Having it all? Broadband technology and the growing divide between high and low skilled women*

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Abstract

We investigate how broadband technology affects labor market outcomes and fertility among high and low skilled women. We leverage the staggered roll-out of broadband internet in Norway during the period 2000-2005 and ask how broadband internet contributes to the growing divide between high and low skilled women's labor market outcomes and fertility choices. We find that employment and weekly working hours increased among high-skilled women and decreased among low-skilled women, consistent with broadband representing a skill-biased technical change. The overall effect on fertility go in the same direction as the labor market effects, increasing the number of children among high educated mothers. The diffusion of broadband internet contributed therefore to the ongoing reversal of the education-fertility relationship. We find evidence that negative effects on labor market returns may explain the reduced labor supply of low educated women. The positive effects on high educated women's labor supply and fertility seem more connected to an easening of the combination of work and family.

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1 Introduction

The development in, and diffusion of, information technology has been one of the main drivers of skill-biased technological change over the last decades (Autor et al., 1998). Skill-biased technological change has increased the demand for, - and returns to,- different skills in the labor market (Autor et al., 1998; Goldin et al., 2007; Goldin and Katz, 2008; Acemoglu and Autor, 2011; Autor et al., 2006, 2008; Autor and Dorn, 2013; Goos and Manning, 2007; Goos et al., 2009), and has on average improved women's labor market position (Goldin, 1990, 2006; Goldin et al., 2006; Black and Spitz-Oener, 2010; Blau and Kahn, 2017; Cortes et al., 2021; Ngai and Petrongolo, 2017). During the same period, fertility has decreased across all OECD countries and the previous negative relationship between income and fertility or education and fertility has been reversed (Doepke et al., 2023). This paper studies the case of the diffusion of broadband technology and how it affected female labor supply and fertility in Norway during the early 2000's. We study the effects separately for high and low-educated women, showing that the diffusion of broadband technology has contributed to a growing divide between high and low educated women in the labor market and the reversal of the education-fertility relationship.

The building of broadband infrastructure has been shown to complement skilled labor, to increase the relative wages of high-skilled workers (Akerman et al., 2015), and to increase the labor supply of high skilled women partly through increasing use of home office (Dettling, 2017). The case of broadband roll-out provides therefore a unique opportunity to investigate how changing returns to education in the labor market is associated with the educational component of female labor supply and fertility. The diffusion of information technology represents also a shift in the price of inter-temporal flexibility in the labor market as it enhances the possibilities of e.g. working from home. Since women have career breaks or work reduced hours in periods when the children are small, they have a higher demand for inter-temporal flexibility in work hours (Goldin et al., 2006; Goldin, 2014; Kleven et al., 2019; Cools et al., 2017). As working from home is only possible in some (often high-skilled) jobs, however, this may also contribute in creating educational divides in the possibilities of combining work and family and in the alternative costs of children.

We leverage the staggered roll-out of broadband internet in Norway as exogenous variation in technological change across local labor markets and study how broadband changed women's employment, weekly work hours and earnings, their probability of having children and number of children. During the period 2000-2005, broadband was rolled out rapidly across the whole country in Norway, increasing broadband coverage from 0 percent in 2000 to above 80 percent in 2005. The building of broadband infrastructure started in different years in different municipalities ("treatment cohorts"), mainly depending on already existing infrastructure and typography (Bhuller et al., 2013). We estimate the effect of broadband internet in a difference-in-difference event-study framework, studying the first (and in most cases the largest) increase in broadband coverage, among prime-aged women (aged 25-54). We estimate a two-way fixed effects model including municipality and year fixed effects to control for municipality constant characteristics and business cycle effects, and apply the method suggested by Sun and Abraham (2021) to account for heterogeneous effects.[1]

We find that the roll-out of broadband affected employment and fertility among high and low-skilled women, and contributed in increasing the gap between them. Employment and weekly working hours increased among high-skilled women and decreased among low-skilled women in areas with better broadband coverage, consistent with broadband representing a skill-biased technical change. Fertility was also affected, but differently at different margins. The probability of having children decreased for high-educated. This effect may be a combination of lower probabilities of ever having children, and/or an effect on the timing of children (more work now can postpone parenthood). The probability of having children was unaffected for the low educated women. Among mothers, effects go in the opposite direction. There is a small, positive effect on number of children for high educated, and a small negative effect for the low educated. Since the majority of women are mothers, the overall effect on fertility go in the

[1]Because broadband was rolled out at an uneven pace between treatment timing groups, there is reason to believe that different "dosage" over time can results in heterogeneity of effects between timing groups that may bias our results in the plain TWFE model (Sun and Abraham, 2021; Callaway and Sant'Anna, 2021; Wooldridge, 2021).

same direction as the labor market effects, contributing to the reversal of the education-fertility relationship.

In the second part of the paper, we explore different mechanisms behind the results. We first investigate the role of changing labor market returns to high and low skilled labor by estimating the effect on hourly wages and how it varies across educational levels. Second, we investigate the role of work-family time constraints by estimating the effect separately for mothers and childless women, and separately in industries with a high and low potential for home-office and time-schedule flexibility. We find evidence that negative effects on labor market returns may explain the reduced labor supply and fertility of low educated. The positive effects on high educated women's labor supply and fertility seem more connected to an easening of the combination of work and family.

Our study is related to the literature on technological change and female labor force participation. Growing real wages and growing returns to education in the labor market pulled women into the labor market at high rates throughout the 19th century (Goldin, 1990, 2006). Autor et al. (2003); Black and Spitz-Oener (2010) study the skill-content of occupational change and find similar patterns of shifts away from routine tasks to more nonroutine analytic and interactive tasks for both men and women, and find that the shifts are more sizeable for women. Other studies point to the rise of the service sector (Ngai and Petrongolo, 2017), increasing demand for social skills (Cortes et al., 2021) and a shift away from home production to market production of e.g. care work (Cerina et al., 2021) as developments in occupational demand that improve women's work opportunities on average.

More specifically, our paper is related to the literature on the diffusion of telecommunication technology and how it affects labor markets. Information communication technologies is usually regarded as a skill-biased technological change, and several papers show evidence consistent with this. (Autor et al., 1998) finds that the rate of skill-upgrading is larger in the most computer-intensive industries. (Autor et al., 1998; Atasoy, 2013; Akerman et al., 2015) find that broadband technology has increased the returns to skill in the labor market. It has also been shown to e.g. increase job search efficiency (Autor, 2001; Bhuller et al., 2019), to shorten unemployment durations (Denzer et al., 2021; Gürtzgen et al., 2021) and to increase employment (Dettling, 2017; Hjort and Poulsen, 2019). Only Dettling (2017) studies how broadband internet affects female labor supply, and find positive effects among high-skilled, married women, similarly to our results. We contribute with further evidence on labor supply effects at the extensive and the intensive margin, as well as effects on fertility.

Our study is also related to the literature on the relationship between income and fertility. Across countries and within countries over time, the negative relationship between economic development and fertility is strong (Jones and Tertilt, 2008; Doepke et al., 2023). Economic development is associated with higher female labor force participation, and the relationship between women's labor force participation and fertility is also negative in most contexts (Baizán, 2007; Aaronson et al., 2021). As women are traditionally the parent that spends more time on childbearing and rearing, increasing returns to work in the market means that the opportunity cost of having children increases, and that women shift their time from home production to market production with resulting declining fertility rates (see Doepke et al. (2023) for an overview of the literature).

In high-income countries, the negative income-fertility relationship largely disappeared during the 1980s. Since then, fertility rates have levelled out, and since the start of the 1990s, the relationship was reversed across countries within this group. Countries with the highest income per capita, like the US and the Scandinavian countries, all had relatively higher fertility rates. Only in recent years (since the financial crisis in 2009), fertility rates have continued the decrease also in these countries. The negative relationship between female labor force participation and fertility is also reversed in recent decades (Del Boca, 2002; Apps and Rees, 2004; Adsera, 2004; Rindfuss and Brewster, 1996; Brewster and Rindfuss, 2000; Engelhardt and Prskawetz, 2004; Billari and Kohler, 2004; Brehm and Engelhardt, 2015). The same pattern appears for the relationship between educational level and fertility; it used to be negative, flattened out in the 1990s, and is now reversed in many countries (Hazan and Zoabi, 2014; Bar et al., 2018). The same is true in Norway. Kravdal and Rindfuss (2008) study cohort-specific completed fertility for women and men born 1940 to 1964 and find that the negative relationship between educational attainment and fertility among women has decreased when comparing younger cohorts to the earlier cohorts. Similarly, Lappegård et al. (2013) compare cohorts 1945-49 and 1960-64 and find that the total fertility rate has increased among the highest educated women, while decreased among the lowest educated women. Yet another study investigating cohort-fertility among women in Sweden, Norway and Denmark find that while childlessness was most prominent among higher educated older cohorts, it is now the lowest educated women who more frequently are childless (Jalovaara et al., 2019). Our paper contributes with causal evidence of how skill-biased technological change has contributed in changing the relationship between education, income and fertility, increasing the education gap in both labor market and fertility outcomes.

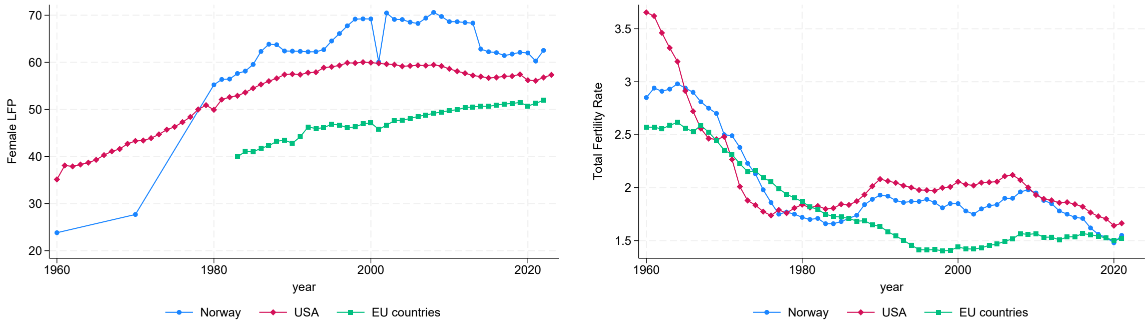
The paper is organized as follows: In section 2 we give an overview of the institutional setting in Norway. In section 3 we present the implementation of the Broadband reform from 1998 and show descriptive results concerning the roll-out of broadband across Norwegian municipalities. In section 4 and 5 we go through the data and our empirical strategy. Section 6 presents descriptive statistics concerning our sample, while section 7 presents the results concerning the effects of broadband on labor outcomes among high- and low-educated women, as well as our investigation of possible mechanisms. We show the results of several robustness check in section 9 before we make some concluding remarks in section 10.

2 Institutional Setting

Norway has maintained a relatively stable fertility level, combined with high female labor force participation since the late 1970's until the financial crisis in 2009 compared to the European average (Figure 1). Several explanations has been suggested for why there has been a weaker negative correlation between female labor force participation and fertility in Norway (as well as the other Nordic countries). Family policy has reduced the alternative cost of having children, as it has promoted the combination of work and family. Mothers do not have to choose between having a job and a career and having children. Parental leave (first for mothers and later also

Figure 1: Female Labor Force Participation and Total Fertility Rates across countries

(a) Female LFP (b) Total Fertility Rate



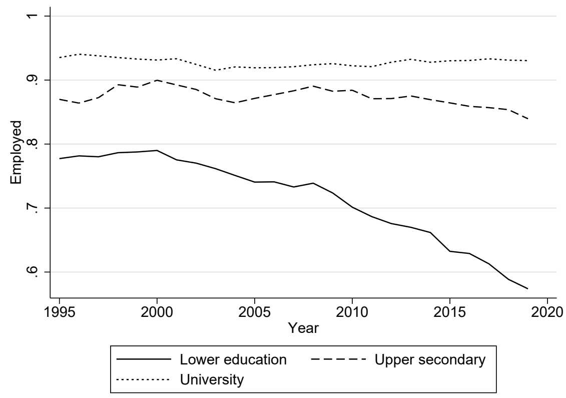
Notes: The figure shows female labor force participation rates, age 15+ (left panel) and total fertility rates (right panel) in Norway, EU-countries and the USA. Source: World Bank Gender Statistics.

for fathers) was expanded from the late 1980's throughout the first decade of 2000, and in combination with strong employment protection laws, it facilitated the combination of parental leave during the first period after birth and employment re-entrance. Also, reserving a part of the parental leave period for the father from 2009, incentivized couples to share child-rearing responsibilities (Rønsen and Kitterød, 2015; Del Rey et al., 2021). During the first decade of the millennium, kindergarten coverage increased across the country and costs became heavily subsidized, which further reduced the alternative cost of having children (Rindfuss et al., 2010). Besides a generous family policy, working life is regulated and relatively "family-friendly" in an international context. The normal week is 37,5, and the worker is entitles to 5 weeks of vacation over the year. The possibilities of working part-time are extensive. General gender equality is also high in the Nordic countries, both in work-life and family-life, which may also facilitate the combination of work and child-rearing (Esping-Andersen and Billari, 2015).

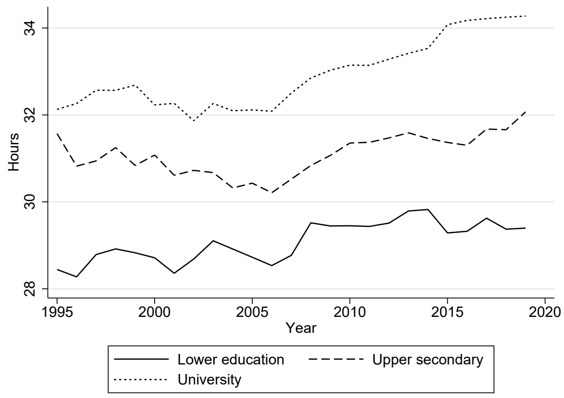
From 2009, when the financial crisis hit, fertility rates have been plummeting also in Norway. And even though the average numbers are relatively stable and high, both for female LFP and fertility, there are large within-country differences between education groups, that exacerbated during the financial crisis. Figure 2 shows employment and fertility patterns in the period 1995-2020 across three education levels; Lower education (less than upper secondary education), upper secondary education and university education. The long term trends are very different between the groups. University educated women and women with completed upper

Figure 2: Employment and fertility across educational levels, women at age 45, years 1995-2020, natives

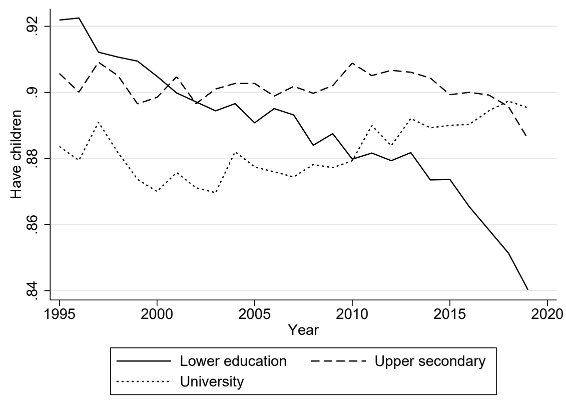
(a) Employment



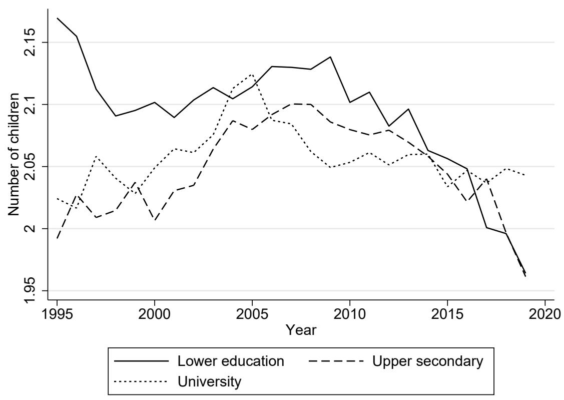
(b) Weekly hours



(c) Probability of having children



(d) Number of children



Notes: The Figure shows yearly means of the outcome variables noted in the figure-headers, measured at 45 years old. THe data used is full population register data from Statistics Norway.

secondary education have high employment rates around 90 percent, stable over the period and increasing weekly hours of work. Low educated women also have high employment rates, but employment stoops over the period.

Family formation has also changed differently for high and low educated women over the period. While low educated women had a higher probability of having children, and had more children than university and upper secondary educated women at the beginning of the period, it is opposite at the end of the period. The probability of having children is even increasing among the highest educated women while they start declining some after the financial crisis among the upper secondary educated women. The number of children increased among the higher educated until 2005, when it started decreasing across all education levels. The decline levelled off among university educated women already in 2008, however, while it continued declining for upper secondary educated women and lower educated women.

Taken together, the graphs suggest that there is a growing gap between low and high educated women, where high educated women to a larger degree both work and have a family, while low educated women are increasingly lagging behind on both arenas.

In our analysis, we group lower education and upper secondary education together, and keep university educated a separate group. Our period of study is 2000-2009, and this is a period of decreasing labor supply and fertility for low educated while labor supply and fertility for the university educated is increasing. The rest of our paper will analyse to what extent technological change is driving some of these changes.

3 The roll-out of broadband technology in Norway

Broadband is a term used to describe the technologies and infrastructure that enables high-speed transfer of data. The definition of ”high-speed” is relative and has changed as new technology has pushed speed boundaries further. The potential to both improve the internet speed and lower costs for users, induced the Norwegian parliament to adopt the National Broadband Policy, in 1998. This policy aimed at speeding up the process of developing the necessary infrastructure and ensure that the public sector, private firms and households across the country had access to broadband (St. Meld. 38 (1997-98).[2]

To implement the policy the government invested in broadband infrastructure, mostly through the state-owned telecom company Telenor. Among important types of broadband infrastructure were transmission centrals, as the ADSL technology requires short distances (less than 5 km) between users and these centrals to provide high-speed internet. During the 2000’s, these access points were rolled out in an uneven pace across municipalities. The building of access points was mostly supply driven, as topography and existing infrastructure influenced when and where access points were built (Bhuller et al., 2013).

[2]See Bhuller et al. for a detailed elaboration of the policy and the implementation

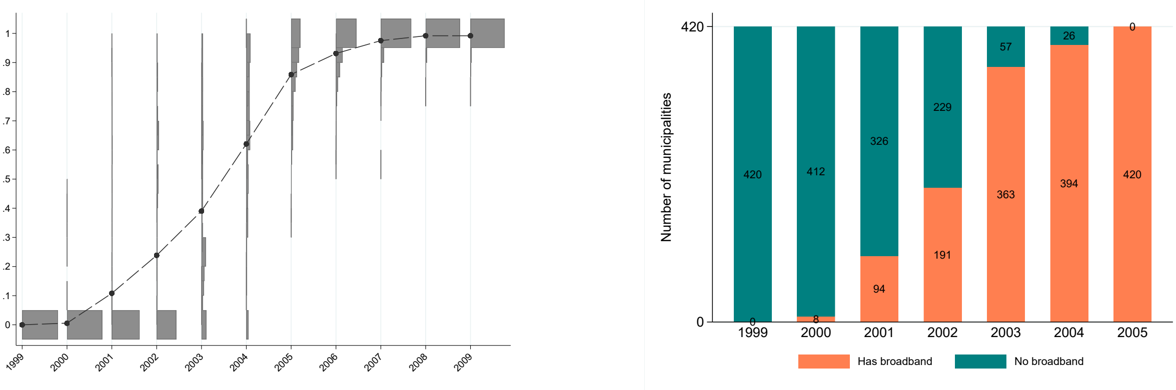
Parallel to the governments investment in infrastructure, a second implementation strategy was to assist rural municipalities in making necessary investments to ensure that public institutions could supply broadband and services over the internet. Through the funding program Høykom, municipalities could apply for partial funding of projects which aimed at reaching this goal, including cabling and other infrastructure investments (Askevold and Junge 2003). By the end of this program, in 2007, more than 600 million NOK had been channeled through Høykom to different municipalities. [3]

Figure 3 panel (a) displays the distribution of broadband coverage across municipalities for the period 1999-2009, as well as the average coverage rate over all municipalities. The coverage rate increases quite rapidly between 1999 and 2005 from zero to above 80 percent. From 2005 and onwards all municipalities has some access to broadband and broadband coverage rates continue to increase, although at a slower pace. By the end of the period, there is almost full broadband coverage across all municipalities.

Our identification strategy utilizes the variation between municipalities who get access to broadband with those who have no access (the comparison group). This means we can only estimate post-treatment effects up until the year before all municipalities have access to broadband. Panel (b) shows the number of municipalities with no broadband access and with some broadband access. The figure shows that if the comparison group consists of only those who in 2004 still has no access, there are only 26 municipalities we can use. We need to balance the need of a large enough comparison group and a meaningful number of post-treatment periods. A natural choice of municipalities in the comparison group are those who by 2002 still has no broadband coverage. This gives us a total of 229 municipalities in the comparison group and 191 municipalities in the treated group. The post-treatment years this allows us to study are consequentially year 2000-2002.

[3] The funding program hinged on municipalities applying for partial funding and also some local investments in e.g. local transmission centers (Leknes, 2003). This implies that the timing of broadband expansion may have been partially demand driven.

Figure 3: Broadband Roll-out Across Municipalities



(a) Broadband coverage trend (b) Distribution of access

Notes: Panel A displays overall mean coverage rates (connected line) and a histogram of coverage rates across municipalities. Panel B displays the number of municipalities with and without any broadband access over years. This informs the choice of cohorts included in the control group for the main estimation strategy.

4 Data

We use two main data sources in our analysis. For the main analysis, we use individual registry data and municipality level data on broadband coverage from the Norwegian Ministry of Government Administration. For the exploration of flexibility and the use of home-office as a causal mechanism, we complement with data from ABU, a firm-level repeated cross-section survey.

4.1 Individual data

Our individual data on labor market outcomes as well as demographic and socioeconomic data come from administrative registers provided by Statistics Norway. We use data from 1995-2002, to cover a five-year pre-period before the first municipality started rolling out broadband internet in 2000. We have full record data on every resident's demographic information (sex, birth, children), as well as socioeconomic information (cohabitation, income, place of residence, education). This data is collected from three records: the Central Population Register, tax records and from Norwegian educational establishments. Data on labor market outcomes, (employment, salary, weekly hours, hiring firm) are collected from the employer-employee registry. In this registry we have information on almost all residents working more than 4 hours per week and more than one week per year. This data is published either monthly or yearly, with the earliest records where all relevant variables are available is 1995.

Our main outcomes are employment, labor earnings, weekly hours, hourly wage and fertility: the probability of having children and number of children. In our main analysis we define people as being employed if their yearly labor income in the tax-register exceeds the lower bound for being eligible for employment benefits (NOK 111 447 in 2022). People with parental leave compensation are defined as employed if their compensation exceeds the earlier mentioned lower bound. In our robustness checks we also use other definitions of employment (see section 9). Weekly work hours is only observed for those with an active employment relationship in the employer-employee register and is recoded from three categories to number of weekly hours (full-time = 37.5, 25, 12.5 = short part-time).

4.2 Broadband coverage data

Our data on broadband coverage data comes from the Norwegian Ministry of Government Administration and cover the years 2001-2009. Broadband is defined as internet connections with download speed exceeding 256 Kb/s. Coverage rates on municipality level are measured in the beginning of each year and is based on detailed information of the localisation of access points and households. The signal range of the access points linked with place of residence of household allow for the calculation of the fraction of households for which broadband is available. Suppliers of broadband are required to report these availability rates to the Norwegian Telecommunication services, and any double counting in areas covered by several suppliers are accounted for when the Ministry aggregate these rates to municipality level. Since coverage rates are measured at the beginning of a year, we use leads of the reported year-by-year coverage rates. During the period 2000-2008, there were seven mergers of municipalities. The broadband data does not include these municipalities involved in a merge and are excluded from our analysis. The total number of municipalities included in our analysis are 420.

4.3 Firm-level survey on Home-office practices

We utilize ABU, a representative cross-section survey of firms, to identify industries where home-office work arrangements has become more common over the period 1997 to 2012. The survey covers between 1888 and 2358 firms and was conducted in 1997, 2003 and 2012. The survey include a question on whether there are employees who work from home at least once a week and the share of employees who use a pc to perform their tasks at home, which we use to identify industries with high potential of home-office work arrangements through the use of information technology when broadband was rolled out. We describe our approach for finding high potential home-office industries in the Appendix Section A.2.[4]

5 Empirical Strategy

The staggered roll-out of broadband internet across municipalities provides us with exogenous variation in broadband coverage between municipalities over time. We use this variation to estimate the effect of broadband coverage on labor market and fertility outcomes in an event-study framework, including municipality and year fixed effects to control for fixed municipality characteristics and common business cycle effects. While earlier studies of the Norwegian broadband reform on labor market outcomes has relied both on randomness of the roll-out and homogeneous effects across municipalities, our empirical strategy relies mainly on the parallel trend assumption and allows for heterogeneous effects. Our main estimation model is the difference-in-difference model suggested by Sun and Abraham (2021), which is robust to treatment effect heterogeneity. We divide municipalities into 4 different cohorts depending on the year broadband internet was first made available, and we use the between-municipality variation in broadband availability to identify the effects.

[4]Previous literature has used variation in home-office use across occupations to identify potential home-office jobs (Dingel and Neiman, 2020). There is no occupational information in our data before 2004 (and limited coverage until around 2009), and we therefore use a similar approach to identify industries that have a large home-office potential.

5.1 Difference-in-difference event-study model

We estimate a difference-in-difference event-study model of the following form, separately for high and low educated women:

$$\mathrm{Y}_{it} = \sum_{j=-4, j\neq -1}^{2} \alpha_j \cdot D_{mt}^{j} + \beta_t \cdot \mathrm{Year}_t + \sigma_m \cdot \mathrm{Municipality}_m + \lambda_k \cdot \mathrm{Age}_{it} + v_{it} \tag{1}$$
$$\text{where } D_{mt}^{j} = \mathbf{I}[t - e_m = j]$$

The outcome Y for person i in calendar year t is determined by a set of event-time indicators D_{mit}^{j} equal to 1 if the calendar year t is j periods since treatment for the person residing in municipality m. The period before the municipality gets first access to broadband is $j = -1$ is the reference period.[5] α_j^g identifies the causal effects of broadband internet using the variation in treatment timing between municipalities. Fixed characteristics of the municipality and common variation over years with the business cycle is controlled for by year and municipality fixed effects in the vectors Year_t and $\mathrm{Municipality}_m$. In addition, we control for shared life-cycle trends in outcomes by including a full set of age-indicators, Age_{it}. The main outcomes are employment, labor earnings, weekly hours, hourly wage, the probability of having a child and number of children. We do not estimate treatment effects past year 2003, meaning we do not estimate effects of being treated for periods when all are treated.

A growing literature has showed that in a setting with heterogeneity of effects across different treatment timing groups (hereby referred to as cohorts) and/or across treatment periods, event-study models with time and unit fixed effects (two-way fixed effects models) will be biased (Goodman-Bacon, 2021; De Chaisemartin and d'Haultfoeuille, 2020; Callaway and Sant'Anna, 2021). The standard two-way fixed effect estimator is a weighted average of comparisons of treated units with both not-yet-treated and already treated units. The comparisons with already treated units are sensitive to heterogeneity of effects across cohorts and over time.

[5] In light of possible multicollinearity issues pointed out by Borusyak et al., we have also estimated the model omitting two event-time periods, -1 and -2. Estimates are similar and posted in Appendix A.5

In our setting, there is not only variation in timing but also the dosage of broadband coverage. It is therefore natural to expect heterogeneous treatment effects across cohorts. To account for heterogeneity of treatment effects, we estimate the model using the method suggested by Sun and Abraham (2021). They suggest using the last treated cohort as the control group, avoiding in that way the comparison of treated units with already treated units. In our case, we pool the three last cohorts (Cohort 2003 to 2005) into one comparison group, as the last cohorts are quite small (as shown in figure 3. The estimation procedure is two-step: first, cohort and time specific average treatment effects are estimated, and then these estimates are aggregated to average treatment effects for each post-treatment period. As robustness, we also investigate cohort-specific effects, and the results are similar across cohorts (See Figure 14).

The sample consists of a panel of municipalities with yearly cross-sections of individuals residing in each municipality. For each year, our observations are women in fertile ages 25-45. We start at 25 to observe women when most have finished their education, but before most have completed their fertility.

The model identifies the causal effects of broadband internet on our outcomes under certain identifying assumptions. Since we compare differences over time in the event-study diff-in-diff framework, the main identifying assumption is that the different treatment timing groups would have parallel post-treatment trends in the outcome variables if broadband internet was not rolled out. While this assumption is not possible to test, parallel pre-trends are reassuring for this assumption to hold. We test pre-trends in Section 7 below, and we confirm they are stable, both within education group and between education groups.

The second important identifying assumption is the no-anticipation assumption. If individuals anticipated the broadband expansion, they may have started to adjust even before broadband was expanded, biasing the estimates. There is reason to believe all cohorts after the first treated cohorts expected broadband expansion also in their municipality, since the policy was widely communicated. The exact timing was however not clear from the start. Inspection of the event-study estimates informs us about early adjustments, if labor market trajectories start changing already before broadband was expanded. The results in Section 7 suggest this is mostly not the case.

In addition, the implementation of the national reform, as explained in section 3, was mainly supply-driven, with the state-owned company Telenor building access points across the country. In Section 6 below, we test if roll-out timing is correlated with a large set of municipality characteristics, and while access does not seem entirely random, we do not find that pre-roll-out labor market outcomes predict timing once we control for urbanization.

6 Descriptive statistics and the exogeneity of broadband internet roll-out

6.1 Descriptive statistics of the treatment cohorts

In this section we present descriptive results concerning our sample and relevant outcomes. With the empirical framework we apply, we need support in the data for each post-treatment effect we want to estimate. All municipalities are treated by year 2003 and we restrict our estimation to a total of three post-treatment periods, which for the first treated cohort corresponds to calendar years 2000 to 2002. This also means that there are three cohorts contributing with treated observations, while cohort 2003, 2004 and 2005 contributes as a combined reference group.

In table 1 we report cohort-specific averages of coverage rates from the first to the third post-treatment period, as well as the maximum and minimum coverage rate for the first treatment period. It is apparent that the introduction of broadband signifies on average a large jump in broadband coverage for each of the cohorts, ranging from around 30 and 47 percent coverage rate. The 2000 cohort experience lower initial coverage rates than the two later cohorts, although the levels are still of significant magnitude for most municipalities. In the second period, average coverage rates are more similar across the two cohorts which contribute as treatment groups. This implies that when we aggregate the individual estimated effects to post-treatment periods, the treatment dosage across observations are on average comparable. There

Table 1: Coverage rates by treatment cohorts

	Cohort 00	Cohort 01	Cohort 02
First period	0.304	0.470	0.442
	(0.118)	(0.208)	(0.245)
Second period	0.625	0.598	
	(0.276)	(0.197)	
Third period	0.719		
	(0.310)		
Min coverage, first period	0.070	0.040	0.033
	(0)	(0)	(0)
Max coverage, first period	0.420	0.910	0.950
	(0)	(0)	(0)
Observations	8	86	97

are still variations within the cohorts, as seen by both the standard deviation and the range of minimum and maximum rate of coverage for this first year. In summary this implies that the year a municipality first get access to broadband constitutes on average a significant event, although there are variations both between and within the cohorts concerning the initial dosage of treatment in the first treatment period.

Table 2 contains descriptive statistics of relevant variables for each cohort the year before the initiation of the reform, year 1999. One important difference between the cohorts is the sample size. The most populous cities were also the first to get access to broadband, leading to large differences in sample size when comparing cohort 2000 and 2001 to the reference group. In addition, the first two cohorts are younger, has lower rate of parenthood and fewer children. They also have higher education, higher weekly hours and earn more, both in hourly wage and annual salary. They are more often single, but within couples the first two cohorts have higher earning partners and a higher household income. These factors are all typical traits of more urban areas. As we conduct separate analysis for high and low educated women, the cohorts become more comparable across these factors (see Table A.1 and A.2 in the Appendix A.1 for differences between high and low educated women by treatment cohort).

There are large level differences in labor market and fertility outcomes between high and low educated women, as shown in Table A.1 and A.2. The difference in weekly hours among

Table 2: Summary Table - Year 1999

	Cohort 2000	Cohort 2001	Cohort 2002	Reference
Higher educ.	0.45	0.31	0.27	0.24
	(0.50)	(0.46)	(0.45)	(0.43)
Age	34.37	34.93	35.09	35.17
	(5.92)	(5.99)	(6.04)	(6.07)
Employed	0.81	0.80	0.81	0.81
	(0.39)	(0.40)	(0.39)	(0.39)
Hours	27.24	24.89	24.93	23.86
	(14.70)	(14.58)	(14.26)	(14.07)
Hourly wage	238.41	199.69	201.35	186.65
	(1,814.34)	(1,357.10)	(1,297.96)	(1,163.49)
Parenthood	0.64	0.78	0.81	0.82
	(0.48)	(0.41)	(0.40)	(0.39)
Number of children	1.25	1.67	1.77	1.86
	(1.18)	(1.18)	(1.20)	(1.23)
No. of children among parents	1.96	2.13	2.19	2.28
	(0.90)	(0.90)	(0.92)	(0.94)
No. children at age 45	1.79	2.11	2.18	2.26
	(1.19)	(1.10)	(1.12)	(1.13)
Home-office industries	0.25	0.16	0.14	0.15
	(0.44)	(0.37)	(0.35)	(0.35)
Annual salary (100K)	2.19	1.82	1.75	1.62
	(1.59)	(1.27)	(1.17)	(1.10)
Has a partner	0.68	0.79	0.80	0.81
	(0.47)	(0.40)	(0.40)	(0.39)
Income of partner (100K)	4.84	4.10	3.79	3.51
	(10.32)	(5.48)	(3.44)	(2.32)
Labor income of partner (100K)	4.11	3.67	3.43	3.19
	(4.85)	(2.18)	(1.87)	(1.62)
Household income (100K)	5.19	4.89	4.67	4.41
	(9.76)	(4.87)	(3.29)	(2.41)
Commutes to work	0.20	0.35	0.32	0.30
	(0.40)	(0.48)	(0.47)	(0.46)
Observations	178286	264168	100371	94164

workers is approximately 6 hours, close to a whole day (7.5 hours). Higher educated women also earn more, both by the hour and by annual earnings. It is also apparent that a higher share of lower educated women are parents and they also have more children. The difference in completed fertility (Number of children at age 45) is smaller, indicating that higher educated women tend to postpone first childbirth, but catches up later in life. Still, higher educated women of age 45 also had fewer children than lower educated women, in year 1999. Lower educated women have a higher probability of having a partner, but their partner's income and household income is less than partners of high educated women. We also find that while on average 16 percent of lower educated women work in industries with high potential of home-office arrangements, while 23 percent of higher educated women work in these industries (more on these industries in Section 8.2).

6.2 The exogeneity of broadband internet roll-out to municipality characteristics

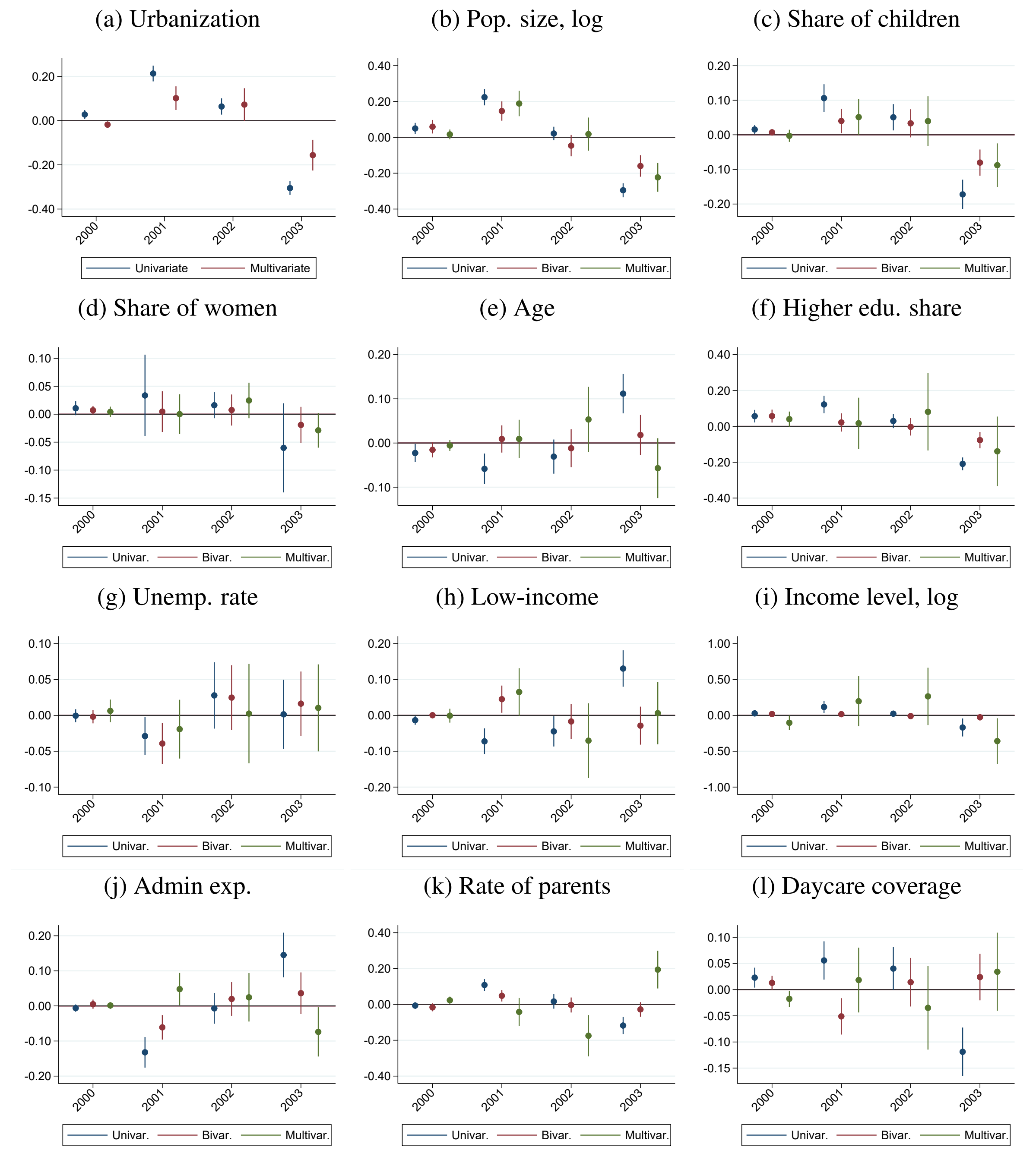
The descriptive statistics in Table 2 indicate that the timing of when municipalities got access to broadband was not random. We further investigate the correlation of pre-roll-out characteristics of municipalities and treatment timing by estimating, in the simplest form, the following model:

$$\Delta T_{mt} = Year_t + \theta_t Year_t \times \alpha_{m,t=99} + \varepsilon_{mt} \tag{2}$$

Where ΔT_{mt} is the change in treatment status for municipality m in year t which has value 1 in the year of first broadband coverage and 0 otherwise. $Year_t$ is a vector of year dummy variables, accounting for the common time trend of change in treatment status. $\alpha_{m,t=99}$ is pre-roll-out standardized level of a range of different factors which are related to labor and family outcomes. The θ_t is the coefficient of the interaction term in the equation, and captures the correlation between these municipality-level factors and treatment timing.

The θ_t's are displayed in Figure 4. We follow Akerman et al. and show the results from regressions where each covariate is included either in a univariate model, a multivariate model where all other covariates are included and a bivariate model where only urbanization is included (2022). We find similar results in our sample as previous literature investigating the same program, namely that there is a negative relationship between urbanization and the treat-

Figure 4: Independence Test Of Timing Of Broadband Expansion



Notes:

ment timing. Most municipality characteristics do, however, not predict the timing. The early treated also tend to have a younger population, higher education level and higher daycare coverage rates, as the coefficients from the univariate models imply. As these characteristics are more common in urban areas, we include urbanization in the bivariate models. Conditional on urbanization-level in 1999, the pre-roll-out age structure, education level and daycare coverage rates in the municipalities correlates less with treatment timing although some differences remain. Our results imply that the timing of broadband expansion is correlated with urbanization and a few pre-expansion municipality characteristics, and these could in turn be correlated with our outcome variables. If the differences are constant, however, they are controlled for in the difference-in-difference model. As a robustness check we nevertheless exclude the five most populous cities from the sample in section 9, and corresponding summary tables for this sample can be found in the Appendix, A.1. Figure A.4 in the Appendix shows that within education level, treatment and control cohorts are on parallel labor market and fertility trajectories before broadband expansion. In the event-graphs in section 7, we further test for pre-trend differences and find similar trends pre-reform.

7 Estimation Results

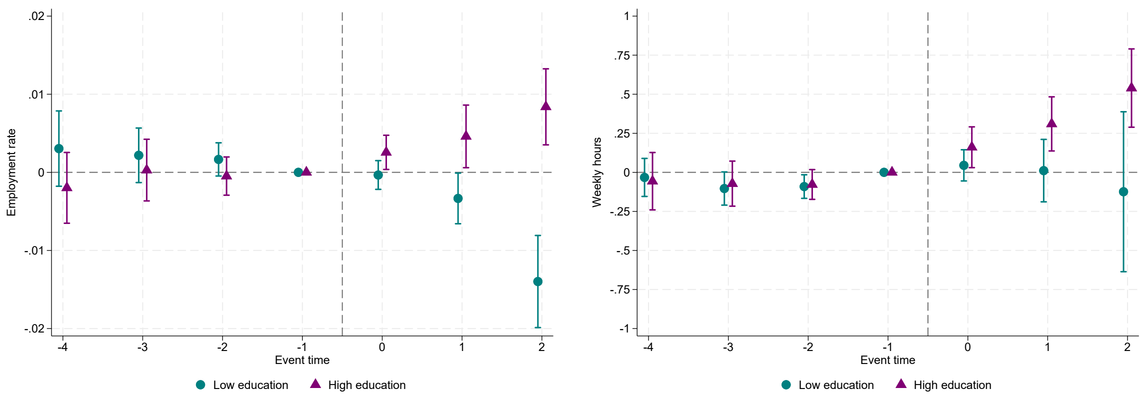
This section presents the findings from estimating the impact of broadband introduction on labor supply among women with different education levels. The influence is assessed through two primary measures: the employment rate and the weekly hours worked among those employed. Figure 5 graphically illustrates the estimated effect in an event-study plot. In the pre-treatment period, coefficients for both outcomes and education groups suggest parallel trends prior to the introduction of broadband, which is reassuring.

Broadband internet has a positive effect on higher educated women's labor supply and a negative effect for lower educated women. The results imply that broadband has widened the education gap in labor supply among women, affecting both the extensive margin (employment) and intensive margin (hours worked per week). Subsequent to the introduction of broadband, the employment rate among women with less education started declining in the second and third treatment year relative to women in municipalities with no broadband coverage. The estimates are conversely positive for women with a college degree, with estimates reaching just below a 1 percentage point increase in the employment rate by the end of the post period.

Furthermore, the estimated effect on the number of weekly hours worked is positive and increasing among higher educated women, amounting to approximately 0.5 hours by the end of the post-treatment period. There is no significant effect on hours for lower educated women. Broadband technology therefore has different effect on different parts of the labor market, consistent with skill-complementarity of high-speed internet.

Figure 5: Effect Of Broadband on Labor Supply Outcomes

(a) Employment rate (b) Weekly hours



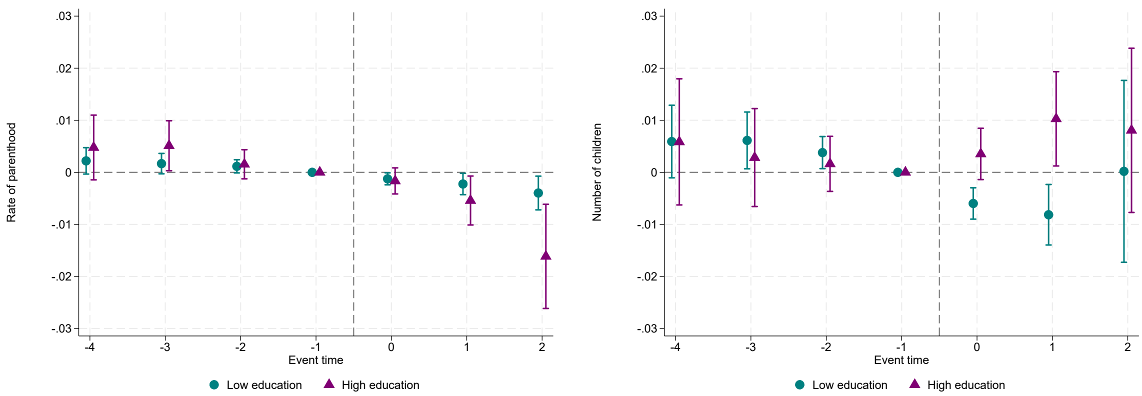
Notes: Estimates are based on estimation model controlling for age

In Figure 6, we show the results for fertility. The two outcomes are an indicator for having children and the number of children among mothers. Looking first at Panel a - the probability of having children - the estimated treatment effects are negative but very small in magnitude for both high and low educated women. We may, however, not expect a very immediate effect on fertility as it takes time to have children. The effects may therefore grow larger over time. The effects on the probability of having children is consistent with a trade-off in time-allocation between work and child-rearing. Higher educated women who increased their labor supply after broadband internet was rolled out, are also the ones who reduce their fertility most. This conclusion is, however, moderated when we look at the effect on number of children among mothers in panel b).

Panel b displays the estimates for the number of children among mothers. The treatment effects seem to be weakly positive for higher educated women and weakly negative for lower educated women in the second year with broadband. An estimated effect of 0.01 would imply an increase in the number of children of 0.5 percent among higher educated women compared to pre-treatment level, which is very modest. Nevertheless, the results indicate that increasing labor supply does not necessarily come at the expense of having a larger family. When we investigate probable causal mechanisms in Section 8 below, we investigate heterogeneity according to motherhood, the results are in line with this conclusion.

Figure 6: Effect Of Broadband on Fertility Outcomes

(a) Rate of parenthood (b) Number of children among mothers



Notes: Estimates are based on estimation model controlling for age

Together, the results show that broadband internet increased the employment gap between high and low educated women in prime age. As the employment rate of high (low) educated women before the reform was 89 (76) percent, this constitutes an approximately 15 percent increase in the employment gap. This increased labor supply among higher educated women does not seem to be coupled with large changes in fertility. Rather, the results among mothers (around 70 percent of the sample of high educated women, and 80 percent of the sample of low educated women) indicate that the average effect on number of children was positive for the high educated and negative for the low educated. Broadband internet has therefore also contributed in the reversion of the education-fertility relationship during this period.

8 Mechanisms

In this section, we explore possible causal mechanisms behind the effect of broadband technology on the education gap in employment and fertility. The two main mechanisms we explore, are changing returns to skill in the labor market and changes in work-time flexibility. Both mechanisms have an education component; broadband technology has been shown to be skill-biased in previous literature. Changes in work-time flexibility is also probable to differ by education levels, as high educated workers are more often in jobs that can be performed from home - at least part of the time.

Higher returns to skill theoretically pulls more high educated women into (full-time) employment. As wages and career opportunities increase, the alternative cost of time to leisure and home production increase (hourly wages). However, this substitution effect may be dampened by the income effect. As wages increase, higher educated women can work the same hours and still increase their income. The effect on fertility is also ambiguous, depending on the relative size of the income and substitution effect. Higher wages in market work increases the alternative cost of spending time with children, which may result in fewer children. On the other hand, if the income effect is large, women can choose to work less with the same income-level and increase their time spent with children - which may result in more children. If higher returns in the labor market and a strong substitution effect is an important mechanism, we should expect to see; i) a substitution away from (to more) leisure/home-time to more (away from) market work for higher (lower) educated women and ii) fewer (more) children among the higher (lower) educated. If the income-effect dominates, however, the direction of the effects would go in the other direction, and higher educated women would work less and have more children, and lower educated women would work more and have fewer children.

Changes in work-time flexibility has some of the same effects as changing returns in the labor market, as high educated women are the ones having jobs that can be performed at other locations than the workplace. This complicates the analysis of causal mechanisms and the separation between the two. However, increased flexibility has implications for employment and fertility outcomes that partly go in other directions than the implications from changes in labor market returns. If broadband increases work-time flexibility, women do not have to substitute between market work and home production to the same extent, and may choose to have more children *and* work more at the same time. Since more high educated women are in jobs that have the flexibility-potential, we should expect to see increased employment and fertility among the high educated and zero or smaller changes in the same direction among the lower educated, if flexibility is an important mechanism.

We explore each of the different mechanisms below, first exploring how broadband affects labor market returns operationalized as hourly wages, then how broadband affects flexibility through heterogeneity analyses of mothers versus non-mothers and employment in industries that have a high potential for home-office.

8.1 Labor market returns

The first mechanism we explore, is changing labor market returns. If broadband internet is complementary to high skilled labor in the workplace, as found in Akerman et al. (2015), the roll-out of broadband internet will increase the demand for high-skilled labor and the returns to high-skilled work. Increasing labor market returns increases the alternative cost of having children, as child-bearing and -rearing demands time spent at home. If the substitution effect dominates, high skilled women will substitute home-time for market work and reduce their fertility more than low skilled women. If the income-effect dominates, however, higher labor market returns may reduce labor supply and increase fertility in the high skilled group. Our main findings are consistent with skill-biased technological change as we find that labor supply of higher educated women increases, and employment of lower educated women decreases. To get indicative evidence of whether changes in labor productivity is a probable causal channel, we therefore estimate the effect on hourly wage for high and low educated women and the results are reported in Figure 7.

Among both higher and lower educated women, we find negative estimated effects on wages in the second and third treatment years. This does not lend support to higher labor market returns being the driving factor behind the coupled effects on labor supply and fertility we have found.

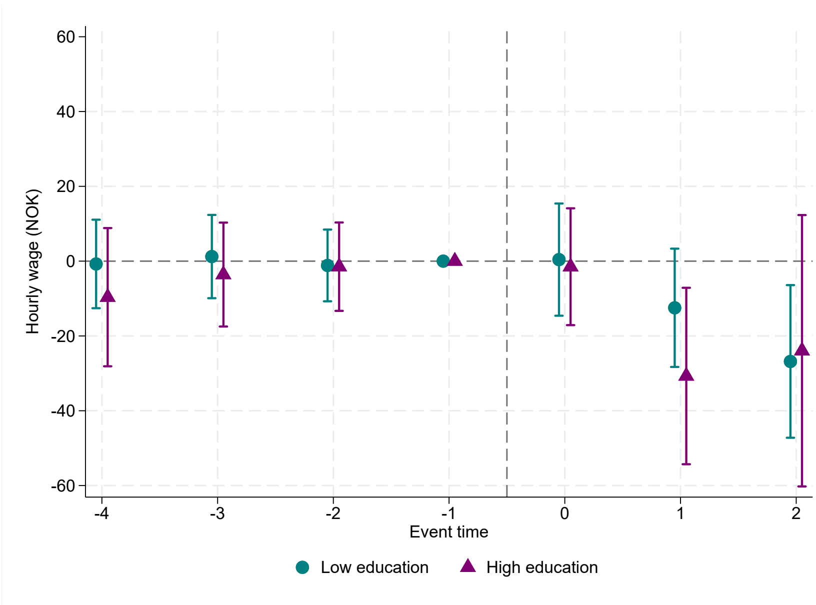
For lower educated women, the negative effect on hourly wage is consistent with broadband technology substituting some of the work tasks of the low-skilled. This in turn, is consistent with lower hourly wage being be a driving factor behind their reduction in labor supply after broadband was introduced. The reduction in alternative costs to work does not however increase fertility. On the contrary, fertility is also reduced among the low-educated, indicating that the income-effect seems to dominate their fertility choices. When they get lower paid and work less, having children is less affordable.

For the higher educated women, however, the results on hourly wages are not in the expected direction if labor market returns is the main mechanism. The effect is negative, and higher returns to work seems an unlikely mechanism for their higher labor supply after broadband.

In both groups, employment was affected by the introduction of broadband internet, and the results on hourly wages may therefore partly reflect selection. If broadband did indeed change productivity and lead to higher demand for - and pay to - high educated women, those women who enter the labor market may on average have a lower labor productivity than those who already work. If the results reflect selection, they are less informative about the role of changes in productivity.

Figure 7: Effect Of Broadband on Labor Market Returns

Figure 8: Hourly wage (NOK))



Notes: Estimates are based on estimation model controlling for age

8.2 Time-constraints and changes in the way we work

The second mechanism we explore, is the role of time-constraints and changes in the way we work (home-office and time-schedule flexibility). Broadband internet has, as described in (Dettling, 2017; Billari et al., 2019), the potential to provide workers with higher work-time flexibility as it increases the productivity also in the home-office. The possibility of working from home in the evenings, or to work from home parts of the week instead of travelling to work, gives increased work time flexibility and cuts travelling time. Several studies show that wage premiums to working long hours is an important barrier for women's careers (Goldin et al., 2006; Goldin, 2014; Cha and Weeden, 2014; Cortes et al., 2021), and increased work-time flexibility may therefore have positive effects on both labor supply and fertility, as it eases the combination of work and family. High skilled women more often have jobs that can be performed from home, and increased work-time flexibility may therefore be a more important mechanism in this group.

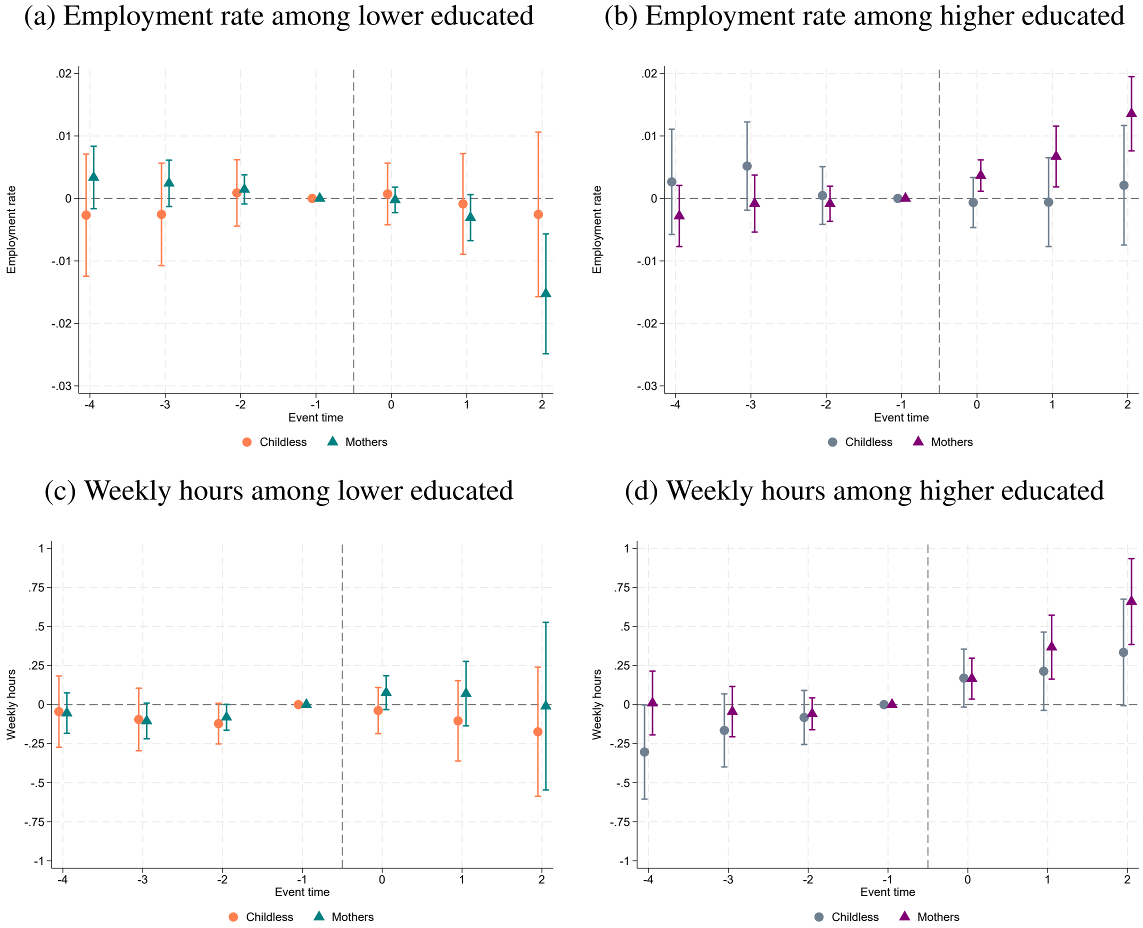
8.2.1 Mothers

The value of working from home should be larger for groups that are time-constrained and experience the trade-off of work and family obligations. We therefore first investigate if broadband actually affected the labor supply of mothers differently than women without children. We also hypothesize that this channel should be more important for higher educated women, as they more often have jobs that can be performed from home. Figure 9 displays the estimated effects on employment and hours separately for childless women and mothers within each eduction group.

We find that the positive effects on employment in the overall sample are almost entirely driven by higher educated mothers, while there is no change in employment among childless women. Among the working population, we also see that mothers work more hours after broadband is introduced. Since employment has increased among mothers, the effects on hours depend on (1) how many hours the mothers who enter the work force as a consequence of broadband will work, and (2) to what extent mothers who would work anyhow change the number of work hours when broadband is introduced. While we are not able to distinguish between the two, there is a positive net effect on hours among mothers. We also find that higher educated childless women increase their work hours, but there is also a pre-trend deviation from the reference group which make interpretation of the post-treatment coefficients as causal more uncertain.

Among lower educated women, it is also mothers who drive the negative employment effects. Broadband therefore seems to have little potential for easing the time-use conflict between work and family for low educated. In this group, the lower returns to work seems to dominate, and pushes especially mothers out of market work.

Figure 9: Differential Effects dependent on motherhood



(a) Employment rate among lower educated

(b) Employment rate among higher educated

(c) Weekly hours among lower educated

(d) Weekly hours among higher educated

Notes: Estimates are based on estimation model controlling for age

8.2.2 Home office

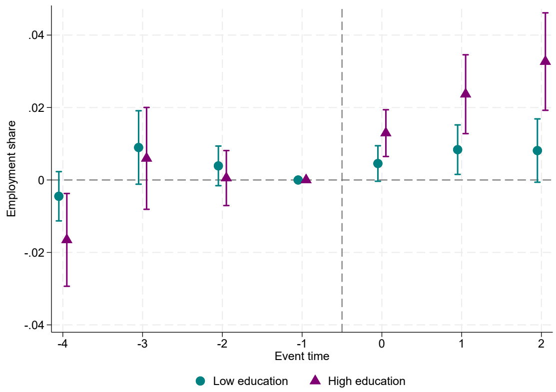
In this section, we explore if an increase in the use of home-office can be a likely causal channel. For some types of occupations and industries, high-speed internet opened up for the possibility of working outside of the physical location of the work-place and also to perform tasks at different hours than normal office-hours. This gives workers the opportunity to allocate time in a more flexible way. For instance by significantly reducing time spent on commuting, or by catching up work in the evenings. The average working hours in home-office industries are consistent with this. Average weekly work hours are 35 for highly educated women and 32 for lower educated women, compared to 32 and 29 respectively in other industries. 88 percent of high educated women work full-time in home-office industries, 70 percent in other industries. 75 and 56 are the corresponding percentages for low educated.

We investigate if the share working in industries with a high home-office potential changed as broadband was introduced to the municipalities. We identify five industries that have an especially high potential, as described in Section A.2. These industries are Information and communication, Professional, scientific and technical activities, Real estate activities, Financial and insurance activities and Public administration. We estimate the same event-study model as before, using a dummy for working in a home-office industry as the outcome all women age 25-45 registered with a job as the sample. Results are presented in figure 10. Panel a shows that the employment share in home-office industries increase as broadband is introduced. The estimated effect also increases over time and amount to 4 percentage points among higher educated women by the end of the period. As the average share of employed women working in these industries in the last pre-treatment period was 23 percent, this amounts to a 17 percent increase. Among lower educated women, the effects are smaller and not significant.

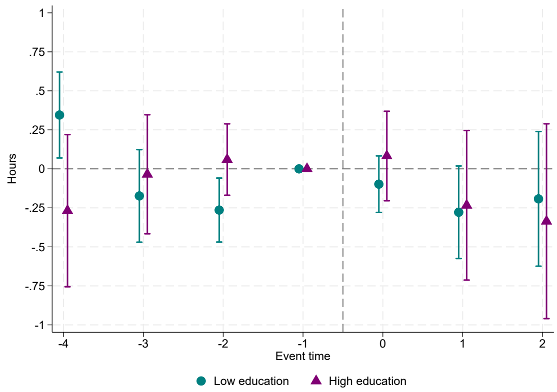
In Panel b we investigate the effects on weekly hours within the home-office industries. The results are not significant and unstable, and the most probable conclusion is that there is no important weekly hour effect within home-office industries. However, since employment increases in these industries, the zero effect on hours within the industry implies that some of the increase in weekly hours for high educated can be explained by more high educated women working in home-office industries - which also have more full-time work. The roll-out of broadband internet pulls more women into industries where the combination of work and family is more feasible, and with this change, hours also increase.

Figure 10: Effects on Home-office Industries

(a) Effects on employment share



(b) Effects on weekly hours



Notes: Panel A show estimated effects on employment share in home-office industries, conditional on being employed. Panel b shows estimated effects on wages within home-office industries. The five home-office industries are Information and communication, Professional, scientific and technical activities, Real estate activities, Financial and insurance activities and Public administration.

8.3 Partner's employment

An alternative explanation of the changes in employment and work hours is that it's a reallocation of the total work hours in the household. If a partners labor market position worsens, the woman might increase her work hours to compensate for the income loss of the partner (Schøne and Strøm, 2021). Conversely, if a partners labor market position improves, the women might reduce her labor supply and allocate more time to home production as the household income increase.

To explore this potential mechanism, we examine the impact of broadband roll-out on the annual labor income and employment of partners. As this analysis includes only women who have a partner, the precision of our estimates are further diminished due to the smaller sample size, but estimates can still be indicative. If changes in partner's labor market position and income is a relevant mechanism, we would expect partners of higher educated women to experience a decrease in employment and/or annual income. Conversely, we would expect partner's of lower educated women to increase either employment, annual income or both.

The effects on partners labor market position do not necessarily need to be similar as for women, or as dependent on education, since the Norwegian labor market is quite gender segregated. In addition, as couples are not perfectly matched when it comes to education level, effects on high and low educated women's partners will be a combination of effects on both high and low educated partners.

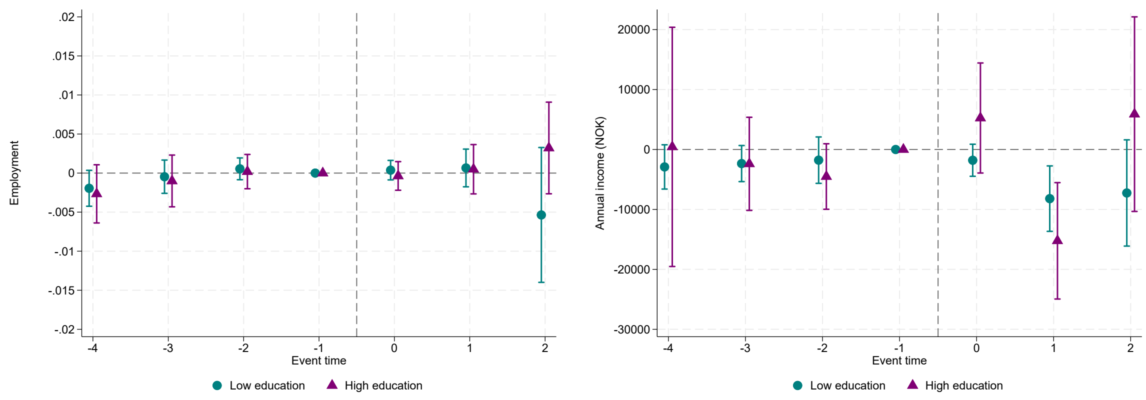
Figure 11 plots the results from this exercise. Looking first at the results on partners' employment (panel a), we do not find such shifts in employment that we would expect if a reallocation of labor within the household was a driving mechanism for the change in women's labor supply. The results concerning annual income fluctuate for partner's of higher educated women, but it seems unlikely that the drop of earnings in the second period is the main driver for why higher educated women work more. As of partner's of lower educated women, we find that annual income is decreasing in the post-treatment period, which render little support for the hypothesis that lower educated women reduced their labor supply in response to a positive shift of household income.

Overall, changes in partner's labor market decisions do not seem to be an important mechanism explaining the widening education gap in the labor market among women.

Figure 11: Effect Of Broadband on Partner's employment and income

(a) Employment

(b) Annual income



Notes: Estimates are based on estimation model controlling for age

9 Robustness checks

In this section we take several steps to test the robustness of our results. First we investigate if our main results are confounded by the introduction of a kindergarten reform in 2003. Second, we check the robustness of our results to the definition of treatment and control group. Third, we investigate if the main results are driven by one of the treated groups by keeping the control group constant and conduct separate regression for each treated cohort. Fourth, we investigate if the results are driven by the most populous municipalities by excluding these from our sample. Fifth, we perform a type of placebo-test where we only include municipalities with low broadband coverage in the treated group. If it is access to broadband which drive the results, we would expect no effect on this sub-sample of municipalities.

Family policy An important potential confounding factor in our context, is family policy. Norway has extensive family friendly policies in place to ease the combination of career and family, including paid parental leave, the right to return to the same job after parental leave, the right to work part-time 3 years after birth, 100 percent kindergarten coverage for children above 1 year old and after-school care programs in every school. Already in 1930 the first law on paid maternity leave was ratified, giving mothers 6 weeks compensated leave. Paid leave has since been extended in many rounds, also to include a quota for fathers in 1993 (Hansen, 1991). During our period of study, 2000-2003, there were no changes in the parental leave system.

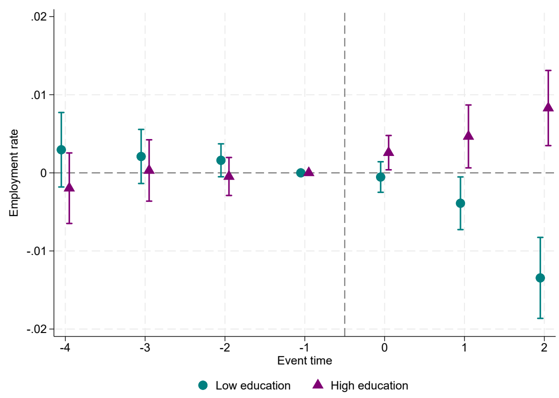
In 2003, however, a central initiative was launched to increase child care coverage for children aged 1 to 3 years. This led to a large-scale construction of kindergarten facilities, beginning in 2003. By 2006, the coverage for children above 1 year of age had reached nearly 100 percent. Importantly, this period of intensive establishment of kindergarten places partially coincides with the study period of interest and was characterized by a staggered expansion across municipalities.

The availability of kindergarten places may have an influential effect on both labor supply and fertility rates, and we therefore use municipality-level data on child-care coverage from

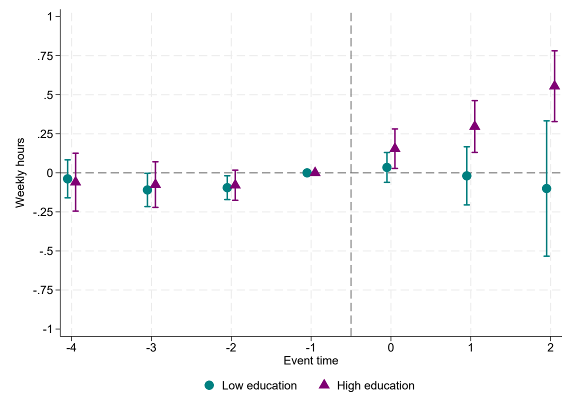
Statistics Norway and include child-care coverage as an additional time-varying control.[6] The results are included in Figures 12 below, and are reassuringly similar to the main results.

Figure 12: Labor Supply and Fertility

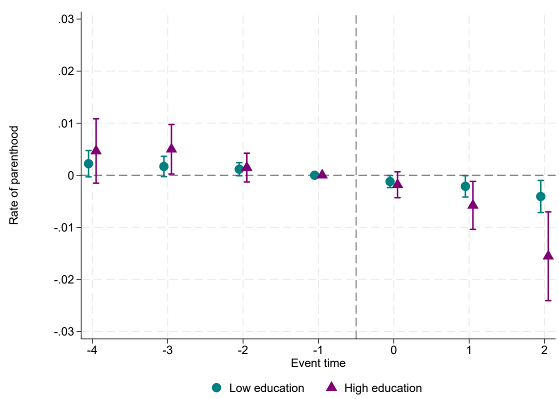
(a) Employment



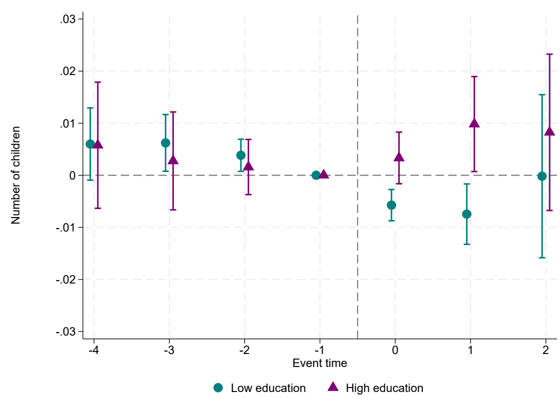
(b) Hours



(c) Motherhood



(d) Number of children among mothers



Notes: The figure shows estimated effects on employment, weekly hours, the rate of motherhood and the number of children when controlling for kindergarten coverage rates.

Alternative specifications of treated and reference group. We investigate if the results are robust to other specifications of the treated and reference groups. In our main specification we have included cohort 2001 to 2002 as treated cohorts and compared with cohorts 2003 to 2005. Our results could as such be sensitive to the composition of the reference group. To test if this is the case, we consecutively include cohort 2002 and 2001 in the reference group and investigate if the coefficients of the remaining treated group change the implications of

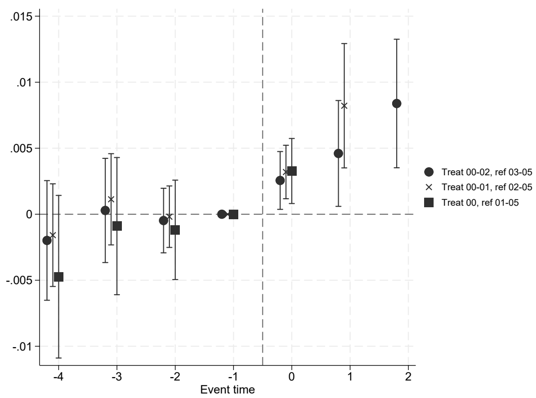
[6]Statistics Norway's official statistics on number of children in kindergarten with at least 33 weekly hours and number of children age 1 to 5, source: https://www.ssb.no/statbank/table/09169 and https://www.ssb.no/statbank/table/07459

our main results. As the reference group grows, the treated group correspondingly shrinks. In addition, the number of post-treatment periods we can estimate effects for will also shrink as we move cohorts who are treated at an earlier stage into the reference group.

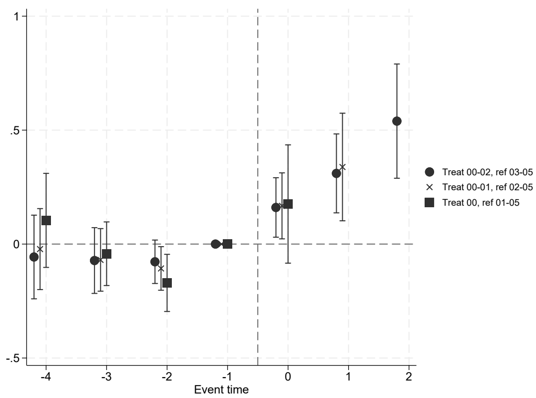
In figure 13 we present the results corresponding to our main outcomes for higher educated women, namely employment and hours. Results concerning lower educated women can be found in the appendix (A.5). The figure show that each specification give comparable coefficients across different specifications of treated and reference group for the first and second post-treatment period, in which we are able to compare estimates.

Figure 13: Alternative Treated and Reference Groups - Higher Educated

(a) Employment



(b) Hours

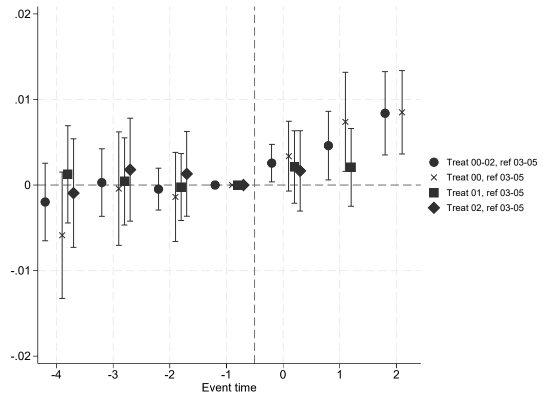


Notes: The figure show estimated effects on employment and hours among lower educated women, using different specifications of treated and reference group

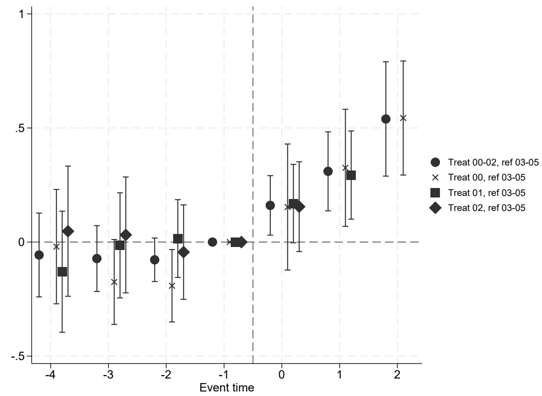
Cohort-specific effects Next we investigate if results are driven by one specific treated cohort, keeping the reference group constant and equal to the main specification with cohorts 2003-2005. We run the regression separately for each treated cohort 2000, 2001 and 2002. Figure 14 present the results from this exercise, for higher educated women (See Appendix A.6 for lower educated women). Estimates from our main specification including all cohorts are included in the figure for comparison (circle symbol). Since the estimate of the third post-treatment period is only based on cohort 2000 in the main specification, this coefficient is identical to the estimate when only this cohort is included in the treated group. Results show that for both outcomes, the estimates are comparable across cohorts for the post treatment periods where comparisons are possible. There is no cohort with opposing direction of effects, and so neither a single year or a single cohort seem to be driving the main effects. This implies (1) all cohorts are affected in the same direction, (2) the dynamic effects over the post-treatment periods are not driven by a single historical year-effect, and (3) the size of the effect in each post-treatment period is similar across cohorts.

Figure 14: Cohort-Specific Effects - Higher Educated

(a) Employment



(b) Hours

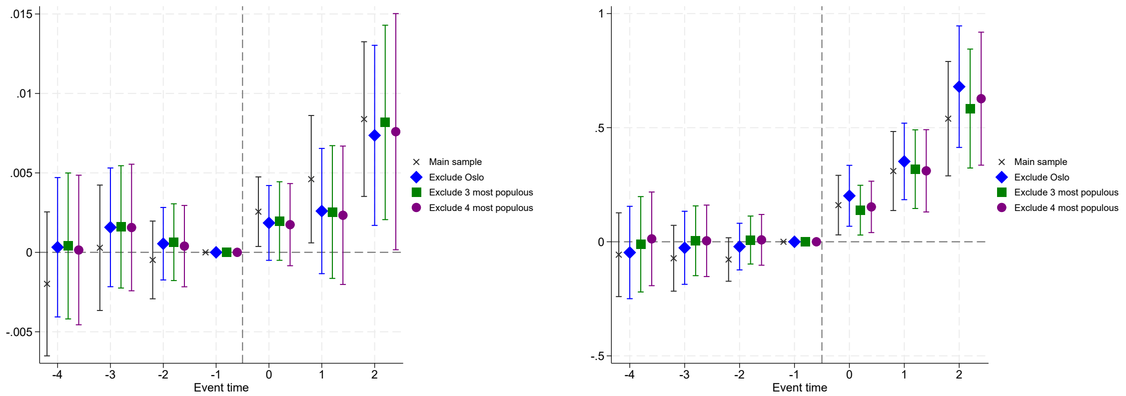


Notes: The figure show estimated effects on employment and hours for each treated cohort, among higher educated women

Excluding populous municipalities We have previously shown that there is a relationship between the timing of the treatment and urbanization. The more populous cities were also the first treated, and they also make up a large share of the treated sample. As cities could be prone to diverge more from less urban areas over time, even without broadband, one concern is that the cities might both be driving the post-treatment estimates and are the least likely to have had parallel trends with the reference group in the post-treatment years had broadband not been introduced. While we cannot test the parallel trend assumption in post-treatment years, we can investigate the effects on our main outcomes when excluding the large cities. In figure 15 we show results from excluding the largest cities from our sample. For employment, the pre-treatment trends become less stable as we exclude the cities from our sample, but the post-treatment coefficients are similar to our main results where all municipalities are included, but the confidence intervals are wider as the sample size is smaller. As of hours, the pre-trends become more similar when excluding the cities and the coefficients are again similar to our main specification. In conclusion, the big cities does not seem to be driving the results.

Figure 15: Estimation Results - Excluding Cities - Higher Educated

(a) Employment (b) Hours



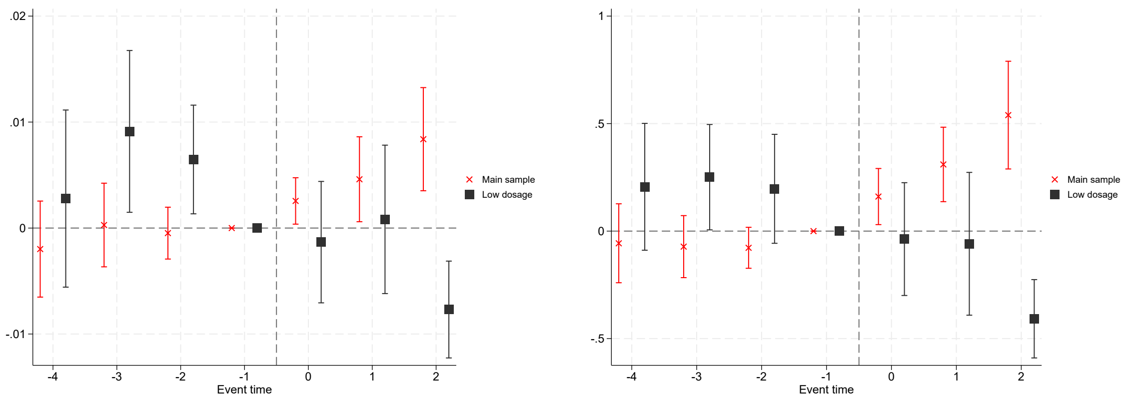
Notes: The figure show estimated effects on employment and hours among lower educated women, excluding the most populous cities from the sample.

Placebo-test We argue that it is the introduction of broadband access which drive our results, and that the increase in employment and work hours among higher educated women is due to supply side changes in the labor market. As the actual coverage rates varies across municipalities, we can use this information to conduct something similar to a placebo test. We would expect that higher educated women in municipalities who during our research window get access to broadband, but with very low coverage rates, should not be affected. While this may not be the case if the demand for labor change as businesses prepare for the adaptation of high-speed internet in their production, it should be the case if women increase their labor supply in response to broadband access. We investigate if this is the case by defining a low-dosage treated group. These are municipalities who in the first treatment period have coverage rates of no more than 0.2, and for those observed over more than one treatment period, no more than 0.3 in the second period. The reference group is same as in our main specification, cohorts 2003 to 2005.

Figure 16 shows the results for our two main outcomes among higher educated women, with coefficients from our main specification shown for comparison. As the pre-treatment trend does not seem to hold for the low-dosage group, we need to be cautious when interpreting the results. Nevertheless, the coefficients of the post-treatment periods are close to zero, as expected. This is reassuring and strengthens the assumption that the effects in our main specification are caused by broadband access.

Figure 16: Placebo - Low Dosage - Higher Educated Women

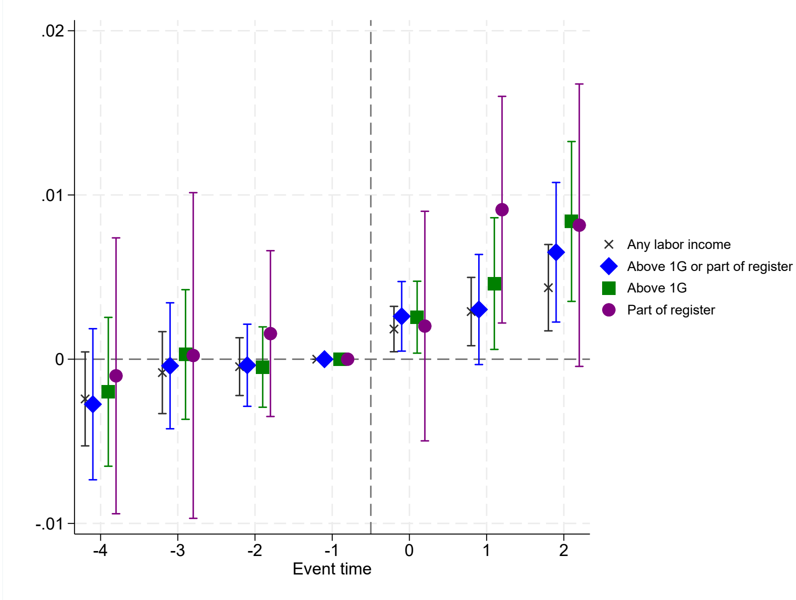
(a) Employment (b) Hours



Notes: The figure shows estimated effects on employment and hours for treated cohorts with low dosage of treatment, among higher educated women. Low dosage is defined as having less than 0.20 broadband coverage rate first year of treatment and no more than 0.30 in second year of treatment

Other employment definitions Our main employment definitions is having labor income above minimum for being eligible to income compensation by the state (above 1G). We base our definition on income because the income registry is the most complete data we have access to. Here we test if our results are robust to three other employment definitions. The widest employment outcome define people as employed if they have any labor income. Next we define employment as having labor income above 1G or being part of employer-employee register. Third we define employment as being part of the employer-employee register. Figure 17 show the estimated effect on each of these employment outcomes, including the main employment definition. As expected, the definitions based on the most complete records are also more precise. Still, all definitions give positive and similar coefficients.

Figure 17: Estimation Results - Different Employment Definitions



Notes: The figure shows estimated treatment effect on higher educated women's employment, with different definitions of employment.

10 Conclusion

In this paper, we have investigated how broadband technology affects employment and fertility among high and low skilled women. Over the last decades, there is an increasing educational divide in labor market outcomes, and the education-fertility relationship has started to turn. High educated women increase their labor supply more than low educated women, and even though low educated women still have more children than high educated women, the long-term trends show that low-educated women are on an increasingly negative trend compared to high educated women. We have showed in the this paper, that the diffusion of information technology - which is one of the main drivers of the last decades' technological change - have contributed in the growing divide between high and low educated women both in labor market outcomes and fertility.

We leverage the staggered roll-out of broadband internet in Norway as exogenous variation in technological change across local labor markets and study how broadband changed women's employment, weekly work hours and earnings, their probability of having children and number of children. During the period 2000-2005, broadband was rolled out across the whole country in Norway, increasing broadband coverage from 0 percent in 2000 to above 80 percent in 2005. We estimate the effect of broadband internet in a difference-in-difference event-study framework, studying the first (and in most cases the largest) increase in broadband coverage, among prime-aged women (aged 25-54). We estimate a two-way fixed effects model including municipality and year fixed effects to control for municipality constant characteristics and business cycle effects, and apply the method suggested by Sun and Abraham (2021) to account for heterogeneous effects.

We find that employment and weekly working hours increased among high-skilled women and decreased among low-skilled women in areas with better broadband coverage, consistent with broadband representing a skill-biased technical change. The overall effect on fertility go in the same direction as the labor market effects, increasing the number of children among high educated women and decreasing the number of children among low educated women. The diffusion of broadband internet contributed therefore to the ongoing reversal of the education-fertility relationship.

In the second part of the paper, we explore different mechanisms behind the results. We first investigate the role of changing labor market returns to high and low skilled labor by estimating the effect on hourly wages and how it varies across educational levels. Second, we investigate the role of work-family time constraints by estimating the effect separately for mothers and childless women, and separately in industries with a high and low potential for home-office and time-schedule flexibility. We find evidence that negative effects on labor market returns may explain the reduced labor supply and fertility of low educated. The positive effects on high educated women's labor supply and fertility seem more connected to an easening of the combination of work and family.

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A Appendix

A.1 Additional Summary Tables

Table A.1: Summary Table By Cohort - Year 1999 - Lower educated

	Cohort 2000	Cohort 2001	Cohort 2002	Reference
Higher educ.	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
Age	34.68	35.21	35.37	35.51
	(5.97)	(5.94)	(5.99)	(5.98)
Employed	0.75	0.76	0.78	0.78
	(0.43)	(0.43)	(0.42)	(0.41)
Hours	24.86	23.03	23.05	21.98
	(15.66)	(14.97)	(14.61)	(14.19)
Hourly wage	209.40	183.09	191.17	175.91
	(1,536.80)	(1,187.69)	(1,314.10)	(1,120.04)
Parenthood	0.70	0.83	0.85	0.86
	(0.46)	(0.38)	(0.36)	(0.35)
Number of children	1.41	1.78	1.87	1.97
	(1.21)	(1.16)	(1.17)	(1.19)
No. of children among parents	2.00	2.15	2.21	2.30
	(0.95)	(0.91)	(0.93)	(0.94)
No. children at age 45	1.84	2.12	2.17	2.25
	(1.21)	(1.09)	(1.12)	(1.12)
Home-office industries	0.21	0.14	0.13	0.13
	(0.41)	(0.35)	(0.34)	(0.34)
Annual salary (100K)	1.80	1.59	1.54	1.44
	(1.40)	(1.17)	(1.09)	(1.03)
Has a partner	0.70	0.82	0.83	0.84
	(0.46)	(0.39)	(0.38)	(0.37)
Income of partner (100K)	4.21	3.91	3.67	3.46
	(10.20)	(5.16)	(2.66)	(2.21)
Labor income of partner (100K)	3.57	3.50	3.32	3.14
	(4.09)	(1.98)	(1.73)	(1.58)
Household income (100K)	4.58	4.68	4.51	4.33
	(8.08)	(4.39)	(2.72)	(2.27)
Commutes to work	0.17	0.34	0.30	0.27
	(0.37)	(0.47)	(0.46)	(0.45)
Observations	97424	182270	72910	71621

Notes: The table displays mean and sd of the main outcomes and additional relevant factors in year 1999 for the lower educated women in our sample (age 25-45), by treatment cohorts and the reference group.

Table A.2: Summary Table By Cohort - Year 1999 - Higher educated

	Cohort 2000	Cohort 2001	Cohort 2002	Reference
Higher educ.	1.00	1.00	1.00	1.00
	(0.00)	(0.00)	(0.00)	(0.00)
Age	34.00	34.32	34.36	34.11
	(5.83)	(6.06)	(6.11)	(6.22)
Employed	0.88	0.89	0.91	0.91
	(0.33)	(0.32)	(0.29)	(0.29)
Hours	30.10	29.05	29.86	29.65
	(12.87)	(12.72)	(11.99)	(11.94)
Hourly wage	268.62	232.05	224.61	215.61
	(2,063.70)	(1,637.26)	(1,260.02)	(1,272.88)
Parenthood	0.56	0.69	0.70	0.69
	(0.50)	(0.46)	(0.46)	(0.46)
Number of children	1.07	1.42	1.50	1.52
	(1.12)	(1.20)	(1.23)	(1.28)
No. of children among parents	1.89	2.07	2.13	2.20
	(0.82)	(0.87)	(0.90)	(0.93)
No. children at age 45	1.73	2.09	2.20	2.27
	(1.15)	(1.11)	(1.11)	(1.16)
Home-office industries	0.30	0.19	0.18	0.18
	(0.46)	(0.39)	(0.38)	(0.38)
Annual salary (100K)	2.65	2.33	2.32	2.21
	(1.69)	(1.33)	(1.18)	(1.10)
Has a partner	0.66	0.75	0.74	0.73
	(0.48)	(0.43)	(0.44)	(0.44)
Income of partner (100K)	5.63	4.53	4.15	3.68
	(10.41)	(6.17)	(5.08)	(2.68)
Labor income of partner (100K)	4.80	4.06	3.74	3.36
	(5.59)	(2.56)	(2.21)	(1.73)
Household income (100K)	5.91	5.36	5.09	4.64
	(11.41)	(5.79)	(4.43)	(2.80)
Commutes to work	0.23	0.37	0.36	0.36
	(0.42)	(0.48)	(0.48)	(0.48)
Observations	80862	81898	27461	22543

Notes: The table displays mean and sd of the main outcomes and additional relevant factors in year 1999 for the higher educated women in our sample (age 25-45), by treatment cohorts and the reference group.

Table A.3: Summary Table By Cohort and Education - Year 1999 - Excluding cities

	Cohort 2000	Cohort 2001	Cohort 2002	Reference	Cohort 2000	Cohort 2001	Cohort 2002	Reference
Higher educ.	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Age	35.20	35.25	35.37	35.51	34.45	34.41	34.36	34.11
	(5.93)	(5.94)	(5.99)	(5.98)	(5.92)	(6.09)	(6.11)	(6.22)
Employed	0.79	0.76	0.78	0.78	0.88	0.89	0.91	0.91
	(0.41)	(0.43)	(0.42)	(0.41)	(0.33)	(0.31)	(0.29)	(0.29)
Hours	24.73	22.92	23.05	21.98	29.21	29.16	29.86	29.65
	(14.77)	(14.93)	(14.61)	(14.19)	(12.95)	(12.54)	(11.99)	(11.94)
Hourly wage	172.85	181.32	191.17	175.91	263.59	221.04	224.61	215.61
	(804.01)	(1,123.95)	(1,314.10)	(1,120.04)	(2,577.68)	(1,186.07)	(1,260.02)	(1,272.88)
Parenthood	0.81	0.83	0.85	0.86	0.68	0.70	0.70	0.69
	(0.39)	(0.37)	(0.36)	(0.35)	(0.46)	(0.46)	(0.46)	(0.46)
Number of children	1.67	1.80	1.87	1.97	1.37	1.47	1.50	1.52
	(1.12)	(1.15)	(1.17)	(1.19)	(1.16)	(1.20)	(1.23)	(1.28)
No. of children among parents	2.06	2.16	2.21	2.30	2.00	2.08	2.13	2.20
	(0.87)	(0.91)	(0.93)	(0.94)	(0.84)	(0.86)	(0.90)	(0.93)
No. children at age 45	2.07	2.14	2.17	2.25	1.94	2.12	2.20	2.27
	(1.08)	(1.08)	(1.12)	(1.12)	(1.03)	(1.10)	(1.11)	(1.16)
Home-office industries	0.15	0.14	0.13	0.13	0.20	0.18	0.18	0.18
	(0.36)	(0.35)	(0.34)	(0.34)	(0.40)	(0.39)	(0.38)	(0.38)
Annual salary (100K)	1.72	1.58	1.54	1.44	2.45	2.33	2.32	2.21
	(1.21)	(1.17)	(1.09)	(1.03)	(1.45)	(1.31)	(1.18)	(1.10)
Has a partner	0.77	0.82	0.83	0.84	0.72	0.76	0.74	0.73
	(0.42)	(0.38)	(0.38)	(0.37)	(0.45)	(0.43)	(0.44)	(0.44)
Income of partner (100K)	3.94	3.91	3.67	3.46	5.08	4.51	4.15	3.68
	(5.57)	(5.38)	(2.66)	(2.21)	(8.49)	(6.43)	(5.08)	(2.68)
Labor income of partner (100K)	3.49	3.49	3.32	3.14	4.42	4.03	3.74	3.36
	(2.17)	(1.97)	(1.73)	(1.58)	(5.53)	(2.51)	(2.21)	(1.73)
Household income (100K)	4.64	4.70	4.51	4.33	5.69	5.40	5.09	4.64
	(4.64)	(4.56)	(2.72)	(2.27)	(6.79)	(6.09)	(4.43)	(2.80)
Commutes to work	0.24	0.37	0.30	0.27	0.35	0.42	0.36	0.36
	(0.43)	(0.48)	(0.46)	(0.45)	(0.48)	(0.49)	(0.48)	(0.48)
Observations	13935	160534	72910	71621	10015	66661	27461	22543

Notes: The table displays mean and sd of the main outcomes and relevant factors in year 1999 for each education group in our sample (age 25-45), excluding the five most populous cities.

A.2 Survey Home-Office usage

In order to identify industries that had a high potential for home-office arrangements, we use a repeated cross-section surveys of businesses, ABU. These representative surveys were conducted in 1997, 2003 and 2012 and firms were asked if they had employees who work from home at least once a week during a typical week. They were also asked how large share of employees use PC to perform their tasks at work. Table A.4 show summary statistics by year for the relevant questions. The mean number of employees ranges between 129 and 177 over these three years. The share of firms with home-office arrangements increase quite drastically from 16 percent to 28 percent between 1997 to 2003, but is stable from 2003 to 2012. During the whole period, the usage of PC among employees increase steadily.

Table A.4: Summary Table - ABU Survey

	1997	2003	2012	Total
Number employees	129.32	165.05	177.45	157.36
	(231.3)	(358.1)	(543.4)	(393.7)
Home-office	0.16	0.28	0.27	0.24
	(0.368)	(0.449)	(0.445)	(0.427)
Share use PC	0.41	0.57	0.74	0.57
	(0.376)	(0.369)	(0.338)	(0.385)
Observations	1990	2358	1887	6235

arrangements To identify the industries with highest potential for flexible work-, we run three OLS-regressions. First, we run a regression on a dummy variable equal to 1 if the firm has employees working from home at least once a week. Our main explanatory variables are a set of industry dummies, in addition to survey year dummies and number of employees in the firm. The industry coefficients are estimates of the difference in share of firms with home-office employees compared to a reference industry. Secondly, for each industry we investigate the change in share of firms with home-office practise over the survey years. For this second analysis we run a regression on the same dummy-variable, but separately for each industry and with year-dummies and number of employees as explanatory variables. The year coefficients estimate the year-fixed effects on home-office within each industry. Third, we investigate variation across industries in the use of pc by running a regression on the share of employees who use a pc to perform their tasks. The explanatory variables are again industry-dummies and year-dummies. In combination, these three regressions help us identify the industries where (1) home-office is relatively more common, (2) has increased relatively more over the period and (3) where using a pc at home is relatively more common. The results are displayed in Figures A.1, A.2 and A.3 below.

We identify five industries for which home-office potential is relatively high according to at least two of the three indicators above. These industries are Information and communication, Professional, scientific and technical activities, Real estate activities, Financial and insurance activities and Public administration.

Figure A.1: Home-office arrangements - Overall variation

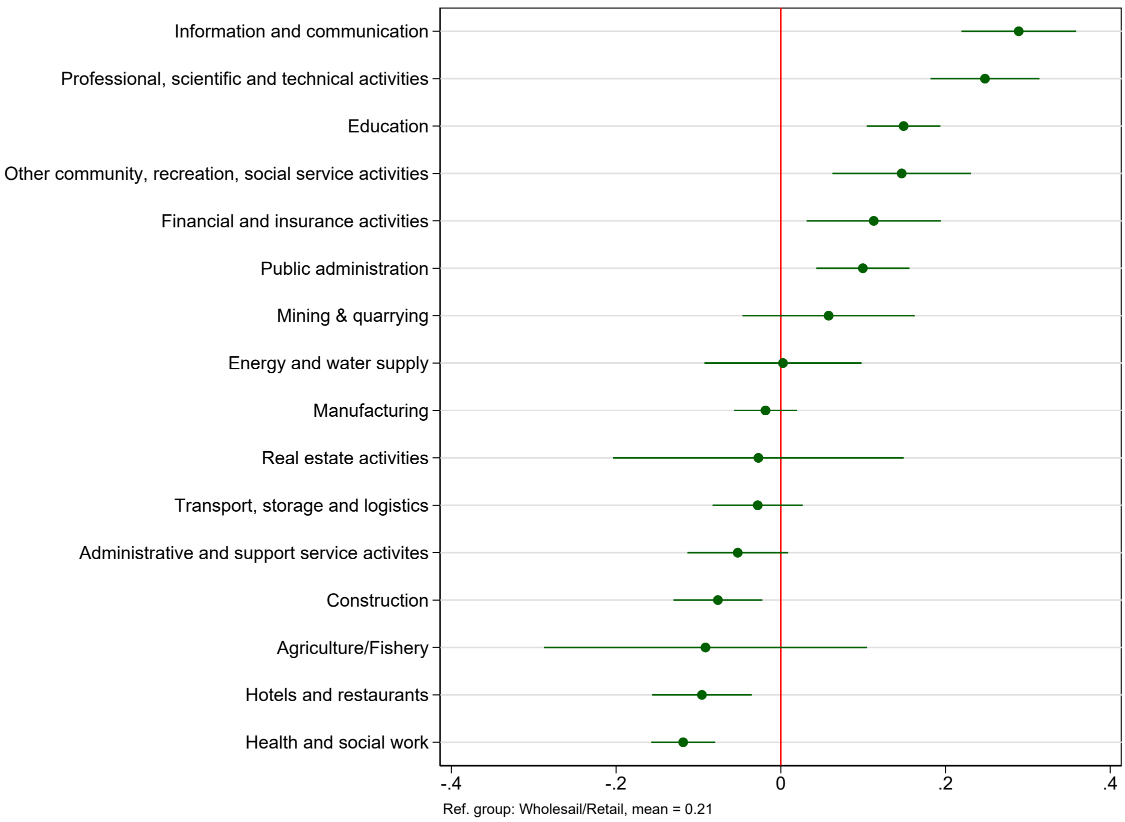


Figure A.2: Home-office - Change over survey period

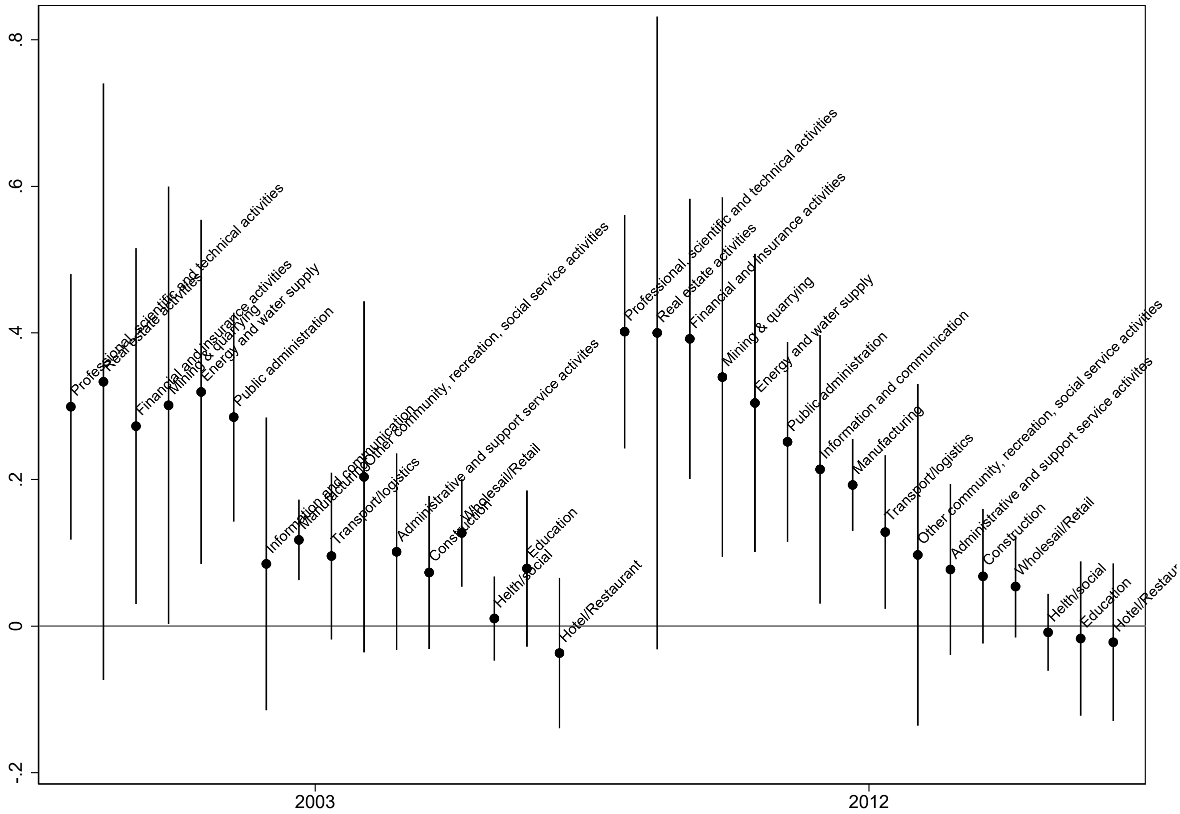
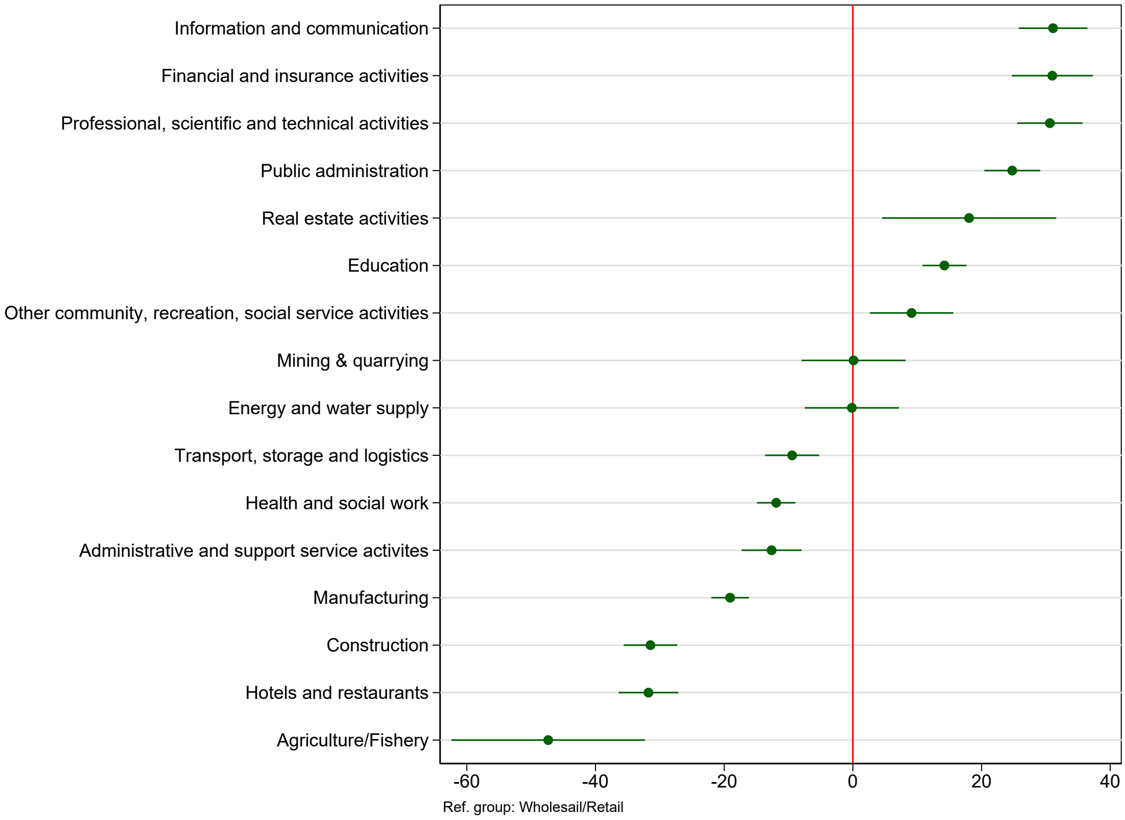


Figure A.3: PC-usage - Overall variation

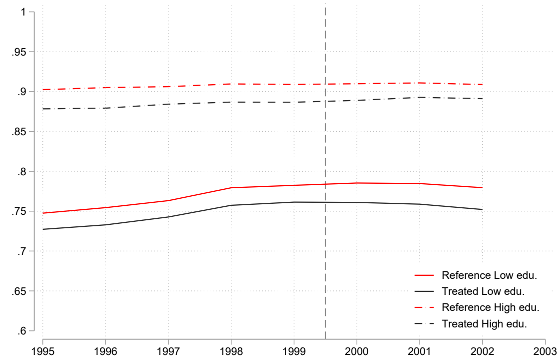


A.3 Raw Trends

As a descriptive investigation of differential trends, we illustrate the yearly, education-specific averages in our estimation period 1995-2003 for our four central outcomes, considering both the treated cohorts collectively and the reference group (figure A.4). The vertical reference line at the year 1999 marks the final year prior to municipalities consecutively gaining access to high-speed internet. While not all cohorts are treated during years 2000-2002, year 2003 marks the year all cohorts have some positive level of broadband coverage.

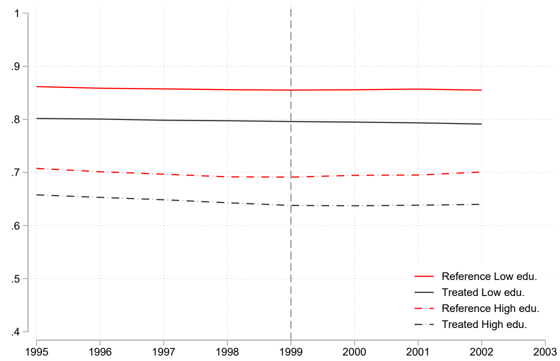
Figure A.4: Trend in outcomes, by education and treatment group

(a) Share employed

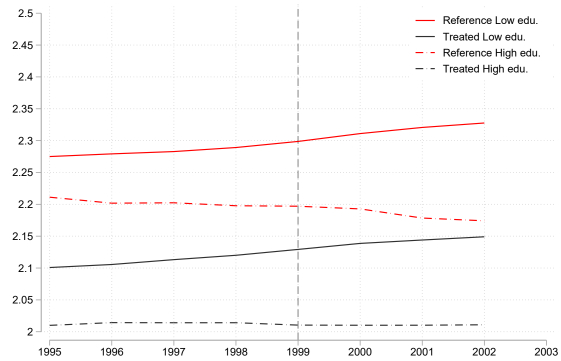


(b) Avg. Weekly hours

(c) Share parents



(d) Avg. number of children among mothers

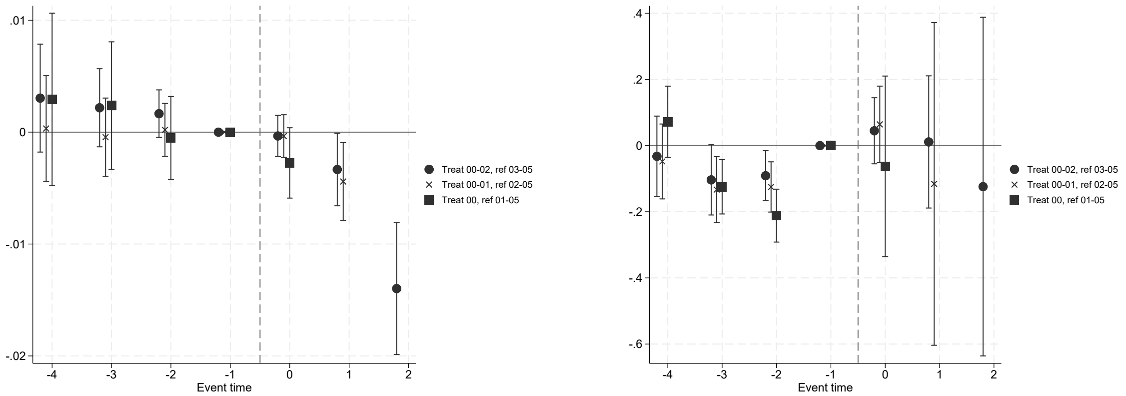


Notes: The figure displays average values of the four main outcomes over years, by education and treatment group. Solid lines represent low educated and dashed lines represent higher educated women

A.4 Robustness Checks - Additional Figures on Lower Educated

Figure A.5: Estimation results - Alternative Treated and Reference Groups - Lower Educated

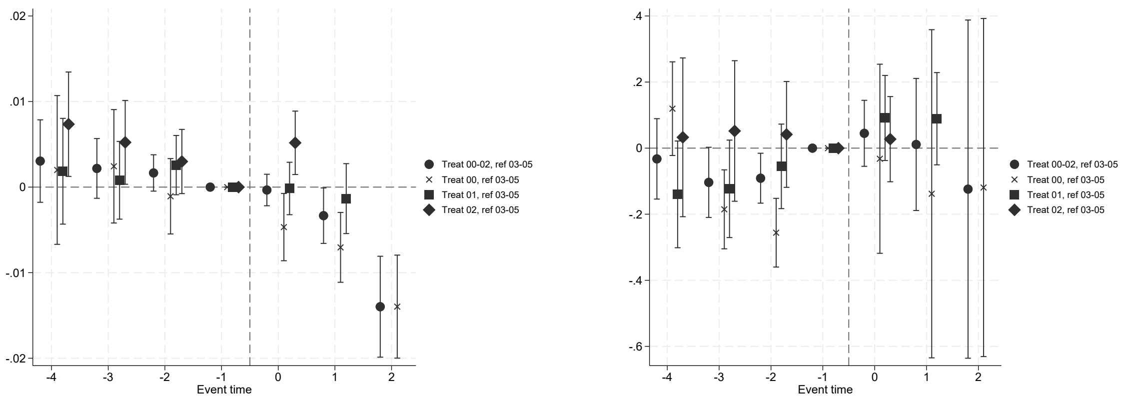
(a) Employment (b) Hours



Notes: The figure show estimated effects on employment and hours among lower educated women, using different specifications of treated and reference group.

Figure A.6: Cohort-Specific Effects - Lower Educated

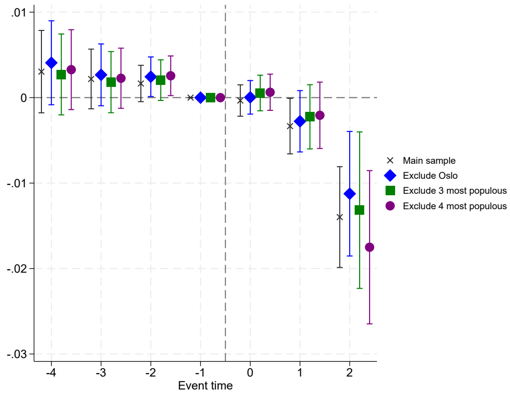
(a) Employment (b) Hours



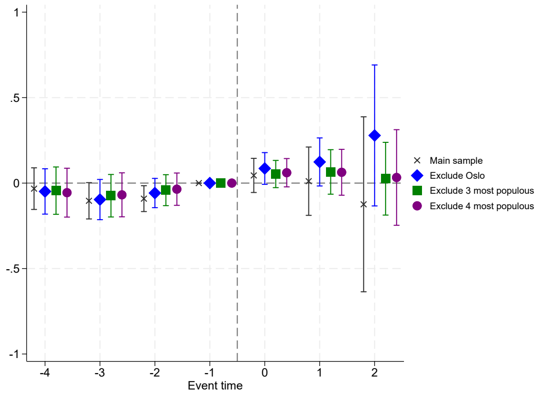
Notes: The figure show estimated cohort-specific effects on employment and hours for each treated cohort, among lower educated women.

Figure A.7: Estimation Results - Excluding Cities - Lower Educated

(a) Employment



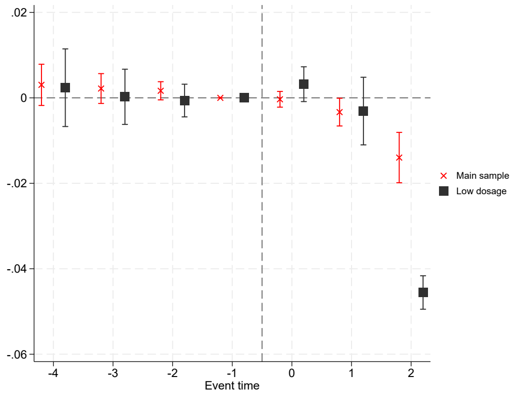
(b) Hours



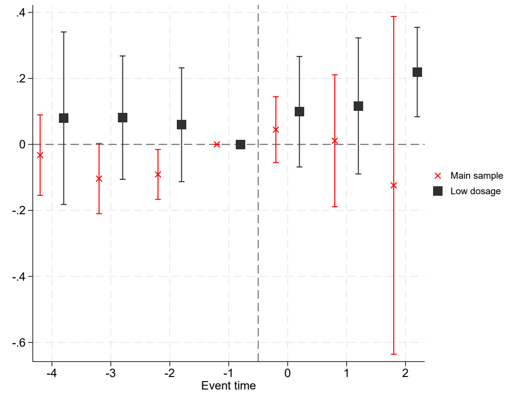
Notes: The figure show estimated effects on employment and hours among lower educated women, excluding the most populous cities from the sample.

Figure A.8: Placebo - Low Dosage - Lower Educated

(a) Employment



(b) Hours



Notes: The figure show estimated effects on employment and hours for treated cohorts with low dosage of treatment, among lower educated women. Low dosage is defined as having less than 0.20 broadband coverage rate first year of treatment and no more than 0.30 in second year of treatment

A.5 Removing Additional Pre-Treatment period