and 64 years old working in financial intermediation and business activities, public administration and defense, education, and health care. *Number of deliveries* is the yearly number of deliveries in the LSOA. *Distance LSOA - LE* is the linear distance in kilometers between the geographical centroid of the LSOA and the local exchange that serves the LSOA. **Panel B.** *Age* is the mother's age in years at the moment of the delivery. Variables *Twins* to *Previous C-section* and indicator variables for mothers' risk factors: multiple deliveries (twins), anemia, whether the baby is in breech presentation, whether the baby suffers from a cord related problem, cardiac or lung conditions, diabetes, cervix problems, hypertension or eclampsia, and whether the mother had a previous C-section. *C-section in 2000* is an indicator variable for cesarean delivery where we restrict the sample to mothers who delivered in year 2000.

Furthermore, we do not find a statistically significant difference between treated and control areas in the number of yearly deliveries. Finally, due to our identification strategy, *close* and *far* LSOAs display a large difference in their distance to the respective LE. *Close* LSOAs are located on average 1.71 km away from the local exchange whereas *far* LSOAs are located on average 3.19 km away, almost twice as much.[37]

6 The effect of the internet on childbirth

We now examine how access to the internet affected childbirth in England. We focus only on the matched LSOAs, in which we distinguish between *close* and *far* LSOAs. A first piece of evidence on the effect of the internet is in Figure 4 which reports C-section rates over time in the *close* LSOAs (dark grey) and in the *far* LSOAs (light grey). We interpolate the yearly rates of both groups of LSOAs with a kernel local polynomial smoother. The figure shows that in the

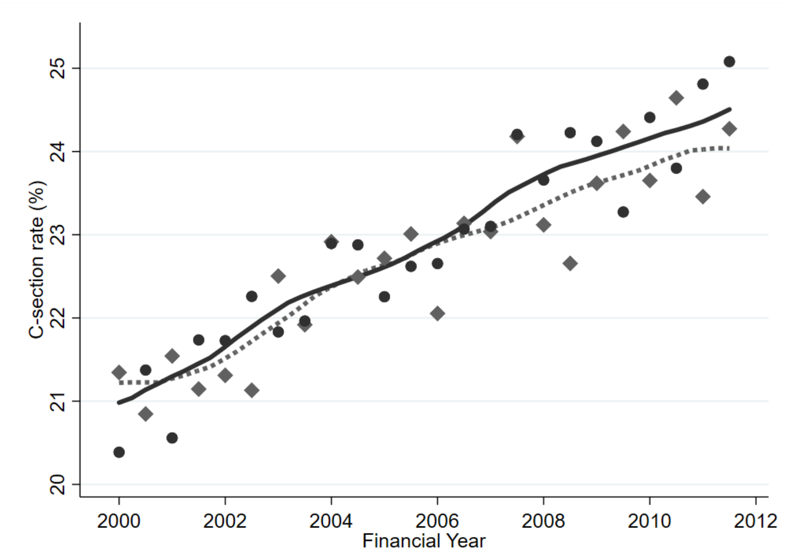

Figure 4: C-section rates over time. *Close* LSOAs are reported in black (solid line and circles) while *far* LSOAs are reported in light grey (dashed line and diamonds).

first part of the period, when overall internet penetration was very low, the two groups had very similar C-section rates. With the growth of internet penetration after 2005 and the widening of

[37] As discussed in footnote 23, the main technological alternative to ADSL during the period we consider is represented by the cable operator Virgin Media, whose market share is approximately 20%. We test for systematic differences in cable coverage between *close* and *far* LSOAs and we conclude that *close* and *far* LSOAs are balanced also in terms of the alternative technology to access the internet.

the speed gap, *close* LSOAs experienced a more rapid growth of C-section rates compared to *far* LSOAs. To exactly locate the point of divergence in time, hospital financial year runs from April 1st of the previous year to March 31st of the current year, and mothers become pregnant approximately 9 months before the delivery. Hence, the divergence that we observe in 2006 is due to mothers who got pregnant and looked for information in the late 2004 and in 2005.[38]

The matching procedure described above allows us to perform a conditional difference-in-differences analysis to measure the effect of internet access on health choices. We compare mothers living on the two sides of the LSOAs' border, before and after the diffusion of the internet. Our regression model is:

$$\begin{aligned} y_{ijht} =& \delta_1 Close_j + \delta_2 Post_t + \delta_3 Did_{jt} + \beta X_{ijht} + \\ & + Time_t + LSOA_j + Hospital_h + LPTime_{jt} + \varepsilon_{ijht} \end{aligned} \tag{1}$$

where i indicates the mother, j the LSOA, h the hospital where the delivery takes place, and t the year. The dependent variable y_{ijht} is the outcome of interest. The outcomes we focus on are: i) the probability of having a C-section (all, elective and emergency); ii) mothers' procedures and outcomes (induction of labor, episiotomy, co-morbidities, anaesthetic, prolonged labor, prolonged pregnancy, and maternal trauma/tears); and iii) newborns' outcomes (premature, low birth weight, distress, stillbirth, resuscitation measures, discharged or died/stayed in hospital).

The controls we use are as follows. X_{ijht} is a vector of mothers' characteristics, including age of the mother, the number of previous pregnancies, and risk factors. The presence of some risk factors (e.g., diabetes, obesity, cardiac or lung conditions, previous abortion, fetal distress, breech position, cephalopelvic disproportion, multiple pregnancy, placenta previa, eclampsia and hypertension) strongly predicts the performance of a C-section (e.g., Currie and MacLeod 2008, Frakes 2013). $Time_t$ is a set of yearly time-effects. $LSOA_j$ are area fixed-effects that control for time-invariant unobserved factors at the level of the local area, $Hospital_h$ are hospital

[38]The change in C-section rates between *close* and *far* LSOAs can be appreciated in the two panels of Figure 7 in the Appendix, which reports the difference between *close* and *far* LSOAs, for all mothers and for first-time mothers. The figure, in line with Figure 4 and Figure 3, shows that in the first part of 2000s when the internet gap is very limited, the two groups display a small difference in C-section rates. This gap increased in the second part of the decade, when the internet gap widened, in particular for first-time mothers.

fixed-effects that control for time-invariant unobserved factors at the level of the hospital, and $LPTime_{jt}$ are LSOA pair fixed-effects interacted with linear trends, so to control for trends at the level of the mothers' neighborhood.[39]

The variables related to the effect of internet diffusion on the outcomes are $Post_t$, $Close_j$, and Did_{jt}.[40] The variable $Post_t$ takes value 0 before the financial year 2006 and value 1 thereafter.[41] This choice is motivated by the path of diffusion of broadband internet access in England, documented in Section 3. Internet penetration in the first part of 2000s was very limited. As reported in Figure 2, before 2005 broadband internet penetration was less than 20%, which means that the vast majority of mothers did not have broadband internet access. *A fortiori*, the difference in internet access between *close* and *far* LSOAs was very small before that year, if not zero. Similarly, the speed differential between areas became larger only after the rapid diffusion of the ADSL technologies introduced in 2004 and 2005, as shown in the right panel of Figure 3. In sum, the spatial difference in internet diffusion we seek to exploit started with the rapid growth of internet penetration, i.e., from 2005 onwards and *post-treatment* mothers are those who had their delivery starting from April 2005, which means that they got pregnant in the second half of 2014 or later. $Close_j$ is an indicator that is 1 if the mother lives in a *close* LSOA, and thus has better internet access compared with the counterfactual mother living in the *far* LSOA, due to the decay in internet quality discussed in Sections 3 and 4. The variable Did_{ij}, which captures the causal effect of internet on the outcome, is the product of $Post_t$ and $Close_j$ and thus is an indicator variable that takes value 1 if the mother lives in a *close* LSOA and if the childbirth takes place in the financial year 2006 or later. In Section 7 we provide a robustness check where we vary the start of the treatment period, and in Section 6.1 we present regression results where we use our measure of internet speed as main explanatory variable in place of the difference-in-differences approach of this section.

Table 2 reports the first results on the effect of the internet on C-sections. Models (1) to (3) consider all types of deliveries, with the following differences: model (1) considers all moth-

[39]We also estimate a regression model where we introduce LSOA-pairs × Year fixed-effect, in place of local trends. As shown in Table 8 in the Appendix, results do not change if we use this alternative specification.

[40]The variables $Post_t$ and $Close_j$ drop out in the estimation, due to inclusion of $LSOA_j$ and $Time_t$ fixed effects, but we include them in (1) and we discuss them for the sake of explaining our identification strategy.

[41]The financial year 2006 runs from April 1st, 2005 to March 31st, 2006.

ers; model (2) considers the subsample of multiple-time mothers; and model (3) considers the subsample of first-time mothers. Models (4) to (7) exclude emergency C-sections with model (4) considering all mothers; model (5) focusing on multiple-time mothers; model (6) focusing on first-time mothers; model (7) using the sample of first-time and multiple-time mothers. Finally, model (8) focuses on the probability to perform an emergency C-section against any other delivery method.

Table 2: Regressions C-section model.

Dependent variable:	**Probability of C-section**						**Probability Emergency C-section**
	All deliv. types			Vag del and Elective C-sec			All deliv. types
	All	Mult-time	First-time	All	Mult--time	First--time	All
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Did	0.52**	0.22	1.36***	0.38**	0.47*	0.52*	0.17
	(0.22)	(0.32)	(0.48)	(0.15)	(0.26)	(0.28)	(0.20)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.307	0.437	0.232	0.482	0.574	0.377	0.138
Observations	522446	220356	135469	451265	195209	111352	522446

Notes: The standard errors in parentheses are clustered at the level of the matched LSOAs to control for correlation between the neighboring LSOAs. *, **, and *** denote significance at the 10, 5, and 1 percent level, respectively. There are missing values in the record of the variables multiple and first-time mothers (which are orthogonal to the treatment). Columns (1) to (3) use the sample of all mothers with the following differences: entire sample in column (1); multiple-time mothers in column (2); and first-time mothers in column (3). Columns (4) to (7) consider the sample of natural deliveries and elective C-sections with the following differences: all mothers in column (4); multiple-time mothers in column (5); first-time mothers in column (6); multiple and first-time mothers in column (7). Column (8) considers the sample of all mothers.

The estimated coefficient of *Did* in column (1) indicates that the probability of having a C-section is 0.52 percentage points higher for mothers residing in *close* LSOAs compared with mothers residing in *far* LSOAs. This corresponds to a 2.5 percent increase in C-sections, starting from the 20.99 percent rate of C-sections in the year 2000 in our matched sample. We consider multiple-time mothers and first-time mothers in columns (2) and (3), respectively. After controlling for mothers' risk factors, internet diffusion does not seem to have influenced mothers who had at least one previous pregnancy. We find instead evidence that first-time mothers are strongly influenced by the internet. The estimated coefficient *Did* in column (3), which is statistically significant at the 1% level, indicates that the probability of having a C-section for mothers living in *close* LSOAs is 1.36 percentage points higher than for mothers living in a *far*

LSOA. This corresponds to a 6 percent increase in C-sections, starting from the 22.55 percent rate of C-sections for first-time mothers in the year 2000 in our matched sample.

The main results hold when we exclude emergency C-sections and focus on elective C-sections, with columns (4) to (6) confirming the previous findings. The estimated coefficient in column (4) indicates that the probability of performing a C-section for mothers living in *close* LSOAs is 0.38 percentage points higher than for mothers living in a *far* LSOA. Given a baseline probability equal to 9.65%, this amounts to a 3.9 percent increase. Finally, column (7) reports the regression results for emergency C-sections. In comparison with elective C-sections, emergency C-sections should not be influenced by the exposure to the internet. We find that the estimated coefficient is positive, and it corresponds to an increase of 1.2 percent (the baseline probability in 2000 being 13.81 percent). The estimated coefficient is not statistically significant.

Our results show that internet diffusion influenced childbirth procedures and the effect of access to information has been strong for first-time mothers. Consistently with mothers looking for C-sections as a planned procedural choice, we find that the effect is driven by elective rather than emergency C-sections.

Estimated coefficients reported in Table 2 are the lower bounds for the true effect. This is because the indicator variable for the treatment takes value 1 in case of a *close* LSOA while it takes value 0 in case of *far* LSOA while internet access in the two LSOAs does not jump from 100% access to 0% access. This implies that, ideally, the coefficient should to be scaled by the gap in access between the two groups of LSOAs, which unfortunately cannot be observed. When we use a measure of internet quality, as reported in Section 6.1 below, we find that the effect of having access to the first version of broadband ADSL (promising a speed of 2-4Mbit/s), compared with narrowband, is to increase the C-section rate by 2.7 percent.

We now discuss the estimation results of a series of regressions estimating model (1) where the dependent variables are related to other procedures (e.g., episiotomy), mother's outcomes and traumas (e.g., prolonged pregnancy), and newborn's outcomes (e.g., low birth weight). In general, these tend to be negative events, which means that a statistically significant negative coefficient would be interpreted as a positive outcome.[42]

Table 3 shows the regression results for induction of labor, episiotomy, co-morbidities, anaesthetic, prolonged labor, prolonged pregnancy and mother's traumas. There is no evidence of significant changes in these variables due to internet diffusion.

Table 3: Regressions for other mothers' procedures and outcomes.

Dependent variable: Procedure and outcome	Induction	Episiotomy	Co-morbidities	Anaesthetic	Prolonged Labor	Prolonged Pregnancy	Maternal Trauma
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Did	0.11	0.13	0.26	-0.33	0.26	-0.02	-0.28
	(0.28)	(0.25)	(0.17)	(0.53)	(0.20)	(0.11)	(0.36)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.144	0.121	0.056	0.253	0.045	0.032	0.064
Observations	522446	402947	522446	372960	522446	522446	402947

Notes: The standard errors in parentheses are clustered at the level of the matched LSOAs to control for correlation between the neighboring LSOAs. *, **, and *** denote significance at the 10, 5, and 1 percent level, respectively. Results on the outcomes *episiotomy* (column (2)) and maternal trauma (column (7)) consider only vaginal deliveries. The number of observations is smaller for the outcome *anaesthetic* due to missing values. We test for zero correlation between the treatment variable and an indicator variable for missing value, and we do not reject the null hypothesis of zero correlation.

Finally, the outcomes for newborns are shown in Table 4.[43] We assess whether there have been significant changes with respect to premature newborns (born before 36 gestation weeks), babies born with low birth weight (less than 2.500kg),[44] stillbirth, use of resuscitation measures, and whether the baby was discharged or died/stayed in hospital. We do not find significant effects for any of the newborn outcomes.[45]

Our results for this large set of maternal and newborn outcomes suggest that the increase in C-sections was not accompanied by improvements in either maternal or newborn health.

[42]To be more precise, all newborn's outcomes are negative events. With respect to the mother's outcomes, induction of labor, episiotomy and anaesthetic are not necessarily bad outcomes.

[43]The total number of observations might not be equal to the total number of deliveries due to missing information regarding these outcomes. Missing values are orthogonal to the treatment.

[44]We also run the same regression using *very low birth weight* as outcome variable (less than 1.500kg) and the results are the same. For both regressions we add as additional control variable gestational weeks, as premature babies tend to have lower weight.

[45]These results, and some of those on mothers' outcomes, are noisy as some outcomes are rare (for example, stillbirth or the need to use resuscitation measures).

Table 4: Regressions for newborns.

Dependent variable:	**Premature**	**Low-birth weight**	**Fetal distress**	**Stillbirth**	**Resuscita tion**	**Died/Stay hosp**
	(1)	(2)	(3)	(4)	(5)	(6)
Did	-0.11	-0.02	-0.25	-0.02	-0.12	-0.09
	(0.24)	(0.19)	(0.25)	(0.07)	(0.23)	(0.09)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.151	0.260	0.056	0.224	0.127	0.105
Observations	331356	325205	522446	381535	336848	522336

Notes: The standard errors in parentheses are clustered at the level of the matched LSOAs to control for correlation between the neighboring LSOAs. *, **, and *** denote significance at the 10, 5, and 1 percent level, respectively. The number of observations is smaller in some columns due to missing values of the dependent variables (and the missing values are orthogonal to the treatment).

6.1 The effect of internet quality on childbirth

We have estimated the effect of the internet on childbirth procedures and outcomes by comparing mothers living in neighboring LSOAs that are *close* and *far* from their respective LEs. This approach relies on the fact that internet access is influenced by availability and quality of internet connections and has the advantage that the only information needed is the location of each LSOA and a detailed knowledge of the telephone network. The results obtained based on this identification strategy can be interpreted as an intention to treat, where the exogenous variation that we exploit are the discontinuities in the distances to the LE.

In this section, we complement our findings by relating the changes in health care choices to a measure of internet access quality. The main variable we examine to capture the quality of internet connections is the average actual speed of connections in the local area. This speed is a combination of two factors, as we discuss in Section 3: the technologies installed in the LE by the ISPs – which determines the maximum achievable speed – and the distance that the signal has to travel to go from the LE to the premises.

For each of the four technologies we can compute a model-predicted speed of internet connections in the LSOA, which is based on the estimates reported by Ahlfeldt et al. (2017). In their paper, the authors estimate a model for the *actual* speed of internet connections (not the advertised speed) as a function of distance from the LE and the type of ADSL technology installed in the LE, exploiting a large dataset of speed tests.[46] The evolution of the average predicted internet speed of the two groups of mothers is reported in the right panel of Figure 3. The figure shows that the effect of distance on internet speed made the internet connection in *far* LSOAs slower that the one in *close* LSOAs. Until 2004, however, due to the low level of internet penetration and the lack of investment by competitive ISPs, the distance gap did not translate into a sizable internet access speed gap. Things changed after 2005 when broadband penetration increased rapidly, new ISPs entered the market and new versions of ADSL were introduced. Higher speed was enabled and emerged, but mostly at the proximity of the LE, while suffering from large decay with distance.

To measure the effect of broadband quality on C-sections, we estimate the empirical model in (2). This model is closely related to the one in equation (1), as we use the sample of close and far LSOAs (which guarantees to have balanced mothers in the sample and the gap in distance which translates into a gap in speed), but we employ our measure of internet speed. Thus, the unit of observation is again the mother i, living in LSOA j, delivering at hospital h at time t.

$$y_{ijht} = \delta Speed_{jt} + \beta X_{ijht} + Time_t + LSOA_j + Hospital_h + LPTime_{jt} + \varepsilon_{ijht} \tag{2}$$

All variables are defined as before, except from $Speed_{jt}$, which is the average download speed available in LSOA j in the financial year t.

The model just described relies on different underlying identifying assumptions compared with model (1), and offers advantages and disadvantages. Firstly, in (2) we exploit the speed gap between matched LSOAs (which is the product of technology and distance) and not the *close* versus *far* distinction. This identification strategy requires the absence of residual correlation between the technologies installed in the LEs that serve the paired LSOAs and the error term.

[46] They fit a fourth-order polynomial in distance d whose coefficients are reported in the equation below.

$$Log(speed) = \begin{cases} 7.869 + 0.184d - 0.293d^2 + 0.058d^3 - 0.003d^4 & \text{if ADSL} \\ 8.214 + 0.057d - 0.287d^2 + 0.07d^3 - 0.005d^4 & \text{if ADSL+LLU} \\ 8.672 + 0.053d - 0.491d^2 + 0.141d^3 - 0.011d^4 & \text{if ADSL2+} \end{cases}$$

The baseline is an ISDN connection. The estimate accounts for other controls, including LE and year fixed-effects. See Table 1 in Ahlfeldt et al. (2017) for more details.

We believe this is a reasonable assumption for the following reasons: (i) due to our design, which produces balanced LSOAs (the LSOA pairs are the same as in previous analysis), and (ii) because the LSOA is a relatively small area compared to the LE and thus does not have a strong influence on the technological decisions taken at the LE level. Secondly, a strong limitation of (2) is given by the fact that speed is not directly measured, but it is predicted, and might therefore suffer from measurement error.[47] Thirdly, an advantage of model (2) over (1) is that the former does not rely on a pre-post assumption (related to the financial year 2005-06), but it exploits the evolution of differential internet speed between LSOAs.

Notwithstanding its limitations, the added value of this empirical model compared with our baseline estimate of equation (1) is twofold. Firstly, it provides a further test for the main results. Secondly, it allows us to estimate the magnitude of the effect of improving internet speed on the outcomes.

Regression results of model (2) are reported in Table 5. Estimated coefficients tend to confirm, at least qualitatively, our previous findings. The estimated coefficient of *Speed* in column (1) is positive, which would indicate that better internet conditions increase the probability of performing a C-section, although not statistically significant. Consistently with the results in Section 6, columns (2) and (3) show that the effect is large and statistically significant for first-time mothers. For this group, an increase in internet speed of 2Mbit/s, which is the increase in the average actual speed experienced in the UK during the decade that we examined, determined an increase in C-section rate of 1.48 percentage points, corresponding to an increase of 6.6 percent. Weighting by the share of first-time mothers, the increase in C-section rate of this subgroup determined an increase of the overall C-section rate of 2.7 percent. Finally, columns (4) to (7) seem to confirm our main findings that the effect is determined by elective C-sections for first-time mothers, while emergency ones have not been affected by internet

[47] The exercise in Ahlfeldt et al. (2017) to predict the decay of speed with distance is based on a rich set of tests run in 2009 and 2010 on a subset of LEs/plans which have been selected in the top 25% of the speed distribution, so to guarantee that actual speed is only limited by technological factors and not by contractual choice. This limits the possibility to estimate a full set of LE fixed effects influencing the actual speed, and, more importantly, it forces to assume that, for each technology, the (average) decay measured in 2009/10 is the same as it was at the beginning of the decade. Also, when predicting the speed at the local level, we cannot correct for the local distribution of plans' choices. Finally, our data does not allow us to perfectly geo-locate the mother within the LSOA, which makes our measure of distance subject to measurement error as we assign mothers to the centroid of the respective LSOA in computing the distance.

Table 5: Internet technology and C-sections.

Dependent variable:	Probability of C-section						Probability Emergency C-section
Sample:	All deliv. types			Vag del and Elective C-sec			All deliv. types
	All	Mult-time	First-time	All	Mult--time	First--time	All
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Speed	0.21	0.11	0.74***	0.11	0.04	0.30*	0.18
	(0.12)	(0.20)	(0.26)	(0.07)	(0.16)	(0.16)	(0.12)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.306	0.437	0.232	0.481	0.574	0.376	0.138
Observations	513763	216582	133556	443711	191851	109811	513763

Notes: The standard errors in parentheses are clustered at the level of the matched LSOAs to control for correlation between the neighboring LSOAs. *, **, and *** denote significance at the 10, 5, and 1 percent level, respectively. There are missing values in the record of the variables multiple and first-time mothers (which are orthogonal to the treatment). Columns (1) to (3) use the sample of all mothers with the following differences: entire sample in column (1); multiple-time mothers in column (2); and first-time mothers in column (3). Columns (4) to (7) consider the sample of natural deliveries and elective C-sections with the following differences: all mothers in column (4); multiple-time mothers in column (5); first-time mothers in column (6); multiple and first-time mothers in column (7). Column (8) considers the sample of all mothers.

diffusion.

6.2 Heterogeneous effects of the internet on C-sections.

We now return to our main specification given by equation (1) and consider heterogeneous effects. As at the heart of our story there is the demand-side ability to access, filter and process information that can be found online, we study whether internet diffusion had a different effect depending on income and education. We construct two indicator variables for whether the mother lives in a neighborhood that is below or above the median IMD for income and education, training and skills (we simply refer to the latter as "education").[48] Table 6 shows the regression results of model (1) where we focus on the subsample of first-time mothers and separate those living in high/low income from those in high/low education areas.[49] The results suggest that internet diffusion increased C-sections performed on first-time mothers residing in low income and low education areas. The *Did* coefficient is not statistically significant for

[48] More precisely, these indicator variables are derived from measures of deprivation. As noted above in Section 4, the measure of income is the percentage of income-deprived households in the LSOA, while the measure of the education level is the percentage of adults who, according to the Office of National Statistics, are considered to have deprived education, training and skills.

[49] We repeated the same test for multiple-time mothers and the results (available upon request) are not statistically significantly different from zero.

Table 6: Heterogenous effects by Income & Education (first-time mothers).

Dependent variable: probability of C-section				
	High Inc	Low Inc	High Educ	Low Educ
	(1)	(2)	(3)	(4)
Did	0.58	2.23***	1.07	1.88***
	(0.70)	(0.68)	(0.73)	(0.63)
Controls	Yes	Yes	Yes	Yes
R^2	0.226	0.225	0.225	0.224
Observations	66475	68994	67419	68050

Notes: The standard errors in parentheses are clustered at the level of the matched LSOAs to control for correlation between the neighboring LSOAs. *, **, and *** denote significance at the 10, 5, and 1 percent level, respectively.

first-time mothers living in neighborhoods with above median income and education.

Figure 5 also shows how C-section rates evolved over time, split by socio-economic background. There are increasing trends for both groups, but these also show interesting differences. Mothers from a higher socio-economic background always had a higher propensity to have a C-section, and this increased over time but was not affected by internet availability. In contrast, mothers from a lower socio-economic background started with a lower propensity to have a C-section. Over time, they adopted C-sections more, and relatively more than the other group of mothers. The C-section 'gap' between the two groups reduced over our time period, and almost closed if we consider the split between low-income and high-income mothers. Our results suggest that internet availability contributed to the closing of this gap.

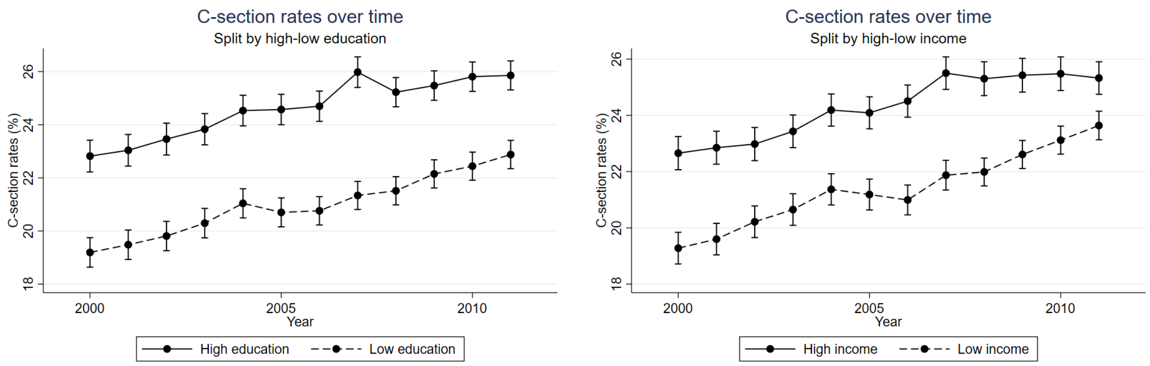

Figure 5: C-section rates over time. LEFT PANEL: split by education. RIGHT PANEL: split by income. Both figures report the 95% confidence interval around the observed frequencies.

We also assess mother's and newborn's outcomes examining only the sample of those mothers who live in low socio-economic status areas (as proxied by the population having low education levels).[50] Tables 9 and Table 10 in the Appendix report the results for mother's and newborn's outcomes, respectively. There are no significant effects on any of these outcomes.

6.3 Financial costs

The effect of internet diffusion on health care choices can have consequences on the total financial costs borne by taxpayers when the service is publicly funded (as in the UK), or on the final insurance cost borne by private insurers. In our case, while we did not find any impact of internet-driven C-sections on health outcomes, unnecessary C-sections can still generate a significant additional financial burden. Hospital costs are higher for C-sections than for vaginal deliveries: the tariff for a normal delivery without complications is £1,606, while the tariff for a similar C-section is £3,225.[51] The extra cost of a C-section is thus £1,619 per delivery. This is a lower bound as we do not account for the fact that, after a woman delivers by C-section, there is a higher probability that subsequent deliveries will be by C-section.

The length of stay in hospital is generally longer for C-sections. In our sample, the average length of stay is 2 days for a vaginal delivery and 4.4 days for a C-section. But as the tariffs remain the same as above as long as the length of stay is lower than 9 days, we are not imputing additional costs with longer hospital stays. Based on our estimated effect, we can thus compute the extra-cost borne by the National Health Service that has been generated by the introduction of broadband internet, through the increase of the C-section rate. Considering that an average UK cohort amounts to approximately 750,000 newborns per year from 2000 until 2011, and an average increase of 0.52 percentage points due to the internet (see column 1 of Table 2), the yearly extra-cost amounts to approximately £6.5m ($\approx$ $8.5m). This is not a large sum, but recall that we find no immediate associated medical benefits.

We are ignoring other benefits such as reducing labor pain, but given existing studies on how much people are willing to pay to avoid pain, there would still be considerable differences in costs. Olafsdóttir et al. (2017), for instance, use subjective well-being methods to estimate the value of pain relief, and find that it amounts to about $100 *per day*, with a lower willing-

[50] Similar results, available from the authors, arise when looking at low/high income mothers.

[51] https://improvement.nhs.uk/resources/national-tariff/#h2-tariff-documents

ness to pay for lower income people. As a normal delivery lasts for about eight hours, it is doubtful that mothers would pay out of their pockets for a C-section if the objective was only to reduce pain. To find a benefit from the increase in C-sections, we would have to consider other effects, such as the value from reducing gaps between C-section uptakes across different socio-economic groups. However, the medical literature suggests that the rise in C-sections is a concern. Therefore, closing this gap upwards in what is considered an unnecessary procedure for healthy mothers may not be a high social priority.

7 Further issues

7.1 Sensitivity of the treatment effect to varying the starting year

The results reported in Table 2 are based on having the financial year 2006 as the beginning of the treatment period.[52] This in turn builds on the uptake of internet access, which increased rapidly with the market and regulatory changes that took place in 2004 and 2005. Before 2005, overall internet diffusion was very limited both for *close* and *far* LSOAs. In other words, the majority of mothers did not have broadband internet at home - independent of living in *close* or *far* LSOAs.

Figure 8 in the Appendix reports the coefficient for the difference-in-differences variable *Did* in model (1) when we vary the starting year of the treatment. Moving the beginning of the treatment period toward the early 2000s reduces the estimated coefficient of the effect of the internet. This is consistent with a lower intensity of the treatment, namely the difference in internet access. In contrast, if we move the start of the internet period toward the end of the decade, the estimated coefficient increases until 2008, and then decreases.[53] Figure 8 shows re-

[52] As reported in Section 6, mothers who deliver between April 2005 and March 2006 (financial year 2006), got pregnant between August-September 2004 and July-August 2005.

[53] Two factors play a role in this case. First, by adding additional years after 2005, the pre-treatment period increases in the number of years in which the treatment is actually at work. Second, with our data we cannot know the difference in internet penetration between *close* and *far* LSOAs, which might have peaked after 2006 and then reduced. This is consistent with the fact that access to the internet became so quickly diffused that, after 2009, the difference in internet penetration between *close* and *far* LSOAs most likely started to reduce as the vast majority of the population got access to the internet through broadband connections, and, more importantly, *far* LSOAs reached the minimum internet quality to have good access to internet content.

sults both for all mothers (left panel) and first-time mothers (right panel), with more statistically significant results for the latter group.

7.2 Choice of hospital vs choice of procedure

One possible consequence of the internet might be that mothers change patterns of care seeking and travel farther to find a hospital with a higher C-section rate. While we find this unlikely given the description of maternity care in England in Section 2, and also given the finding reported in Section 4 that 97.5% of mothers living in neighboring LSOAs deliver in the same set of hospitals, we empirically test for this change in behavior in two ways. First, we examine whether the distance from mother's residence to hospital changed after 2006 in *close* LSOAs compared with *far* LSOAs. Second, we test whether mothers with more exposure to the internet delivered more frequently in hospitals with higher C-section rates.[54]

Table 11 in the Appendix reports the results of a series of regressions where the empirical model is similar to the one in equation (1) but the outcome variables are the distance from mother's residence to the hospital, and two indicator variables for the hospital being in the top 10 or 25 percentile in the distribution of C-section rates in the year before giving birth. Should mothers opt for a hospital with high C-section rates, they would most likely consider rates from the previous year.[55]

We do not find evidence that the increase in C-sections due to internet access is associated with increased mobility. Column (1) shows that distance did not change after 2006 for *close* LSOAs. Column (2) shows the results using as dependent variable a dummy that is equal to one if the mother delivered in a hospital among the top 10 percentile with respect to C-section rates in the previous year. Column (3) considers the top 25 percentile instead. Based on this evidence, we conclude that mothers with more internet access managed to obtain a C-section through the interactions with their local doctors instead of opting for a different hospital.

[54] Card et al. (2018) find that C-sections for low-risk first births tend to be accompanied by worse outcomes except where mothers sort to high C-section hospitals.

[55] We also consider C-section rates in the current year, and the results are similar.

8 Mechanisms

Our results indicate that better internet access increases the likelihood of having an elective C-section for less educated first-time mothers. There are at least two potential channels through which the internet could affect treatment decisions and, although we cannot directly observe these, we explore them here. First, having better access to the internet may allow mothers to obtain information about hospitals which in turn may result in changes in choice of hospital for delivery. However, in our context this is unlikely to be the channel by which elective C-sections rose. Whilst the NHS implemented a policy of choice of elective surgery from 2006 onwards, this was not extended to maternity care until 2010 and the implementation of this policy was very slow even after that date (National Audit Office 2013). Thus delivery in the closest hospital remained the norm for the period we study. In support of this, we find no evidence that mothers with better internet access travel further to the hospitals in which they gave birth (Section 7.2). We also find that both mothers with better and poorer internet deliver in the same hospitals and our results are robust to hospital fixed effects. There is thus no evidence that sorting to hospitals is the mechanisms that drives our results.

Second, better internet access may have allowed mothers to communicate better their preferences or to put more pressure on their care deliverers. This mechanism should be more relevant for first-time lower income and educated mothers, as evidence suggests higher income and educated mothers were exercising this right before the internet roll-out.[56] An inquiry in 2002 found evidence that disadvantaged women felt that maternity services focused exclusively on their babies, to the detriment of their experience of birth and pregnancy. This lack of control over the care that they received, and a lack of awareness about their choices, were argued to be part of the explanations for widespread socio-economic inequalities in care (House of Commons 2003). Sociological studies also describe how women from different social status might have different attitudes and be given different options during childbirth. For instance, Zadoroznyj (1999) found that first-time middle-class mothers were more likely to try to exercise control during birth, which can be considered as a form of empowerment.

[56] Cancer patients are also more likely to search for online information if they are younger, wealthier and higher educated.

Song et al. (2012) argued that the internet can play a role in empowering women to make choices during pregnancy and childbirth. This is not unique to childbirth, as there is evidence that the internet also empowers cancer patients by making them more actively involved in medical decision making. Lagan et al. (2010) performed a study in 24 countries and found that the internet enabled pregnant women to communicate with their healthcare professionals and also played a role in decision making and thus empowered women to make childbirth choices. They found that 83% of mothers used the internet to influence their pregnancy decision making and, by 2010, both higher educated and lower educated mothers used the internet as a source of information. Shieh et al. (2009) speculate that, conditional on having access to the internet, internet use might not differ significantly between low and high health literacy pregnant women. This is consistent with the findings of O' Higgins et al. (2014) who surveyed women using maternity services in Ireland. They found that even socially disadvantaged women show a high internet usage (97%). Thus it is plausible that internet access allowed lower socio-economic status to express their preferences in a way that women of higher socio-economic status had already done.

In terms of the information available discussion forums and social networks rather than official sites were the types of websites most commonly used by women for pregnancy information (O' Higgins et al. 2014). It seems plausible thus that the internet gave low income mothers access to childbirth stories posted on-line. Many of the negative childbirth stories are about natural deliveries, celebrities posted their preferences for C-sections (see Section 2.1), and this all may have communicated positive social narratives of mothers choosing a C-section (*e.g.*, Munro et al. 2009). Of course, mothers might also be able, with access to more information, to assess the quality of the information on-line and understand that some beliefs are inaccurate (*e.g.*, that C-sections are safer for the baby). However, as we noted above, government websites conveying such more accurate information were not in operation either in the UK or in the USA in the period we study. Access to medical journals would also not be available for most people and the information presented therein is not generally in a form easily understood by non-academics and highly trained medical professionals. Thus it seems plausible that access to the internet allowed less educated women to better express their preferences, and these preferences were for more elective C-sections rather than for other forms of delivery.

9 Conclusion

We examine whether internet diffusion affects health care choices and outcomes by studying how broadband take-up has influenced childbirth. We take advantage of geographical discontinuities in internet access in England to estimate the causal impact of broadband internet access on use of C-sections and health care outcomes of mothers and newborns. Our design focuses on the demand side and shuts off the role of financial incentives for suppliers by examining patients living in adjacent pairs of LSOAs, almost all of whom deliver in the same hospital.

We find that mothers with better internet access have higher C-section rates. The effect is driven by an increase in elective C-sections, rather than in emergency C-sections where the choice is that of the medical supplier. We find no significant changes in procedures that are generally performed during labor and delivery or in the health care outcomes of mothers and newborns. The differences are driven by first-time mothers, who are less informed by experience about childbirth than multiple-time mothers, and by mothers living in areas where the population has poorer education and lower income.

Overall, this paper provides evidence that increasing access to the internet *per se* has no positive (or negative) effects for outcomes from a strictly medical point of view. The rise in C-sections is not accompanied by any change in health for mom or baby. Our main findings – higher C-section rate and no sizeable improvements in health care outcomes – suggest a negative impact of internet diffusion on health care costs. More C-sections that are not strictly necessary are performed due to the internet and this is costly for the taxpayers without any gains in terms of health benefits.

However, we believe that the welfare conclusions should be more nuanced, also considering the most plausible mechanisms. We also find that the internet, by giving lower income/lower education mothers the ability to exercise choice over their treatment, considerably reduces their 'elective C-section gap' with higher socio-economic status mothers. The internet has allowed lower income/lower education demanders to catch up with their richer/more educated counterparts. In a health care system where those with a higher socio-economic status have access to more tailored care without paying higher prices (Cookson et al. 2016), the internet may allow those who are currently less able to negotiate this to increase their access. In this sense, the internet seems to have empowered some demanders and changed their relationship with their care providers. This is a more general phenomenon related to information and health care decisions, as similar patterns have been found for other types of patients, such as cancer. Whether this is of benefit or not will depend on the quality of the information available to internet users. Public health authorities should ensure that evidence-based public health advise is not only available online, but it is also easily accessible and understood.

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Appendix

9.1 Survey in Redshaw and Hikkila (2010)

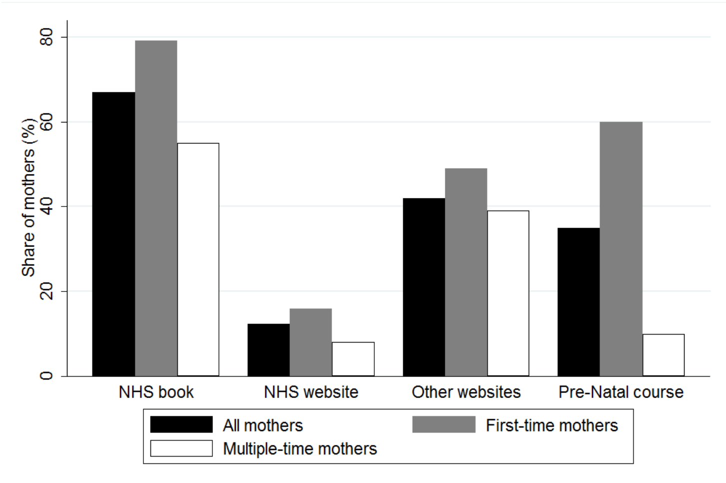

Figure 6: Share of mothers reporting access to different sources of antenatal information. Source: Redshaw and Heikkila (2010).

9.2 Sensitivity of the treatment effect re-balancing the age of mothers

We show in Table 1 that mothers in *close* and *far* LSOAs have a small, although statistically significant, difference in average age at delivery. In order to verify the consequences of this unbalance on our estimates we re-balanced the two samples of mothers through a propensity score matching procedure, as in Rosenbaum and Rubin (1983). With this procedure, we pair each mother living in a *close* LSOA with a mother with similar characteristics (among which there is the age) living in a *far* LSOA.

The re-balancing procedure has two consequences on our sample of mothers: the first one is to re-balance the age variable. On average, mothers living in *close* LSOAs give birth when they are 29.58 years old, while mothers living in *far* LSOAs give birth when they are 29.61 years old, and in this case we do not reject the null hypothesis of equal means. The second consequence is to restrict our sample to the matched mothers, which determines a reduction from 522,751 to 508,926 mothers (i.e., a loss of 2.6 percent of the sample).

We estimate the same model as in equation (1) on this restricted sample. Table 7 shows the estimated coefficients which are the equivalent to those reported in Table 2.

Table 7: Regressions C-section model - re-balancing mothers' age.

Dependent variable:	**Probability of C-section**						**Probability Emergency C-section**
	All deliv. types			Vag del and Elective C-sec			All deliv. types
	All	Mult-time	First-time	All	Mult--time	First--time	All
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Did	0.51**	0.23	1.34***	0.39***	0.48*	0.56*	0.16
	(0.23)	(0.32)	(0.48)	(0.15)	(0.26)	(0.29)	(0.21)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.306	0.436	0.233	0.481	0.573	0.377	0.138
Observations	508926	215273	131390	439390	190659	107899	508926

Notes: The standard errors in parentheses are clustered at the level of the matched LSOAs to control for correlation between the neighboring LSOAs. *, **, and *** denote significance at the 10, 5, and 1 percent level, respectively. There are missing values in the record of the variables multiple and first-time mothers (which are orthogonal to the treatment). Columns (1) to (3) use the sample of all mothers with the following differences: entire sample in column (1); multiple-time mothers in column (2); and first-time mothers in column (3). Columns (4) to (7) consider the sample of natural deliveries and elective C-sections with the following differences: all mothers in column (4); multiple-time mothers in column (5); first-time mothers in column (6); multiple and first-time mothers in column (7). Column (8) considers the sample of all mothers.

We do not find any relevant difference in estimated coefficients after re-balancing. The effect of better internet access estimated by the *Did* variable in Column (1) of Table 7 is 0.51, i.e., almost the same as the corresponding coefficient in Table 2. Other coefficients move only slightly, and in all cases within the standard errors of the corresponding coefficient in Table 2.

9.3 Sensitivity to the introduction of LSOA-pairs × Year fixed-effects.

As a robustness to the main specification 1 in Section 6, we estimate a model where we replace the local trends (i.e., the interaction between LSOA pairs and linear time trends) with LSOA pairs × Year fixed effects. Results are reported in Table 8. We do not find any relevant difference

Table 8: Regressions C-section model.

Dependent variable:	**Probability of C-section**						**Probability Emergency C-section**
Sample:	All deliv. types			Vag del and Elective C-sec			All deliv. types
	All	Mult-time	First-time	All	Mult- -time	First- -time	All
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Did	0.56**	0.24	1.34***	0.39**	0.49*	0.66**	0.21
	(0.23)	(0.33)	(0.51)	(0.15)	(0.27)	(0.30)	(0.21)
LSOA FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes
LSOA-Pair × Year FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Hospital FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.323	0.466	0.284	0.497	0.603	0.423	0.159
Observations	513752	215926	132536	443698	191077	108731	513752

Notes: The standard errors in parentheses are clustered at the level of the matched LSOAs to control for correlation between the neighboring LSOAs. *, **, and *** denote significance at the 10, 5, and 1 percent level, respectively. There are missing values in the record of the variables multiple and first-time mothers (which are orthogonal to the treatment). Columns (1) to (3) use the sample of all mothers with the following differences: entire sample in column (1); multiple-time mothers in column (2); and first-time mothers in column (3). Columns (4) to (7) consider the sample of natural deliveries and elective C-sections with the following differences: all mothers in column (4); multiple-time mothers in column (5); first-time mothers in column (6); multiple and first-time mothers in column (7). Column (8) considers the sample of all mothers.

in estimated coefficients after introducing the LSOA-pairs × Year fixed-effects. The effect of better internet access estimated by the *Did* variable in Column (1) of Table 7 is 0.56, i.e., very close to the corresponding coefficient in Table 2. Other coefficients move only slightly, and in all cases within the standard errors of the corresponding coefficient in Table 2.

9.4 Differential C-section rates between *close* and *far* LSOAs

Figure 7 reports the difference in C-section rates between *close* and *far* LSOAs over time. The left panel of the figure reports the C-section rates for all mothers, while the right panel of the figure reports the C-section rates for the subsample of first-time mothers.

Figure 7: Left panel: Difference in C-section rates between *close* and *far* LSOAs - All mothers. Right panel: Difference in C-section rates between *close* and *far* LSOAs - First-time mothers. Both panels report 90% confidence intervals.

9.5 Heterogeneous effect of the internet on C-sections — Other results

We present the tables discussed in the main text at the end of Section 6.2.

Table 9: Mother's outcomes - low educated mothers.

Dependent variable: Procedure and outcome							
	Induction	Episiotomy	Co-morbidities	Anaesthetic	Prolonged Labor	Prolonged Pregnancy	Maternal Trauma
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Did	-0.46	0.05	0.11	-0.94	0.46	-0.01	-0.26
	(0.62)	(0.39)	(0.31)	(1.35)	(0.31)	(0.20)	(0.65)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.128	0.116	0.051	0.282	0.034	0.026	0.051
Observations	205370	163249	205370	148072	205370	205370	163249

Notes: The standard errors in parentheses are clustered at the level of the matched LSOAs to control for correlation between the neighboring LSOAs. *, **, and *** denote significance at the 10, 5, and 1 percent level, respectively. Results on the outcome *episiotomy* (column (2)) and maternal trauma (column (7)) consider only vaginal deliveries. The number of observations is smaller for the outcome *anaesthetic* due to missing values. We test for zero correlation between the treatment variable and an indicator variable for missing value, and we do not reject the null hypothesis of zero correlation.

Table 10: Newborns' outcomes - low educated mothers.

Dep var:	Premature	Low Birth Weight	Fetal Distress	Stillbirth	Resusc	Discharged
	(1)	(2)	(3)	(4)	(5)	(6)
Did	-0.17	-0.01	-0.15	0.08	-0.28	-0.05
	(0.60)	(0.50)	(0.52)	(0.19)	(0.50)	(0.20)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.130	0.244	0.045	0.042	0.084	0.083
Observations	139601	137358	205370	158409	139427	205328

Notes: The standard errors in parentheses are clustered at the level of the matched LSOAs to control for correlation between the neighboring LSOAs. *, **, and *** denote significance at the 10, 5, and 1 percent level, respectively.

9.6 Further issues — Other results

We first report the figure discussed in Section 7.1, followed by the table discussed in Section 7.2.

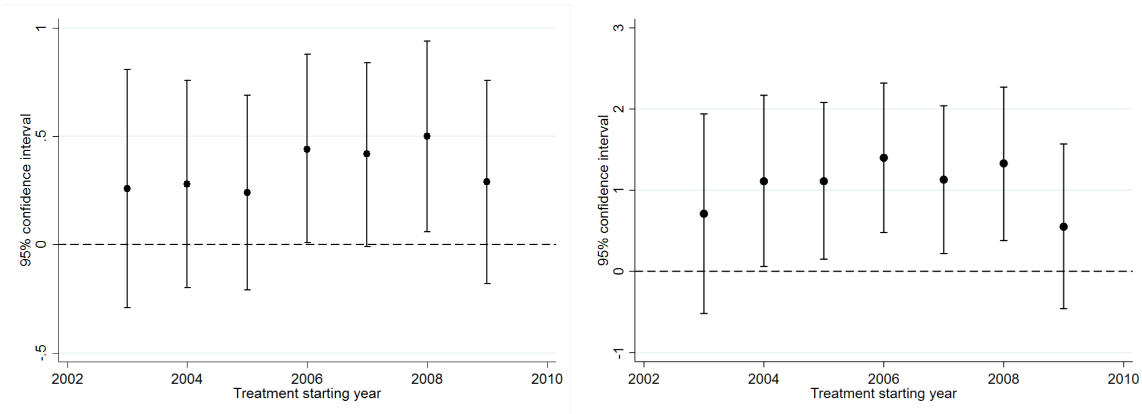

Figure 8: Estimate of the difference-in-differences *Did* coefficient with 95% confidence interval varying the starting year of treatment. LEFT PANEL: all mothers. RIGHT PANEL: first-time mothers.

Table 11: Choice of Hospital

Dependent variable:	**Distance**	**Hospital top 10% C-section**	**Hospital top 25% C-section**
	(1)	(2)	(3)
Did	0.07	0.00	-0.00
	(0.06)	(0.00)	(0.00)
Mothers covs	Yes	Yes	Yes
LSOA FEs	Yes	Yes	Yes
Time FEs	Yes	Yes	Yes
Hospital FEs	Yes	Yes	Yes
R^2	0.334	0.059	0.081
Observations	522751	473490	473490

Notes: The standard errors in parentheses are clustered at the level of the matched LSOAs to control for correlation between the neighboring LSOAs. *, **, and *** denote significance at the 10, 5, and 1 percent level, respectively.