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How Broadband Internet Affects Labor Market Matching

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ABSTRACT

How Broadband Internet Affects Labor Market Matching*

How the internet affects job matching is not well understood due to a lack of data on job vacancies and quasi-experimental variation in internet use. This paper helps fill this gap using plausibly exogenous roll-out of broadband infrastructure in Norway, and comprehensive data on recruiters, vacancies and job seekers. We document that broadband expansions increased online vacancy-postings and lowered the average duration of a vacancy and the share of establishments with unfilled vacancies. These changes led to higher job-finding rates and starting wages and more stable employment relationships after an unemployment-spell. Consequently, our calculations suggest that the steady-state unemployment rate fell by as much as one-fifth.

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1 Introduction

The internet has fundamentally changed the way job vacancies are matched with job seekers. Online job boards (e.g., hotjobs.com and monster.com) have lowered the cost of advertising, allowing firms to announce vacancies to a larger pool of potential applicants.[1] As a result, the fraction of job seekers that use the internet for job search increased from 25 percent in 2000 to 75 percent in 2011 in the U.S. (Faberman & Kudlyak, 2016); and by 2015, nearly 70 percent of job openings were posted online (Carnevale *et al.* , 2014). This trend is not unique to the U.S.: Figure 1 illustrates that in Norway, the share of online job postings tripled in just five years starting in 2003. The increased availability of new search technologies suggests that the internet may have reduced information asymmetries and labor market frictions, potentially leading to higher pay, more stable employment and lower unemployment rates.

Figure 1: Sources of Vacancy Posting in Norway.
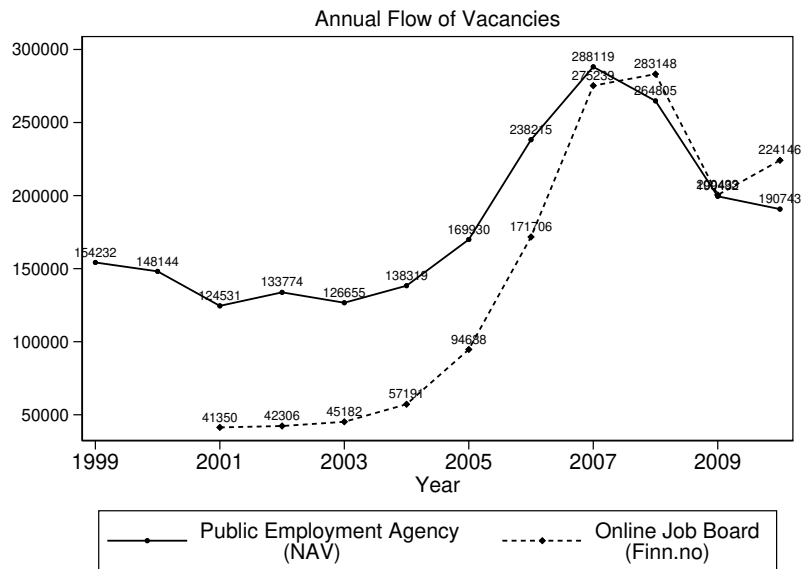
Notes: This figure shows the number of vacancies posted on the only major online board Finn.no and official vacancy statistics from the National Public Employment Agency (NAV).

While the internet may have had substantial impacts on the process of allocating workers to firms, little is known about the impacts of the internet on labor market matching. The key difficulties are the lack of available data on *both* sides of the labor market and identifying sources of exogenous variation in internet use. The first challenge is crucial as theory predicts that when filling a job is easier, firms respond by posting more vacancies. As a consequence, the outcomes of job search are in part determined by firms' endogenous responses, in addition to any improvement in search technology. Distinguishing between effects from labor demand vs. matching, therefore, requires data on firms' recruitment efforts and assessing the impacts on pay and match quality requires data on the outcomes of the search process.[2] The second challenge is that internet

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[1] Alan Krueger provided estimates of changes in the cost of advertising in his opinion piece "The Internet is lowering the cost of advertising and searching for jobs" from 2000. The article is available in the NYT Online Article Archive (accessed 27/06/2019).

[2] Existing studies are limited to the outcomes of job seekers (e.g., Kuhn & Skuterud, 2004, Kuhn & Mansour, 2014, Denzer

use is not random, but is likely determined by unobserved factors that also affect a person's labor market success. Therefore, identification is hampered by the confounding effects of self-selection at the individual level. At the aggregate level, separating the effect of the internet from a general time trend is either not feasible or requires strong parametric assumptions.

This paper addresses this lack of knowledge by estimating how the availability of broadband internet affects labor market matching. Two key features of the Norwegian labor market facilitate our assessment. First, we use a national broadband policy that generated plausibly exogenous variation in broadband internet infrastructure across households and firms.[3] Second, a comprehensive set of survey and administrative data allows us to shed light on the behavior of both sides of the labor market. Crucially, our data includes newly matched data on firms' vacancy-postings and large-scale survey data with qualitative information about firms' recruitment endeavors. These data sources allow us to provide the first evidence on how broadband internet affects the way firms recruit (e.g., their use of online job boards), how fast their vacancies are filled, as well as their vacancy posting and hiring growth. Using survey and linked employer-employee data, we assess the effect on re-employment rates of job seekers and the effects on starting wage and duration of newly formed matches. Finally, we employ a regional approach to account for potential search externalities that may not be captured when studying individual outcomes, which allows us to assess the aggregate implications of broadband internet expansions.

The main results of our paper can be summarized in three broad conclusions. First, our evidence suggests that broadband internet has improved the recruitment process: We find that establishments are more likely to post vacancies on online job boards and report fewer recruitment problems within the first quarter after the broadband coverage expands. Looking at the duration of a vacancy, the average duration falls by nearly 1 percent for every 10 percentage point increase in broadband coverage. This finding is consistent with improvements in the recruitment process, but is inconsistent with a positive labor demand shock. In the canonical search and matching framework by Diamond, Mortensen and Pissarides, lower recruitment costs and higher productivity induce firms to post more vacancies. More vacancies on the market increase the competition for available job seekers, which would extend the duration of the recruitment process.

Second, we document important benefits of broadband internet availability for job seekers. In line with existing evidence, we find that internet coverage increases the job-finding rates of job seekers. We then expand on the existing evidence by assessing the impacts on starting wages and tenure in new jobs formed after an unemployment spell. Our evidence shows that average starting wages are 3-4 percent higher among job seekers with full broadband coverage compared to job seekers with zero coverage. This finding supports the view that higher expected re-employment rates improve the outside option of job seekers who negotiate wages with prospective employers. We find that the impact on job tenure is of a similar magnitude and is mostly driven by a reduction in the number of short employment spells. To the extent that online platforms provide job seekers with more information about potential employers and vice versa, the tenure effect is consistent with the idea that improved access to information increases match quality.

_et al._ , 2018, Gürtzgen _et al._ , 2018). A notable exception is Kroft & Pope (2014), who studied how the penetration of the website Craigslist affected local unemployment rates. None of these authors study the impacts on wages and tenure.

[3]This variation is used in other contexts by Bhuller _et al._ (2013) and Akerman _et al._ (2015). For program details see Report no. 38 to the Storting (1997-1998) and Report no. 49 to the Storting (2002-2003).

Third, our granular data allow us to take a deeper look at the potential mechanisms behind our two main results. Our evidence suggests that acccess to information is a key mechanism behind our results: Job seekers are more likely to find employment in establishments located farther away from their own residence. This evidence strengthens the view that the internet improves access to information about job openings and has thereby increased the size of local labor markets. Moreover, the evidence suggests that the productivity effects of information and communication technologies (ICT) are not the key drivers of our results, as pure productivity effects should lead to more employment locally. We substantiate this conclusion by showing that our results remain both qualitatively and quantitatively the same if we redo our analysis among less ICT-intensive occupations (e.g., plumbers, cleaners), for whom one may not expect a productivity effect.

Our empirical results should be interpreted as the intention-to-treat estimates of broadband internet on labor market matching. We show that availability of broadband internet is likely to affect workers' outcomes both through their own internet use and by firms' responses. While this suggests that the exclusion restriction is unlikely to hold, we take several steps to help interpret the evidence. We show that the broadband policy is a multifaceted treatment: The availability rate significantly increases i) the adoption rate among both firms and households by about 25-30 percent, and ii) increases firms' use of online job boards, and households' use of internet to browse online ads.[4]

Our identification relies on calendar time fixed effects and municipality fixed effects to remove any systematic differences in labor market conditions between cities and more rural labor markets.[5] A key threat to identification is that the broadband expansion is related to time-varying unobserved and underlying labor demand and supply factors. To address this concern, we show that the timing of expansion is unrelated to pre-determined factors that may be positively correlated with the speed of labor market matching (e.g., unemployment rate, road infrastructure, commuting time). Moreover, several specification checks confirm that our results are qualitatively the same and quantitatively very similar when we include a large number of observable labor market, firm, and worker characteristics (e.g., industry- and occupation-fixed effects) and allow differential trends across geographic areas. We also perform several placebo tests, all of which support our main findings.

Our paper is primarily related to a small literature that studies job search strategies and individual employment outcomes. Kuhn & Skuterud (2004) is the first and a widely cited study of the relationship between unemployment duration and the internet as a method to search for jobs. These authors find that, after controlling for observables, the use of online search leads to slightly longer unemployment durations than job seekers who use more traditional search strategies.[6] More recently, Denzer *et al.* (2018) and Gürtzgen *et al.* (2018) use variation in broadband internet availability across German municipalities to study how the internet as a means of job search affects job finding probabilities. We contribute to these studies in two ways. First, we document important benefits for job seekers in terms of higher wages and more stable employment

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[4]The online job board Finn.no had a market share of 95 percent in the market for online vacancies in Norway (see Anand & Hood (2007) and further details in Appendix B.2). Households' use of internet to browse ads includes both job and housing ads.

[5]Key drivers of spatial variation in broadband are topographical differences, with fjords and mountains separating local labor markets. The most cost effective broadband infrastructure was typically based on existing cables, and road and railroad infrastructure. Due to limited funding, these supply limitations often dominated demand factors (see Section 3.1).

[6]Kuhn & Mansour (2014) use a more recent sample of job seekers and find that internet usage is associated with a 25 percent reduction in unemployment duration. Stevenson (2009) uses a similar empirical strategy and finds that workers who look for jobs online have more job-to-job transitions than workers that use other strategies.

relationships. Second, we show that part of the employment effect is due to firms' endogenous response. Our paper is thus more closely related to Kroft & Pope (2014), who study equilibrium effects of "Craigslist" – a website that allows users to post job and housing ads. Using variation across metropolitan areas in the U.S. and over time, the authors do not find any evidence of lower unemployment rates. While these authors may not capture competition from other websites, we contribute by showing that internet availability leads to a sharp increase in firms and job seekers' use of online job boards. This may explain why internet access has large impacts on the aggregate flows in and out of unemployment, while a single website does not.

Our paper also contributes to other studies of labor market frictions. Belot *et al.* (2019) show that information provision about jobs broadens the scope of jobs young job seekers apply to and end up interviewing for. Hjort & Poulsen (2019) document large employment effects from expansions in the internet across the African continent – consistent with the view that information frictions are particularly important in developing countries. By contrast, Martellini & Menzio (2018) find that vacancies and unemployment rates in the U.S. have not fallen as much as expected given the large improvements in search efficiency due to the diffusion of telephones, computers and the internet.[7] While impacts on job-finding rates and unemployment risk may be offset by other macro trends, we complement their study by identifying the mechanisms that render a zero impact on vacancies.

Our study sheds light on aspects of vacancy posting and hiring decisions at the establishment-level. Davis *et al.* (2013) examine time-varying and cross-sectional variation in vacancy filling rates and argue that higher employment growth is explained by more intense recruiting. To the best of our knowledge, Kettemann *et al.* (2018) is the only other study that combines administrative data on vacancies, firms, and workers. Their main finding is that high-paying firms fill their vacancies faster.[8] We contribute to this literature by documenting important feedback effects in recruitment: Establishments respond to improvements in the search efficiency by recruiting even more. Finally, Autor (2001) argues that it is natural to expect increases in the quality of a worker-firm match following improved search technology. Our evidence of longer employment spells is consistent with this idea (see also Autor & Scarborough, 2008 and Hoffman *et al.*, 2017).[9]

Our findings have several important implications for policy. One is to help interpret the falling rates of job-to-job mobility, a trend which has fueled a growing concern about the decline in labor market fluidity in the U.S. (e.g., Molloy *et al.*, 2016). We provide a nuanced view of the role of internet and job-matching are shaping these trends. Our evidence suggests that broadband internet has improved match quality and thereby reduced the need for employees to switch employers in search for better job-specific matches. This is in line with recent work by Pries & Rogerson (2019) who argue that improvements in employer screening (i.e. online employment tests) can explain the observed fall in job-to-job mobility in the U.S. Another implication

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[7]Interestingly, Atasoy (2013) finds a strong association between internet access and employment in the U.S.

[8]This is broadly consistent with evidence from survey data or online platforms showing that vacancies postings with higher wages receive more applications (e.g., Marinescu & Wolthoff, 2016 and Banfi & Villena-Roldan, 2018). Other related studies of vacancy posting behavior use survey data (e.g., Holzer *et al.*, 1991, van Ours & Ridder, 1991, Van Ours & Ridder, 1992, Burdett & Cunningham, 1998, Davis *et al.*, 2014, Faberman & Menzio, 2018), or microdata from online job boards (e.g., Barron *et al.*, 1997, Modestino *et al.*, 2016, Hershbein & Kahn, 2018).

[9]Our paper is also related to the literature on productivity-effects of digital technology adoption at the firm level (for a review, see Goldfarb & Tucker, 2019). Notably, Akerman *et al.* (2015) use the same expansion in broadband coverage, and estimate using 2SLS that broadband internet adoption widened the pay-gap of skilled relative to unskilled workers in Norway. While these authors study wages in existing employment relationships within manufacturing and wholesale, we focus on job seekers and recruiting firms from a broader set of occupations and industries.

relates to the aggregate effects of labor market mismatch (see e.g., Sahin *et al.* , 2014, Herz & van Rens, 2018 and Marinescu & Rathelot, 2018). Our findings suggest that information frictions may contribute to the mismatch between job seekers and vacancies. Improvements in job search technology would, therefore, lead to an inward shift in the Beveridge curve — the negatively sloped relationship between job vacancies and unemployment — which has been observed in several countries from the 1990s to the early 2000s (see, e.g., Bova *et al.* , 2018). Using our regional evidence on flows in and out of unemployment, we calculate that the steady-state unemployment rate in 2012 would have been 10-25 percent higher in the absence of broadband internet.[10]

The paper proceeds as follows. Section 2 describes the institutional background and our data sources. Section 3 presents our empirical design, and Section 4 motivates our empirical assessment from a simple search and matching framework. Section 5 presents our main evidence on the recruitment and outcomes of the matching process. Section 6 presents evidence on possible mechanisms behind our main results, and Section 7 presents a regional analysis and equilibrium effects. Section 8 concludes.

2   Institutional Background and Data Sources

We begin this section by describing some key institutional details of labor markets in Norway. We then describe a variety of administrative and survey data sources on workers and employers, including details on the analytical samples we use.

2.1   Institutional Background

2.1.1   Labor Market Regulation

The Norwegian labor market is characterized by a combination of institutional regulation and flexibility. Labor laws regulate firms' hiring and firing practices, while wages and working hours are typically negotiated and set in accordance with collective bargaining agreements. Most private sector jobs are covered by collective agreements that are negotiated by unions and employer associations at the industry level. Minimum (tariff) wages are set centrally and wages are supplemented by local adjustments, or wage drift, which is bargained over at the firm level. Firms can hire employees on either fixed-term or permanent contracts. Hiring on a permanent contract typically entails a probationary trial period of 6 months, during which the employee can be dismissed on the grounds of the employee's lack of suitability for the work following a 14 day notice.[11] Firms can fire workers when operating at a loss or are under-performing relative to their peers (see Huttunen *et al.* , 2011, for details).

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[10]Another implication of improvements in matching efficiency and falling cost of gathering information about job vacancies is that the natural rate of unemployment falls, which in turn may facilitate more expansionary monetary policy (Friedman, 1968).

[11]Fixed-term hiring has stricter regulations, and an employee can only be temporarily hired if the work is of a temporary nature, or if the employee is a temporary replacement hire, a trainee, or a participant in an active labor market program. Moreover, a firm can hire additional temporary staff only if no more than 15% of firms' employees hold temporary contracts within a period of up to 12 months. According to the Eurostat, around 8.8% of working age individuals in Norway held temporary contracts in 2016.

2.1.2 Unemployment Insurance

Job losers are eligible for unemployment insurance (UI) benefits after a three-day waiting period. Benefits replace around 62 percent of workers' past earnings and all unemployed workers below retirement age are eligible for 104 weeks of benefits if their previous earnings are above a fairly low threshold (see, e.g., Røed & Zhang, 2003). To remain eligible for benefits, recipients are required to actively look for jobs and to be willing to take any type of employment (full-time or part-time) at any geographic location (within or across commuting zones). At the end of the potential benefit period, unemployed workers can apply for other means-tested transfer programs available though the social safety net.[12] The Norwegian UI system is financed by payroll taxes, and there is no experience rating on the firm.

2.1.3 Comparison with the U.S.

Figure 2: Stocks and Flows in Norwegian Labor Market.

(a) Gross Labor Market Flows   (b) Vacancy and Unemployment Rates
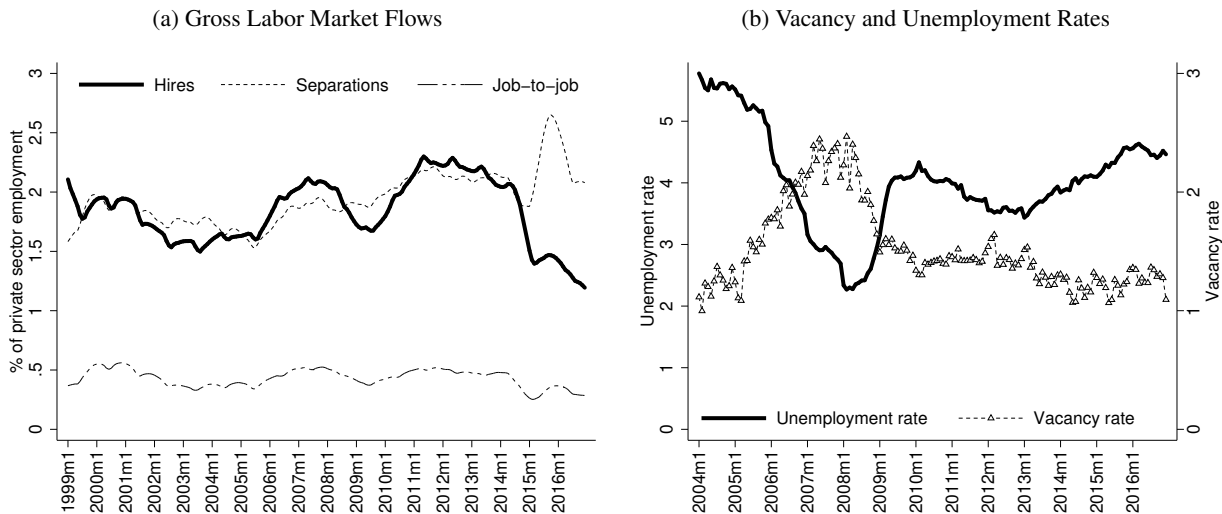
Notes: Figure 2a shows hires and separations in the private sector in Norway for workers aged 25-66. The time series are seasonally adjusted, and smoothed using a three month moving average. Figure 2b shows the monthly unemployment rate among workers aged 25-66, and includes workers who are partially employed and participating in active labor market programs. The vacancy rate is based on vacancy data provided by the National Public Employment Agency (NAV), and is divided by the labor force aged 25-66.

Figure 2a shows that despite a high degree of regulation and high replacement rates from UI benefits, hiring and separation rates in Norway are relatively high. The turnover rates in the private sector are comparable to those in many other countries. For example, turnover in Norway is about 20 percent lower than corresponding numbers in the U.S. private sector (see Davis *et al.* , 2006). Figure 2b illustrates the economic environment in Norway by the co-movement between unemployment and vacancy rates over the period from 2004 to 2016. Both series are seasonally adjusted, and are divided by the labor force. The average unemployment rate over

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[12]Social assistance (i.e. traditional welfare benefits) replaces on average 30 percent of previous earnings, and eligibility requirements (activity and means-testing) vary across geographic administrative units. Vocational rehabilitation and early retirement programs provide cash transfers that cover about 60 percent of past earnings, but eligibility depends on workers' health status, educational attainment and the transferability of skills to other occupations. Other may leave the labor force for early retirement at the age of 62, or by successful applications for disability insurance benefits (see Kostol & Mogstad, 2014).

the period was low relative to other European countries. Compared with the U.S., Norway experienced a milder Great Recession, where unemployment peaked at 4.4 percent by the end of 2009.

2.2 Data Sources

2.2.1 Administrative Data

Our empirical analysis combines several administrative data sources that can be linked by unique and anonymized identifiers for every resident individual and both registered establishments and firms. Our administrative records include the Matched Employer-Employee Register, the Job-Seeker/Unemployment Register, and the Register of Job Vacancies. The first two registers are provided by Statistics Norway, while the last register is provided by the National Public Employment Agency (NAV) and includes detailed data on the posting dates and duration of vacancies at the firm and establishment level.[13] Using unique identifiers for workers and establishments, we can link these sources to various other population-level registers. Appendix B.1 describes these data sources in detail.

A strength of the administrative data is that outcomes such as income and wages are measured with comparatively little measurement error, as individual employment histories and most income components are third-party reported (e.g., employers, financial intermediaries). The administrative data are a matter of public record. Hence, there is no attrition due to non-response or non-consent by individuals or firms. Further, individuals can only exit these registers due to natural attrition (i.e., death or out-migration). As a consequence, every resident and registered firm are included in our initial data, and the coverage and the reliability are rated as exceptional by international quality assessments (see, e.g., Atkinson *et al.* 1995).

2.2.2 Data on Broadband Internet Coverage

We link our administrative data with information about the fraction of households covered by broadband internet in each municipality. This information is collected from the Norwegian Communications Authority (NKOM), a government agency that monitors the coverage of broadband internet across Norway. The agency requires suppliers of broadband access to file annual reports about the locations of their broadband infrastructure and availability rates. Using the area signal range of each access point and detailed information on the location of households, the agency computes the broadband availability rates at the municipal level at the beginning of each year.[14] This availability rate serves as our proxy for the availability of broadband internet across areas and over time in Norway. Throughout this article, broadband coverage is defined as having the possibility to connect to the internet with a download speed that exceeds 256 kbit/s. Earlier studies by Bhuller *et al.* (2013) and Akerman *et al.* (2015) use the same data source over a shorter period.

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[13] The employment agency collects information about vacancies from several sources including online job boards and newspapers, as well as vacancies that are directly reported by employers to the agency in accordance with the Norwegian Labor Market Act.

[14] The agency takes into account that multiple suppliers may provide coverage to households living in the same area, so that double-counting is avoided. Note that we distinguish between actual take-up (access or use) of broadband internet, which could be an endogenous choice of a household or a firm, and having the possibility of use (coverage or availability), which is determined by the existence of broadband infrastructure in a local area. We argue in Section 3.1 that the roll-out of broadband infrastructure in Norway gave an exogenous increase in the actual take-up of broadband internet by households and firms.

2.2.3 Survey Data

Our empirical analysis employs three firm-level surveys that can be merged to administrative data sources using unique firm identifiers. First, we use the Annual Survey of Firms' ICT Use performed by Statistics Norway to shed light on firms' internet use and their online search behavior. Second, we use Statistics Norway's Annual Survey of Establishment-level Vacancies to compare survey-based information on vacancies to the data on vacancies from the employment agency and the online job board Finn.no.[15] Third, we use the employment agency's Annual Survey of Establishments' Recruitment Behavior, covering around 10 percent of establishments in each cross-section. This survey provides us with one of our key outcome variables: whether an establishment reports having experienced recruitment problems. This outcome is equal to 1 if the establishment failed in an attempt to recruit during the last three months, and is measured consistently over the whole period exactly three months after the measurement of broadband internet availability.[16]

Finally, we employ two individual-level surveys. The first is the anonymized individual-level Survey on Media Use. This survey allows us to assess how broadband internet coverage affects workers' information technology use, online search behavior, and whether a person uses the internet for work purposes. The second is the Quarterly Labor Force Survey, which allows us to measure how broadband internet affects workers' time spent searching for a job. The different sources of survey data are presented in Appendix B.1.

2.3 Summary Statistics

Our empirical analysis employs a main sample of establishments and another covering working-age individuals. We provide details on sample restrictions and summary statistics for key variables in each of these samples below.

Establishments.   Our main sample is restricted to establishments with at least one (part-time or full-time) employee over the period 2000 to 2014. Table 1 provides means (column 1) and standard deviations (column 2) of the key variables in this sample. There are 255,678 establishments and more than 1.8 million establishment-year observations. The average establishment is 17.5 years, and has 9.5 employees. The average worker has completed 12.5 years of education and earns an annual salary of about USD 51,700.[17]

Our second sample covers establishments with at least one job posting in the employment agency's Register of Job Vacancies. This sample includes 240,793 establishments and more than 1.6 million establishment-year observations, and covers about 6 percent fewer establishments relative to the main sample. This differ-

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[15]Finn.no is the only major online board in Norway, was established in March 2000, and has a market share of around 95 percent (Anand & Hood, 2007). Appendix B.2 illustrates that the employment agency's vacancy data track both the survey data and online job board well. The vacancy survey is administered by Statistics Norway and is only available from 2010 and onward.

[16]As the survey samples are large, we successfully matched this information to 12.2 percent of establishment-year observations in our main analytical sample. Appendix Figure A1 plots the average fraction of establishments reporting having experienced recruitment problems in each year, and shows a highly pro-cyclical pattern where recruitment problems reach a peak at the beginning of the Great Recession. Recruitment problems are also highly correlated with labor market tightness or the vacancy-unemployment ratio. The dashed line illustrates that the more vacancies per job seeker, the more likely firms are to report being unsuccessful in recruitment.

[17]These firm characteristics are measured in year *t*-1, and will be included as additional predetermined control variables in some of the specifications in our empirical analysis.

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ence is mainly due to data on vacancies were available from 2002 onward. Table 1, columns 3-4, show that establishments in the vacancy posting sample are very similar to the main sample.

Table 1, columns 5-6, report summary statistics for establishments included in the Survey of Establishments' Recruitment Behavior. There are 102,771 establishments – i.e., more than one-third of all establishments – in the recruitment survey sample. Although the recruitment survey is designed as a representative survey of firms, we observe noticeable differences in firm characteristics across survey respondents (columns 5-6) and the main sample establishments (columns 1-2).

Table 1, columns 7-8, further report summary statistics for firms included in the Survey of Firms' ICT Use. Applying the same criteria as for the other samples, we retain 22,476 firms and 50,269 firm-year observations that responded to the ICT use survey. These columns document that firms responding to the ICT use survey are larger and older compared to the main sample of establishments. As we can only observe the firm in the survey, and not its establishments, the size of a firm size is mechanically larger than the size of establishments. Therefore, we apply survey weights when using variables extracted from this survey in our empirical analysis.

Table 1: Summary Statistics – Establishments.

Establishment Characteristics:	Administrative Data				Survey Data			
	Main Sample		Vacancy Posting Sample		Recruitment Survey Sample		ICT Use Survey Sample	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Age	17.5	[13.5]	17.7	[13.7]	20.8	[14.0]	21.5	[13.7]
Size	9.5	[47.3]	9.5	[47.5]	24.1	[109.6]	32.3	[59.6]
< 1	21.8	-	21.8	-	6.1	-	1.7	-
1-3	29.0	-	28.9	-	23.2	-	9.1	-
3-5	14.5	-	14.5	-	16.4	-	10.3	-
5-10	15.5	-	15.5	-	19.9	-	19.4	-
10-50	16.6	-	16.7	-	24.9	-	42.6	-
> 50	2.6	-	2.6	-	9.5	-	16.9	-
Average Years of Education	12.5	[2.6]	12.5	[2.7]	12.4	[2.2]	12.1	[1.9]
Average Annual Wage (2014-USD)	51,689	[60,452]	53,076	[75,249]	52,215	[39,469]	57,609	[35,985]
No. of Obs. (B×T)	1,821,902		1,611,573		222,472		50,269	
No. of Establishments (B)	255,678		240,793		102,771		22,476	
Time Period	2000-2014		2002-2014		2000-2014		2001-2014	

Notes: The table displays means and standard deviations of the firm characteristics in the samples of establishments used in the analysis. The samples are restricted to establishments with at least one worker. Note that the ICT Use Survey Sample (columns 7-8) consists of firms, while all other samples (columns 1-6) are defined at the establishment level. For consistency, in columns 7-8, if a firm in the ICT Use Survey consists of more than one establishment, establishment characteristics are averaged across all establishments within the firm. Establishment age is top coded to 51 years, while establishment size measures the number of workers employed in the firm. The distribution of establishments across size categories shows percentage of establishments in each category. Average level of education is measured in years across all workers in the establishment, while the average annual wage (annualized using annual wage paid and annual total number of hours) is rebased to 2014-NOK using the CPI and then converted to USD (1 USD = 8 NOK). All control variables are measured in year *t*-1.

Working-age Individuals. To avoid issues of entry and exit from the labor force from schooling or to retirement, we include 2.8 million individuals in the ages 25–55 in our main sample of working-age individuals. Table 2 reports means (column 1) and standard deviations (column 2) of key variables: The average person is 40 years old, has one child below age 18 and has completed 12.5 years of education. Our (sub)sample of full-time and part-time unemployed covers 736,467 individuals who were registered as a job seeker for at least one month. The average job seeker is three years younger, is 10 percentage points less likely to be married, and has lower educational attainment (columns 3-4) than the main sample of working-age individuals. Finally, columns 5-6 provide summary statistics for a sample of individuals aged 25–55 drawn from the media use surveys. There are 10,959 respondent-year observations in the media use survey. Notably, the survey respondents are more likely to be married, have older children and have completed high school than the overall working-age population.

Table 2: Summary Statistics – Working-age Individuals and Job Seekers.

| | Administrative Data | | | | Media Use Survey | |
| | Working-age Individuals | | Job Seekers | | Working-age Individuals | |
Worker Characteristics:	(1) Mean	(2) Std. Dev.	(3) Mean	(4) Std. Dev.	(5) Mean	(6) Std. Dev.
Age	40.0	[8.72]	37.2	[8.43]	39.6	[8.44]
Female	0.49	[0.50]	0.50	[0.50]	0.50	[0.50]
Married	0.60	[0.49]	0.50	[0.50]	0.75	[0.43]
Fraction with Young Children	0.56	[0.50]	0.57	[0.50]	0.37	[0.48]
Number of Young Children	1.04	[1.19]	1.05	[1.14]	-	-
Fraction with Old Children	0.28	[0.45]	0.19	[0.39]	0.26	[0.43]
Number of Old Children	0.50	[0.92]	0.33	[0.78]	-	-
Years of Education	12.5	[4.22]	11.1	[4.75]	-	-
< 11 years	0.25	-	0.38	-	0.14	-
11-13 years	0.41	-	0.40	-	0.66	-
14-16 years	0.20	-	0.15	-	0.03	-
> 16 years	0.14	-	0.08	-	0.16	-
Number of Obs. ($N \times T$)	24,248,439		1,339,779		10,959	
Number of Individuals (N)	2,758,357		736,467		-	
Time Period	2000-2012		2000-2012		2000-2013	

Notes: The table displays means and standard deviations of worker characteristics for the population of working-age individuals and job seekers. The samples are restricted to individuals aged 25-55. The sample of job seekers in columns 3-4 is further restricted to individuals who were registered as job seekers with the National Public Employment Agency (NAV) in year *t*-1, being either full-time or part-time unemployed for at least one month in year *t*-1. In the administrative data, all control variables are measured in year *t*-1, with $t \in [2000,2012]$. In the survey data, all control variables are measured in year *t* (and not year *t*-1), with $t \in [2000,2013]$. Young children are those younger than 18 years, older children are aged 18 and over.

3   Empirical Design

In this section, we describe key aspects of the Norwegian broadband policy and discuss our empirical design and outline how we use the policy-generated variation to estimate the causal effects of broadband internet

coverage on job matching.

3.1 The Norwegian Broadband Policy

Several OECD countries expanded their information and communications technology (ICT) infrastructure during the past decades. These efforts were seen as essential for retaining competitiveness and achieving high standards of living in a global economy. Norway took several steps to enhance its ICT infrastructure from the late 1990s and onward.[18]

Policy Goals and Implementation. In 2003, the Norwegian parliament enacted a broadband policy with two main goals. The first was to ensure that every household and private enterprise had access to broadband at a reasonable and uniform price. The second was to ensure that the public sector quickly adopted broadband internet.

To reach these goals, the Norwegian government took several steps. First and foremost, it invested heavily in the necessary infrastructure. The investment in infrastructure was largely channeled through the (state-owned) telecom company Telenor, which was the sole supplier of broadband access to end-users in the early 2000s.

Second, local governments were required to ensure access to broadband internet by 2005 to local public institutions, such as administrations, schools, and hospitals. To assist municipalities in rural areas, the government provided financial support through the *Høykom* funding program. Local governments could receive funds from this program by submitting a project plan that had to be evaluated by a program board with expert evaluations. Once approved, financial support was provided in the initial years of broadband access to cover relatively high initial costs.

Supply and Demand Factors. The transmission of broadband signals through fiber-optic cables required installation of local access points. Since 2000, such access points were progressively rolled out, generating considerable spatial and temporal variation in broadband coverage. The staged expansion of access points was in part due to limited public funding. Another reason was due to the geography: Norway is a large and sparsely populated country, driving distances between populated areas are often long and partitioned by mountains or the fjord-broken shoreline.[19] The main supply factors determining the timing of roll-out are therefore topographical features and existing infrastructure (such as roads, tunnels, and railway routes). Furthermore, the existing infrastructure mattered for the marginal costs of installing cables to extend the availability of broadband within a municipality and to neighboring areas.

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[18]These attempts started with the *Policy for Regional ICT Competence* introduced by the Norwegian parliament in 1998 (Report no. 38 to the Storting, 1997–1998), followed by introduction of the *Program for High-Speed ICT (Høykom) Innovation in the Public Sector* in 1999 (Statskonsult, 2007; Bygstad & Lanestedt, 2009), and passing of the *National Broadband Policy* by the Norwegian parliament in 2003 (Report no. 49 to the Storting). The policy goals are outlined in Report no. 38 to the Storting (1997–1998), Section 4.5, and Report no. 49 to the Storting (2002–2003), page 7.

[19]The Norwegian territory covers about 149,400 square miles, an area about the size of California or Germany, with around 13 percent and 6 percent of those regions' populations (in 2008), respectively. The country is dominated by mountainous or high terrain, as well as a rugged coastline stretching about 1,650 miles, broken by numerous fjords and thousands of islands.

In terms of demand factors, we expect demand for broadband infrastructure to be related to income level, educational attainment, and the degree of urbanization in the municipality. Due to the second goal of the broadband policy, the size of the public service sector is another potential demand factor.[20]

Evolution of Broadband Availability.   The progressive roll-out of broadband access points generates considerable variation in broadband coverage across municipalities and over time. Figure 3 summarizes the evolution of broadband availability rates between 2000 and 2009. In each year, we report the overall means and the distributions across municipalities. While virtually no municipalities had broadband access-points available in 2000, the average availability rate increased to almost 40 percent by early 2004 and exceeded 80 percent by early 2006. The geographic variation in broadband coverage is illustrated in Appendix Figure A2. The heat maps illustrate the wide variation in availability rates across municipalities, and within municipalities over time. Few municipalities experienced abrupt changes from zero coverage to full coverage from one year to the next. The access points were rather progressively rolled out within and across municipalities, which generates a continuous measure of broadband availability that displays considerable temporal and spatial variation. Figure 3 illustrates that by 2009 there was almost complete coverage across the country.

Figure 3: The Evolution of Broadband Internet Availability in Norway.
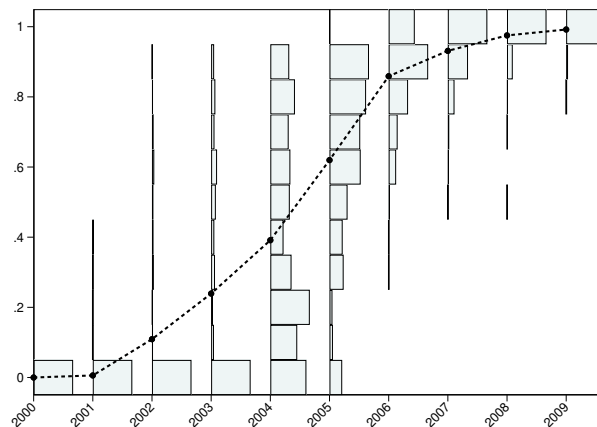
Notes: This figure shows the mean and distribution of broadband availability across 420 municipalities using data from the Norwegian Communications Authority (NKOM). For each year, the mean broadband availability rate across municipalities is displayed by black circles as a fraction along the vertical axis. Similarly, the distribution of broadband availability rates is displayed as a blue-shaded histogram in 11 equidistant bins.

Lastly, we assess how growth rates in broadband coverage vary with baseline municipality characteristics in Appendix Figure A3. As expected, these patterns of roll-out suggest that (i) the population size and (ii) the degree of urbanization predict that a municipality had early increases in broadband coverage. However, key labor market characteristics such as local unemployment rate, average income, and sector composition; socio-economic factors such as years of education, fraction of student enrollment, population age composition, immigrant population share; and other geographic features including distance to city center, travel time and road networks do not predict the roll-out patterns.

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[20]These factors are discussed in the several documents describing the National Broadband Policy and the roll-out of broadband access points (see Report no. 38 to the Storting (1997–1998); Report no. 49 to the Storting (2002–2003); Bhuller *et al.* , 2013).

3.2 Specification

The key challenge in identifying the effects of broadband internet on labor market matching is that use of broadband internet is not random. Unobservable factors,such as ability, or size of social network, are likely to determine both the use of ICT and labor market success in general, thereby confounding the effects of online job search. While randomizing the use of online job search is not feasible, one may, however, think of the broadband policy as a natural experiment that generates plausibly exogenous spatial and temporal variation in broadband availability. Our empirical specification thereby mimics the ideal experiment and breaks the correlation between unobserved determinants of use of ICT and labor market outcomes.

To fix ideas, consider the following equation for an outcome $y_{m,t}$ (e.g., the indicator for recruitment problems experienced by an establishment located) in municipality m in year t:

$$y_{m,t} = \delta z_{m,t} + \beta x_{m,t-1} + \kappa_m + \tau_t + \varepsilon_{m,t}, \tag{1}$$

where $z_{m,t}$ is the broadband availability rate in municipality m measured at the *start* of year t. This specification includes a full set of municipality indicators κ_m and year indicators τ_t. We assume that conditional on κ_m and τ_t, broadband internet availability is exogenous and uncorrelated with unobserved factors $\varepsilon_{m,t}$. Then, our parameter of interest, δ, captures the short term effect of going from zero to full coverage.[21]

In Equation (1), time-invariant unobservable determinants of labor market matching at the municipality level are captured by municipality fixed effects. This effectively controls for permanent differences across municipalities that have early and late broadband internet expansions. Common time shocks across areas are absorbed by the year fixed effects. Our specification thereby uses *within* municipalities changes in broadband coverage over time, while removing all changes over time in the outcome and increases in broadband coverage that are *common* across municipalities. Under our assumption of conditional independence between potential labor market outcomes and roll-out of broadband infrastructure, i.e., an assumption of common trends across municipalities, we can identify the effects of broadband coverage.

In addition to municipality and year fixed effects, our baseline specification of Equation (1) also controls for a set of time-varying municipal characteristics, $x_{m,t-1}$, including average travel time to municipal center (in hours), distance covered by municipal road networks (in kilometers) and municipal spending on infrastructure. These factors may correlate with demand and supply factors of broadband expansion (see Bhuller *et al.* (2013) and Section 3.1), and by controlling for these factors we can reduce residual variation in the outcomes. Similarly, in the analysis of re-employment outcomes for unemployed workers, we include controls for 4-digit past occupation categories to remove permanent variation in levels of outcomes between occupations. Throughout the paper, all standard errors are robust to heteroskedasticity and are clustered at the level of the commuting zone. By clustering at this higher level of aggregation, we account for possible spatial correlations across municipalities within a commuting zone.[22]

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[21]For the firm-level analysis, we follow Akerman *et al.* (2015) in measuring broadband availability rate at the start of the same year as when the outcome is measured, which allows us to estimate the short term (same-year) effects based on Equation (1). For the worker-level analysis, we instead use lagged broadband availability rate $z_{m,t-1}$ as our variable of interest, since our analysis suggests that the adoption of new technology and changes in online activities for workers respond to increases in broadband availability with a short time lag. This is consistent with firms being quick adopters, while household adoption of new technology is slower.

[22]For this purpose, we use a regional classification of Norway by Bhuller (2009) in 46 commuting zones constructed based on

We challenge our empirical specification in several ways and show that controlling flexibly for pre-determined characteristics of each establishment, such as 3-digit industry fixed effects, establishment age, and size to ensure that our main conclusion is not affected by differential workforce composition across rural vs. urban labor markets. Similarly, in the analysis of job seekers, we show that our estimates do not materially change if we include individual characteristics, such as age, gender, family background, and education. To further assess the validity of our identifying assumption, we estimate alternative specifications where we include controls for differential time trends in Equation (1) to depart from the standard common trends assumption. We also perform placebo analyses by changing the timing of the outcome variable to be before the timing of increases in broadband availability. These results are presented at the end of Section 5.

3.3 Interpreting the Broadband Policy

To interpret the broadband internet policy and argue why it is relevant for job matching, we begin by esti-mating Equation (1) on firms' and households' broadband internet use. Table 3 presents our results. We find that among both firms (panel A) and workers (panel B), a 10 percentage point increase in broadband avail-ability triggers an increase in their broadband adoption rate by almost 3 percentage points (row 1).[23] The coefficient estimates are remarkably similar across both groups and are highly robust to adding controls for firm characteristics (panel A) or worker characteristics (panel B). In Appendix Table A1, we show that the survey-based estimates remain similar if we use the population-weights from our main analytical samples.

We next turn to the use of online job boards. Table 3, row 2, shows that both firms (panel A) and workers (panel B) change their online behavior along dimensions that are relevant to search and recruitment. We find that firms with full broadband coverage are 20 percentage points more likely to use the major online job board Finn.no for posting job vacancies compared to firms with zero coverage. This website is the main job board in Norway and covers close to 100 percent of the market (see Appendix Figure 1). Our estimated impact corresponds to a 70 percent increase relative to the baseline mean and suggests that broadband internet significantly affected recruitment behavior. Using the media use survey, we find that broadband coverage also increases households' use of the internet to browse online advertisements.[24] While this estimate is smaller in percentage points, the relative increase equals a four-fold increase.

Finally, it is worth noting that the coefficient estimates in Table 3 could be interpreted as the first-stage coefficients in a 2SLS model where the outcome in Equation (1) is replaced by either use of broadband or use of online job boards and is instrumented using our measure of broadband availability rate. The second-stage would estimate the effect of such a treatment variable on the outcome of interest. The results in Table 3 indicate a highly significant first-stage coefficient. However, as we doubt the IV exclusion restriction is likely to be satisfied in our context, we present reduced-form relationships throughout our paper. Our estimates should, therefore, be interpreted as intention-to-treat effects of broadband internet availability on

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commuting statistics. On average, a commuting zone comprises of around 9 municipalities and may cross administrative boundaries.

[23]These estimates show that both firms and households are more likely to use broadband internet (i.e., have a device with broad-band installed) as a consequence of an increase in broadband availability in their municipality. By contrast, we do not find that any impact on the probability of using internet via an ISDN connection. This result is available upon request.

[24]The outcome in panel A, row 2, is at the municipality level. Due to difficulties in matching digital job postings to the hiring establishment (online ads are often posted by recruitment and temp agencies), we aggregate this outcome to the municipality level.

job matching.

Table 3: Firms' and Workers' Internet Access and Online Activities.

	A. Firms in the ICT Use Survey		B. Working-age Individuals in the Media Use Survey	
	(1)	(2)	(3)	(4)
	Baseline	Controls	Baseline	Controls
Dependent Variable:	1. Has Broadband Internet Access		1. Has Broadband Internet Access	
Broadband Availability	0.276***	0.278***	0.282***	0.282***
(Standard Error)	(0.040)	(0.040)	(0.027)	(0.026)
[p-value]	[0.000]	[0.000]	[0.000]	[0.000]
Base Dep. Mean	0.380	0.380	0.059	0.059
Obs. ($B{\times}T$ / $N{\times}T$)	50,217	50,217	10,959	10,959
Dependent Variable:	2. Online Job Board Use Rate		2. Uses Internet for Browsing Ads	
Broadband Availability	0.198***	0.196***	0.091**	0.088**
(Standard Error)	(0.041)	(0.041)	(0.044)	(0.044)
[p-value]	[0.000]	[0.000]	[0.043]	[0.049]
Base Dep. Mean	0.284	0.284	0.022	0.022
Obs. ($B{\times}T$ / $N{\times}T$)	50,217	50,217	8,612	8,612

Notes: This table displays estimation results of firms from the ICT Use Survey for various outcomes in year t on broadband internet availability rate in year t, with $t \in [2001,2014]$ (panel A) and working-age individuals from the Media Use Survey for various outcomes in year t on broadband internet availability rate in year t-1, with t-1 $\in [1999,2012]$ (panel B). Results in panel A are constructed using survey weights, while the results in panel B are based on a representative survey. Control variables for firms (panel A, column 2) include establishment age, size and establishment composition. Control variables for individuals (panel B, column 4) include age, gender, family background and education. The reported dependent mean is pre-assignment, i.e. when the broadband internet availability rate equals zero. All specifications include controls for municipal infrastructure (municipal road networks (in kilometers) per capita, average travel time to municipal center (in hours) and public spending on infrastructure), and fixed effects for time and municipality. Heteroskedastic robust standard errors are clustered on the regional level. **$p < 0.05$, ***$p < 0.01$.

4 Expected Impacts

In the previous section, we established that the broadband internet policy is a multifaceted treatment that changed the use of broadband among both firms and households, as well as behaviors that are relevant for job search and recruitment. How and why would we expect these changes to affect labor market matching and what are the implications for vacancies, unemployment, turnover, and wages? To discipline our empirical assessment, we discuss the expected impacts of broadband internet through the lens of the standard theory of unemployment and vacancies developed by Diamond (1982), Mortensen (1982) and Pissarides (2000).

4.1 Framework

A key concept in the DMP-framework is the "matching function", which governs the speed that workers are matched with vacancies. Workers maximize the net present value of income and randomly search for vacant jobs while unemployed. Firms maximize the present value of profits by hiring workers but need to use resources to search for workers. This search process prevents immediate hiring and leads to positive levels of both unemployment u_t and vacancies v_t. Formally, the matching function produces a number of firm-worker matches using job vacancies and job seekers as input, $H_t = A_t f(u_t, v_t)$. Free entry of vacancies in the market

ensures that, in equilibrium, there is no expected profit of existing vacancies, and the costs of recruitment create positive profit for existing matches. This profit is shared among firms and workers according to a Nash bargaining solution: The outside option of the worker is the discounted value of unemployment and the threat point of the firm is the value of a vacant job. The bargaining power is assumed constant and the Nash bargaining solution assigns a fraction of the profit to the worker by offering wages above his marginal productivity. Hence, the matching function affects the wage of a worker by affecting his or her outside option and via the cost firms pay for time spent on recruiting. A formal presentation of the framework and derivations are presented in Appendix C.

4.2 Implications

We discuss two main mechanisms through which internet coverage may operate. The first is higher matching efficiency and the other is by lowering the cost of recruitment. Throughout our comparative statics, we assume that the bargaining power and size of the labor force is independent of broadband internet.

4.2.1 Improved Matching Efficiency

If internet coverage improves the matching technology, its impact would *initially* operate via the parameter A_t. A higher value of A_t increases the expected matching rate and generates more hires from the same number of job seekers and vacant jobs, thereby increasing the re-employment rate of job seekers and lowering the unemployment rate. Because job seekers expect to find a job faster, their outside option improves, which drives up wages in new employment relationships. Better matching technology implies a lower duration of a vacancy, but the free entry condition induces firms to post more vacancies. These counteracting forces lead to an ambiguous effect on the vacancy rate. The predictions of the basic model are summarized in the first row of panel A in Table 4. The second row shows that accounting for endogenous recruitment intensity does not alter the predictions from the basic model.[25]

Finally, we consider a model with endogenous job destruction and on-the-job search. There is a reservation productivity such that jobs with idiosyncratic productivity below the threshold R are dissolved. There is another reservation productivity S that determines whether workers search on the job: If the idiosyncratic productivity is above this threshold, they do not search. Finally, if a matching efficiency shock affects the reservation productivity R, workers with idiosyncratic productivity below the new level are better off by quitting and search for a new job while unemployed. The matching function thereby determines both the flow from unemployment to new jobs, as well as the share of workers who search and the rate of job-to-job mobility. An improvement in the matching technology will, therefore, increase the reservation productivity level among the unemployed, so it increases the expected wage in new jobs. It also increases the reservation productivity among workers, so the share of workers that search on the job goes up. Since the probability of finding a new job goes up, the expected tenure in new jobs falls. Finally, an improvement in matching efficiency renders some existing employment relationships unprofitable, which increases the separation rate among existing employment relationships while transitioning to the new steady state. We summarize the

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[25]Our discussion builds on Chapters 2, 4, and 5 of Pissarides (2000).

predictions in the third row of panel A in Table 4.

4.2.2 Lower Recruitment Cost

The second mechanism we consider is a reduction in the costs of advertising a vacancy. A change in the cost would increase the number of vacancies because of the free entry condition, and the duration of a vacancy goes up because of tougher competition for the available workers. Lower recruitment costs thus predicts effects on the vacancy duration in the opposite direction compared to a matching efficiency shock. The effects on duration and posting lead to a higher stock of vacancies both in transition and in the new steady-state. In all three models, there are more vacancies, which increases the job finding rate and the starting wage following an unemployment spell. In the model with on-the-job search, the higher matching efficiency increases separation rates among existing employment relationships. It also lowers the expected tenure in new employment relationship because more workers choose to search. The predictions are summarized in panel B of Table 4.

Table 4: Theoretical Predictions.

	A. Improved Matching Efficiency				
	Wages	Tenure	Job Finding Rate	Vacancy Duration	Separation Rate in Transition
Model:	(1)	(2)	(3)	(4)	(5)
1. Basic Model	+		+	−	
2. Endogenous Search	+		+	−	
3. On-the-Job Search	+	−	+	−	+
	B. Lower Recruitment Cost				
	Wages	Tenure	Job Finding Rate	Vacancy Duration	Separation Rate in Transition
Model:	(1)	(2)	(3)	(4)	(5)
1. Basic Model	+		+	+	
2. Endogenous Search	+		+	+	
3. On-the-Job Search	+	−	+	+	+

Notes: This table summarizes the theoretical predictions of a change in the matching efficiency (panel A) and a reduction in the recruitment cost (panel B). We maintain the assumption that broadband internet coverage does not impact the Nash bargaining parameter, that labor supply is fixed and that there is a constant returns to scale Cobb-Douglas matching function. The first row shows the expected impact from the basic search and matching model from Pissarides' (2000) Chapter 1, the second row extends the model with endogenous firm recruitment effort from Chapter 5, and the third row adds on-the-job search and endogenous job destruction. Column 1 shows the expected impact on wages in new jobs following unemployment. Column 2 shows the expected impact on subsequent tenure in a new employment relationship. Column 3 shows the expected impact on job seekers' re-employment rate. Column 4 shows the theoretical predictions for vacancy duration. Column 5 shows the predictions for expected impacts on separation rates in transition between steady states. The derivations are presented in Appendix C, and codes with numerical solutions are available from our website (with hyperlink).

4.2.3 Improvements in Screening

While the standard framework predicts a negative tenure effect in some settings, other models generate effects in the other direction. Pries & Rogerson (2019) consider a model that differs from the standard DMP

framework in two ways. First, workers and firms can only observe a noisy signal about the match quality. Second, workers and firms learn about the match quality after the job starts. This gives a positive relationship between tenure and match quality. They argue that expansions in ICT and online recruitment have facilitated better screening of applications, and show that a higher probability of finding a good match predicts a fall in the separation rate in new employment relationships. Their equilibrium framework is thus consistent with tenure as a proxy for match quality (used previously by Card *et al.* , 2007, Nekoei & Weber, 2015 and Schmieder *et al.* , 2016).

5 Main Results

Guided by the theoretical predictions from standard search and matching models, this section presents evidence on how broadband internet availability affects job-matching. We start by documenting impacts on establishments' recruitment behavior and then turn our attention to outcomes of the job search process.

5.1 Establishment-Level Evidence

We first investigate the relationship between broadband availability and the prevalence of recruitment problems using the Annual Survey on Establishments' Recruitment Activities. To this end, we matched each establishment's survey responses when asked "Have you encountered problems in recruiting staff during the last three months?" to our analytical sample using the geographic location of each establishment and the timing of survey responses.

We begin by illustrating our empirical design with an event study of establishments' recruitment problems around the year of the largest increase in broadband availability. The change in availability is measured three months prior to the survey date and we center time around the event date. After removing permanent differences in availability between municipalities and across years, the events are evenly distributed over the period 2002 to 2008. Figure 4 plots the fraction of establishments experiencing recruitment problems two years before and after the event, with time relative to the event along the horizontal axis.[26] The vertical axis to the left denotes the fraction of establishments experiencing recruitment problems and the vertical axis to the right shows the average broadband availability around the date. The figure illustrates a slight decline in the last year before the event and a large fall – 1.5 percentage points on average – in the fraction of establishments reporting a problem in the year with the largest increase in broadband internet availability. The graphical evidence suggests that broadband internet improved the recruitment process and that the effect materialized very quickly.

We turn to the regression counterpart of the graphical evidence in panel A of Table 5. We calculate that 20.5 percent of establishments in our sample experience recruitment problems. The point estimate of 2.7 percentage points is highly significant and suggests that establishments become more effective in recruitment. Relative to the baseline mean, the share falls by an economically significant 13 percent.

To further elaborate on this finding, we draw on our establishment-level vacancy data. In panel B of Table 5, we assess the impact of broadband internet availability on the average duration of vacancies where the

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[26]Due to data availability, the sample becomes highly unbalanced and noisy if we add more pre- and post-event periods.

sample is restricted to establishments with at least one vacancy in a calendar year. The duration of a vacancy is measured from the date the vacancy is posted to the date the vacancy is either filled or removed. The average duration of a vacancy in our sample is 15.2 days.[27] Our regression result shows the average duration falls by 1.4 days in response to an increase in broadband coverage, implying a decline of 9 percent compared to the average duration. Appendix Figure A4 shows that this effect is prevalent throughout the distribution of vacancy duration. This finding strengthens our view that broadband internet led to improvements in matching efficiency. If the effect of broadband coverage was primarily through a reduction in the cost of recruiting, we would expect a longer vacancy duration: By posting more vacancies, establishments would find it increasingly more difficult to fill a vacancy. Similarly, this evidence suggests that the impact of broadband was not a positive labor productivity shock, which would increase the duration of vacancies because there would be fewer job seekers per job vacancy.[28]

Figure 4: Event Study – Recruitment Problems Around the Year of Increase in Broadband Availability.
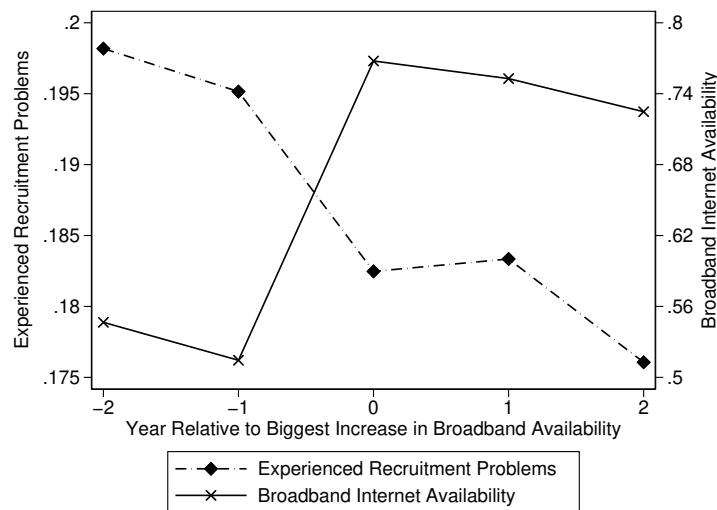
Notes: For each municipality, year zero represents the year after the largest increase in broadband availability rate, such that the variables are re-centered to illustrate the cause and the effect in the same year. To construct this figure, the data are collapsed to the municipality and year level, and both the outcome and the broadband availability rate are residuals from a regression on municipality and year fixed effects, re-scaled to sample means. Only municipality-year cells observed over the complete two-year window around year 0 are retained (i.e., we use a five-year balanced panel).

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[27]For the U.S., Burdett & Cunningham (1998) find that 80 percent of vacancies were filled within 14 days of posting.

[28]The effect on duration is also consistent with an increase in labor supply from outside of the labor force. However, we find no impact of broadband coverage on the probability of moving from outside of the labor force to employment (-0.005, se=0.006) nor on the probability of moving from outside of the labor force to job seeker status (-0.005, se=0.007).

Table 5: Firms' Recruitment Problems, Vacancy Duration and Vacancy Flows.

Dependent Variable:	A. Experiencing Recruitment Problems	B. Conditional Vacancy Duration	C. Annual Vacancy Flow
Broadband Availability	-0.027***	-1.376***	0.032***
(Standard Error)	(0.009)	(0.469)	(0.008)
[*p*-value]	[0.003]	[0.005]	[0.000]
Dep. Mean	0.205	15.2	0.222
Obs. ($B \times T$)	222,472	358,266	1,611,573

Notes: Panel A displays estimation results of establishments from the Annual Survey of Establishments' Recruitment Behavior reporting recruitment problems in year *t* ("Have you encountered problems in recruiting staff during the last three months?") on broadband internet availability rate in year *t*, with $t \in [2000,2014]$. The Recruitment Survey is conducted in the first quarter of year *t*, usually opening in February and closing in late March. Panel B displays estimation results of conditional mean duration in days of vacancy postings posted during year *t* on broadband internet availability rate in year *t* using data from the vacancy database. Panel C displays estimation results of posting at least one vacancy during year *t* on broadband internet availability rate in year *t* using data from the vacancy database. All specifications include controls for municipal infrastructure (municipal road networks (in kilometers) per capita, average travel time to municipal center (in hours) and public spending on infrastructure), and fixed effects for time and municipality. Heteroskedastic robust standard errors are clustered on the regional level. ***$p < 0.01$.

In theory, a matching efficiency shock leads to a fall in the effective cost of filling a vacancy. The basic DMP framework would then predict that the number of vacancies should increase in response to this drop in relative posting costs. We assess this prediction in panel C of Table 5, and find that higher broadband coverage increases the probability of posting at least one vacancy by 3.2 percentage points. Compared to the dependent mean of 22.2 percent, this implies an increase in the share of establishments posting at least one vacancy of almost 14 percent.

Hiring and Separations.

We now turn to how broadband internet coverage affects hiring and separation rates. We follow Davis *et al.* (2013) in measuring an establishment's hiring growth rate as the annual change in the number of new hires and then normalizing the changes by the average employment in the previous and current year (excluding new hires) for each establishment-year observation. As vacancies are filled faster, we expect establishments to experience higher hire growth. Our estimate confirms this prediction: establishments experience higher hiring rates following an increase in broadband availability. We report the result from this regression in Table 6, panel A. The increase of 0.6 percentage points is statistically significant and economically meaningful at about 5 percent of the baseline mean hire growth rate.

Table 6: Firms' Hire, Separation and Net Employment Growth.

Dependent Variable:	A. Hire Growth	B. Separation Growth	C. Net Employment Growth
Broadband Availability	0.006***	0.005*	0.000
(Standard Error)	(0.002)	(0.003)	(0.002)
[p-value]	[0.003]	[0.053]	[0.884]
Dep. Mean	0.129	0.114	0.015
Obs. ($B{\times}T$)	1,821,902	1,821,902	1,821,902

Notes: This table displays estimation results of hire growth (panel A), separation growth (panel B) and net employment growth (panel C) on broadband internet availability rate in year t, with $t \in$ [2000,2014]. Construction of the outcome variables follows Davis *et al.* (2013), normalizing the change in employment/hires/separations by the establishment's mean employment in the previous and current year. All specifications include controls for municipal infrastructure (municipal road networks (in kilometers) per capita, average travel time to municipal center (in hours) and public spending on infrastructure), and fixed effects for time and municipality. Heteroskedastic robust standard errors are clustered on the regional level. *$p < 0.10$, ***$p < 0.01$.

As the search and matching framework predicts higher separation rates with on-the-job search, we now turn to the separation rates among existing employment relationships. Again, we normalize the change in separation by each establishment's mean employment. Panel B of Table 6 shows that establishments experience higher separation growth when broadband availability increases. As the change in the separation rate is of similar magnitude as the hire rate, panel C shows a precisely estimated zero impact on net employment growth. These results are consistent with the view that internet caused an increase in turnover rates because workers expected to find better jobs elsewhere. We elaborate on this result in the next subsection.

5.2 Worker-Level Evidence

We now turn to how availability of broadband internet affects the outcomes of job seekers. We focus on individuals registered as job seekers with the employment agency for at least one month in the previous year (i.e., during year *t-1*). To assess the outcomes of the search process, our re-employment outcome is equal to one if the job seeker is observed employed for at least one month at some point during the following two years (i.e., the maximum duration of unemployment benefits), and zero otherwise. Panel A of Table 7 reports that the employment rate among job seekers with full coverage is 1.6 percentage points higher than the (counterfactual) employment rate of a job seeker with no coverage. While our results are statistically significant and consistent with previous research (e.g., Kuhn & Mansour, 2014 and Gürtzgen *et al.*, 2018), the impact corresponds to a relatively modest 2.5 percent increase relative to the dependent mean of 65.9 percent.

Table 7: Employment Outcomes After an Unemployment Spell.

Dependent Variable:	A. Re-employment	B. Wage in First Job (USD)		C. Tenure in First Job (months)	
		Un-conditional	Conditional	Un-conditional	Conditional
	(1)	(2)	(3)	(4)	(5)
Broadband Availability	0.016***	124***	100***	0.397***	0.234**
(Standard Error)	(0.006)	(34)	(33)	(0.088)	(0.112)
[p-value]	[0.006]	[0.001]	[0.004]	[0.000]	[0.043]
Dep. Mean	0.659	2,061	3,128	7.3	11.8
Obs. ($N \times T$)	1,339,779	1,339,779	882,569	1,191,827	734,617

Notes: This table displays estimation results of transition from unemployment in year *t*-1 to employment in year *t* or *t*+1 (panel A), starting monthly wage in new job following unemployment measured in 2014-USD (panel B), and tenure length in the first job measured in months (panel C) on broadband internet availability rate in year *t*-1, with *t*-1 ∈ [2000,2012]. For unconditional outcomes, the outcome is not conditional on finding a job in either year *t* or *t*+1, and tenure and entry wage level is set to zero for non-job outcomes while unemployment is measured in year *t*+2 for non-job outcomes. For conditional outcomes, the outcome variable is conditional on finding a job in either year *t* or *t*+1. In panel B, monthly wage is rebased to 2014-NOK using the CPI and then converted to USD (1 USD = 8 NOK). In panel C, we drop observations with tenure equal or greater than 48 months due to censoring. All specifications include controls for municipal infrastructure (municipal road networks (in kilometers) per capita, average travel time to municipal center (in hours) and public spending on infrastructure), and fixed effects for time, municipality and 4-digit code for past occupation. Heteroskedastic robust standard errors are clustered on the regional level. **$p < 0.05$, ***$p < 0.01$.

We now turn to the impacts on starting wages in a new employment relationship following an unemployment spell. As wages are only observed among those who find a new job, an outcome that we know is positively affected itself, we also report estimates on unconditional outcomes where we include observations where the outcome has zero values. Panel B of Table 7 presents our evidence. Column 2 shows that full broadband coverage increases the starting wage by more than 6 percent of the unconditional mean. If we, instead, condition on having found a job, column 3 shows that wages increase by about 3.5 percent relative to the monthly salary.

This finding is consistent with the view that internet has improved the matching efficiency where wages increase because workers have a stronger outside option when bargaining over wages with prospective employers. As a benchmark to our estimate, Jäger *et al.* (2018) find less than $0.01 change in wage per $1.00 UI benefit increase. Our estimate is substantially larger, which may suggest that the wage effect is coming via other channels than the outside option. For instance, a large wage effect is consistent with a reduction in hiring costs. If we assume the first job after unemployment lasts 12 months on average, the wage increase corresponds to nearly 42 percent of a monthly salary. By comparison, Blatter *et al.* (2012) estimate hiring costs between 10 to 17 weeks of wage payments. Their estimates include fixed costs of hiring, e.g., HR departments, and are highly convex: The marginal hire may cost up to 24 weeks of wage payments. Our estimate would suggest that broadband availability reduced hiring costs by 7 to 17 percent.[29]

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[29] Assuming that the wage gain is entirely due to reductions in hiring costs, the estimate of 3.5 percent of a monthly wage for 12 months is 0.42 percent of a month. Compared to the lower and upper bound of estimates, this gives a reduction in recruitment costs by 0.42/2.5 and 0.42/6.

Figure 5: Tenure in First Job.

Outcome: Pr(Tenure > x)

Another mechanism that may lead to higher wages is through improvements in match quality. Pries & Rogerson (2019) show that when the quality of a match is uncertain, better screening can improve the match quality and lead to more sustainable employment relationships. Several empirical studies in labor economics have used tenure as a proxy for match quality (e.g., Card *et al.* , 2007, Nekoei & Weber, 2015 and Schmieder *et al.* , 2016). We follow this literature and measure tenure by the number of months a person stays in the first job after an unemployment spell and report how broadband availability affects tenure in the first job in panel C. Column 4 reports the impact on the unconditional mean (i.e., including extensive margin), and column 5 reports the impact on average tenure among those who successfully find a new job (around 65 percent over a two-year period). Our estimates show that broadband availability increases tenure in the first job after unemployment by about week on average.

To further elaborate on this finding, we assess the impacts of broadband availability on the probability of staying in a job at different spell lengths. Figure 5 plots the impacts of broadband availability on the probability that a new employment relationship lasts longer than 1 month, 2 months, and up to 47 months. The solid line illustrates the point estimates, and the thin lines represent 90 percent confidence intervals. The figure shows that broadband availability primarily affects job spells that would have otherwise lasted less than twenty months. This is consistent with Pries & Rogerson (2019), who argue that a efficient screening of new hires led to a decline in the number of short employment spells.

Finally, we examine the impacts of broadband availability on on-the-job search. We use the labor force surveys which allow us to estimate how broadband internet affects the time spent searching for a job while employed. In Appendix Table A2, we document a small and positive, however, not statistically significant, effect on time spent searching. This effect can be decomposed into a statistically significant reduction in the probability of searching, and an increase in the time spent searching among those who search.

5.3 Heterogeneity

While the immediate impact of broadband availability on establishments experiencing a recruitment problem (3 months after the measured broadband expansion) is consistent with an improvement in matching efficiency, this finding is not consistent with positive productivity effects from ICT for two reasons. First, higher productivity would increase labor demand which, in turn, would lead to more recruitment problems and longer vacancy-duration. Second, productivity effects would arguably materialize over a longer time period.

Still, the worker-level evidence may be consistent with higher demand for skills that complement ICT: Akerman *et al.* (2015) document increased wage dispersion among high vs. low-skilled workers in manufacturing and wholesale after firms adopted broadband internet. To assess whether the impact on starting wages after unemployment is due to higher labor demand, we use information about the average use of internet for work purposes in occupations from the Survey of Media Use. We proceed by first dividing our sample by whether the average use of internet for work in an occupation is above or below the median occupation. Next, we redo our analysis among the least ICT-intensive occupations (e.g., plumbers and cleaners). We find that broadband availability lowers vacancy duration and leads to higher vacancy posting among non-ICT occupations and confirm the positive and statistically significant effect on tenure and wages in new employment relationships after a spell of unemployment. These results are quantitatively the same as our baseline specifications and are presented in Appendix Table A3. Taken together, these results strengthen our conclusion that broadband internet availability improves the labor market's ability to match job seekers to vacant jobs.

A primary goal of the Norwegian broadband policy was to promote ICT among household and firms in all parts of the country at a reasonable and uniform price. These efforts would prevent a "digital divide" between cities and rural parts of the country and between the more or less fortunate. We assess heterogeneity in broadband adoption rates by estimating the probability a person uses the internet by gender and age. Panel A of Appendix Table A4 illustrates the results and shows that prime-age males are more likely to use broadband internet when the access points arrive in their municipality. While some of our estimates are too noisy to make inferences about differences across groups, the results suggest males aged 35-45 are more likely to comply with the intention of the policy than younger and older cohorts. Given this heterogeneity, one might worry that some cohorts of job seekers are left behind as establishments switch to online recruitment. We test for such a "digital divide" in the labor market by estimating how broadband internet affects the probability of finding a new job and the subsequent wages and tenure in the new jobs following unemployment. While we lack the precision to draw firm conclusions, the effects of broadband availability on employment rates is larger among younger than older males. By contrast, we find that the impacts of coverage on tenure and starting wage are broadly similar across age and gender groups.

5.4 Robustness

In this subsection, we challenge our identification strategy in a number of ways. First, we test the assumption that the roll-out of broadband internet is unrelated to other drivers of labor market matching by adding a large set of controls for establishment and worker characteristics. Second, we challenge the assumption

of common trends by adding region-specific time shocks in our estimation equations. Finally, we perform placebo experiments.

Compositional Changes. To assess whether changes in the composition of industries over time may affect our conclusions, we add fixed effects for the three-digit industry corresponding to each establishment (264 categories) as additional controls to Equation (1). This specification ensures that we are comparing recruitment outcomes for establishments operating in the same industry. The results from this analysis are provided in Table 8, panel A, column 2. To facilitate comparison, we include our baseline establishment-level estimates in panel A, column 1. Comparing estimates in panel A, columns 1-2, we conclude that adding a large set of industry fixed effects to our specification doesn't affect our results.[30]

Controls for Time-Varying Firm and Worker Characteristics. Our identification strategy rests on the roll-out of broadband internet being unrelated to other drivers of labor market matching, conditional on municipality and year fixed effects. To test this assumption, we examine the degree to which our estimates vary when we include additional time-varying observables measured prior to the broadband expansion. In column 3 of panel A in Table 8, we add controls for establishment age (51 dummies) and size (6 dummies), and further add controls for average level of education and average annual wage of workers in column 4. In panel B, we similarly control for worker's gender and age in column 2, add marital status and number of children (by age group) in column 3, and further add flexible controls for level of education (18 dummies) in column 4. In all specifications, we already control for average travel time to municipal center (in hours), distance covered by municipal road networks (in kilometers), and municipal spending on infrastructure.[31] Reassuringly, our main estimates for both establishments and job seekers remain stable across columns 1-4.

Common Trend Assumption. A key threat to identification is that cities face different underlying time trends in outcomes than rural labor markets. We assess the validity of this "common trend" assumption by including region-specific trends.[32] Using pre-broadband expansion data for each outcome (available back to 1997 for most of our variables), we obtain a slope estimate for each labor market region. This procedure will account for variation in broadband availability that coincides with pre-existing differential trends in the outcome.[33] A second and related test is to include additional controls that interact the baseline year (2000) outcome with time dummies. By interacting time with pre-determined average outcomes, we allow differential time trends across regions depending on the levels of the outcome in the baseline year. The time dummies allow these trends to take any non-linear functional form. Columns 5-7 in Table 8 report the estimates based on these specifications. The estimates are quantitatively similar to our baseline estimates and our qualitative conclusion remain the same across the alternative specifications.

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[30]Note however that the inclusion of such controls could be problematic if the assumption of strict exogeneity is not satisfied. For this reason, we also estimated worker-level regressions without occupation fixed effects. The results are similar to those reported in Table 8, panel B, column 1, and available upon request.

[31]These are factors deemed important for the roll-out of broadband internet by Bhuller *et al.* (2013).

[32]For this purpose, we use a regional classification of Norway by Bhuller (2009) in 46 commuting zones constructed based on commuting statistics.

[33]Specifically, we obtain a slope estimate $\hat{v}_{r(m)}$ for each labor market region. We then include fitted pre-expansion time trends in our specification as follows $y_{mt} = \delta z_{m,t} + x'_{mt-1}\beta + \kappa_m + \tau_t + \lambda_1 \hat{v}_{r(m)}t + \lambda_2 \hat{v}_{r(m)}t^2 + \varepsilon_{mt}$

Table 8: Specification Checks.

	Main Specification	Additional Time-Varying Controls			Region-Specific Time Trends		
					Linear	Quadratic	Baseline Interacted FEs
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
A. Firms' Recruitment							
Experienced Recruitment Problems	-0.027***	-0.031***	-0.033***	-0.032***	-0.031***	-0.031***	-0.029***
	(0.009)	(0.009)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
Annual Vacancy Flow	0.032***	0.033***	0.032***	0.031***	0.030***	0.029***	0.027***
	(0.008)	(0.007)	(0.007)	(0.007)	(0.006)	(0.006)	(0.006)
Vacancy Duration	-1.376***	-1.233**	-1.153**	-1.121**	-1.063**	-1.017**	-1.017*
	(0.469)	(0.496)	(0.477)	(0.492)	(0.499)	(0.474)	(0.507)
Hire Growth	0.006***	0.006***	0.006***	0.006***	0.006***	0.006***	0.004***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)
Separation Growth	0.005*	0.006**	0.006**	0.006**	0.006***	0.005**	0.005**
	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Municipality and Year FEs	✓	✓	✓	✓	✓	✓	✓
Industry FEs		✓	✓	✓	✓	✓	✓
Firm Age and Size			✓	✓	✓	✓	✓
Firm Composition				✓	✓	✓	✓
B. Workers' Job Search and Employment Outcomes							
Re-employment	0.016***	0.015***	0.014***	0.012**	0.008*	0.007*	0.007*
	(0.006)	(0.006)	(0.005)	(0.005)	(0.004)	(0.004)	(0.004)
Wage in First Job (unconditional)	124***	120***	119***	101***	97***	94***	93***
	(34)	(32)	(31)	(31)	(27)	(27)	(27)
Tenure in First Job (unconditional)	0.397***	0.381***	0.379***	0.343***	0.341***	0.316***	0.232**
	(0.088)	(0.084)	(0.083)	(0.083)	(0.083)	(0.081)	(0.096)
Municipality and Year FEs	✓	✓	✓	✓	✓	✓	✓
Occupation FEs	✓	✓	✓	✓	✓	✓	✓
Worker Age and Gender		✓	✓	✓	✓	✓	✓
Family Background			✓	✓	✓	✓	✓
Dummies for Years of Education				✓	✓	✓	✓

Notes: See notes provided in Tables 5-7 relating to the definitions of each outcome variable. In panel A, column 2, 3-digit industry dummies (264 categories) are included. In panel A, column 3, establishment age and size include dummies for establishment age (51 dummies) and size (6 dummies), and in column 4, establishment composition includes average level of education of workers in the establishment and average annual wage rebased to 2014-USD. In panel B, column 1 includes dummies for 4-digit past occupation (pre-determined), column 2 includes a vector of controls for age and gender, column 3 further includes indicators for marital status and number of children (by age group), and in column 4, controls for education (18 dummies) are added. Columns 5 and 6 include linear and quadratic region-specific time trends, respectively, in the outcome variable constructing using pre-rollout data and a regional classification of Norway by Bhuller (2009) in 46 commuting zones. Column 7 further adds controls time dummies interacted with baseline year (2000) value of the outcome variable. Heteroskedastic robust standard errors are clustered on the regional level. $*p < 0.10$, $**p < 0.05$, $***p < 0.01$.

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Placebo Tests. Finally, we perform placebo regressions to examine whether future broadband internet availability affects current outcomes. If it did, it would suggest that the expansion of broadband internet is correlated with the underlying growth rates of our outcomes of interest. Specifically, we regress the outcome in year t on a set of variables capturing broadband availability in years $t+1$ to $t+5$ (i.e., the lead values of $z_{m,t}$), where the coefficient estimate on each lead variable represents a placebo test.[34] We report the results from this placebo test for the key establishment-level and worker-level outcomes in our analysis in Appendix Figure A5. Reassuringly, we find no effect of future availability on recruitment and outcomes of job seekers, supporting our assumption of parallel trends.

6 Mechanisms

Our main empirical analysis shows that broadband internet improves labor market matching and is broadly consistent with the predictions from the search and matching models outlined in Section 4. This section takes a deeper look at the data to shed some light on the possible channels behind the results.

6.1 Information

We begin by assessing the information channel: Does improved access to broadband internet improve job matching due to a reduction in information asymmetries between hiring firms and job seekers? An implication of improved access to information is that workers would search more broadly than if their primary sources of information are local newspapers. This hypothesis implies that increased broadband availability leads to (i) new employment relationships located further away from a worker's residence and (ii) increased probability of finding a job with a new employer (i.e., not recall hiring). To test these predictions, we estimate how broadband availability affects the probability of being re-employed by new versus old firms and in more geographically distant establishments.

We begin by decomposing a job seeker's re-employment outcome into two mutually exclusive dummy variables. The first variable equals one if the job seeker becomes re-employed in a new firm and is zero otherwise. The second outcome represents a recall hire and is equal to one if the new job is in the person's previous firm. Table 9 reports the results, where panel A copies in the baseline estimate on re-employment and panel C shows the estimate on recall employment. Recall employment is quite common: About 30 percent of re-employed job-seekers ($0.199/0.659 \approx 0.3$) are hired by their previous employer. Panel C shows that the increase in broadband availability has no impact on the probability of recall hiring.[35] On the contrary, and consistent with an increased flow of information, the estimate in panel B shows that the increase in re-employment probability is entirely explained by higher employment in new firms.

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[34]Since the broadband availability rate is cumulative, in this exercise we control for the broadband availability measured at the start of year t (i.e., $z_{m,t}$) in each regression. Not controlling for broadband availability at the start of year t would raise the concern that we are incorporating variation that precedes the outcome in the placebo test.

[35]For the U.S., Fujita & Moscarini (2017) document that 40 percent of the employed workers who separate into unemployment return, after the jobless spell, to their last employer. Despite differences in labor market regulations across Norway and the U.S. (see Section 2.1), our estimate of the recall rate for Norwegian job seekers at 30 percent is similar to the U.S.

Table 9: Unemployed Workers' Re-Employment – Recall Hiring and Distance to Employer.

Dependent Variable:	A. Re-employment	B. Employed With New Employer	C. Employed With Previous Employer (Recall Hire)	D. Distance to the Employer (Conditional)
Broadband Availability	0.016***	0.015*	0.001	0.227**
(Standard Error)	(0.006)	(0.009)	(0.006)	(0.107)
[*p*-value]	[0.006]	[0.092]	[0.864]	[0.039]
Dep. Mean	0.659	0.460	0.199	8.7
Obs. (*N*×*T*)	1,339,779	1,339,779	1,339,779	691,541

Notes: This table displays estimation results of availability of broadband internet in year *t*-1 on the cumulative probability of re-employment (panel A), finding employment with a new employer (panel B), finding employment with a previous employer (panel C) and distance to employer in kilometers (panel D) in year *t* or *t*+1, with *t*-1 ∈ [2000,2012]. Employment is defined as at least one month of employment in year *t* or *t*+1. Distance between hiring employer and previously unemployed is conditional on being re-employed, which happens for 66% of job-seekers within a two-year period (N=882,569), and to observations where we could match both workers' residential address and establishments' address at location of operation to exact geographic coordinates and construct reliable distance measures. We could do this for almost 80% of job seekers who were re-employed (*N*×*T* = 691,541). Since matching of establishments' addresses to geographic coordinates was done based on fuzzy matching on text strings, we tried to minimize measurement errors in geographic distance by excluding matches with a distance above 30 miles (approx. 50 kilometers). All specifications include controls for municipal infrastructure (municipal road networks (in kilometers) per capita, average travel time to municipal center (in hours) and public spending on infrastructure), and fixed effects for time, municipality and 4-digit code for past occupation. Heteroskedastic robust standard errors are clustered on the regional level. *$p < 0.10$, *$p < 0.05$, ***$p < 0.01$.

Our second test uses the coordinates of a worker's residential address and the new workplace. We construct the Euclidean distance to the workplace among those who find a new job after a spell of unemployment, and regress this geographic distance measure on broadband availability. The result is presented in panel D, and shows that broadband internet increases the distance by 227 meters on average. Compared to the dependent mean of 8.7 kilometers, the size of the effect suggests that full broadband coverage increases the distance between job seekers and hiring establishment by 2.5 percent.[36]

Finally, improved access to information about vacancies could also increase the probability of relocating to a new local labor market. We test this prediction by constructing an outcome variable equal to one if an individual relocates to a different local labor market within a two-year period after broadband availability is measured. Appendix Table A6 illustrates that broadband availability does not change the likelihood of moving to other labor markets. This result holds both among employed workers and job seekers who presumably have stronger incentives to move. Taken together, these findings indicate that broadband internet coverage increases the effective size of a local labor market by increasing the commuting distance.

6.2 Reallocation

We proceed by assessing whether higher growth rates in hiring reflect more intensive poaching and/or on-the-job search. To perform this test, we decompose the hire growth (and separation growth) by workers' past (and future employment status). Panels A-B in Table 10 shows that establishments predominantly hire from the pool of workers that were either unemployed or outside the labor force (i.e., from non-job status). A comparison of the dependent means and the point estimates suggests that while 70 percent of the overall hire growth ($0.09/0.129 \approx 0.7$) is from the hiring of previously non-employed individuals, the increase in

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[36]Appendix Table A7 confirms this result by assessing the impact of broadband availability on average distance between all hiring establishments and their newly hired workers. Most of the increase in distance between an employer and its workers is concentrated among hires from unemployment.

hire growth due to broadband availability is more evenly spread across the two types of hires.

Table 10: Decomposing Firms' Hire and Separation Growth By Workers' Past and Future Job Status.

Dependent Variable:	A. Hire Growth From Another Job	B. Hire Growth From Non-Job Status
Broadband Availability	0.002***	0.003**
(Standard Error)	(0.001)	(0.001)
[p-value]	[0.010]	[0.027]
Dep. Mean	0.039	0.090
Dependent Variable:	C. Separation Growth Into Another Job	D. Separation Growth Into Non-Job Status
Broadband Availability	0.004***	0.002
(Standard Error)	(0.001)	(0.002)
[p-value]	[0.007]	[0.340]
Dep. Mean	0.050	0.064
Obs. ($B \times T$)	1,821,902	1,821,902

Notes: This table displays estimation results of hire growth in year t, with hires coming from another job (panel A), hires coming from either unemployment or outside the labor force (panel B), separations into another job (panel C) and separations into either unemployment or outside the labor force (panel D) on broadband internet availability rate in year t, with $t \in$ [2000,2014]. Job status for hires is based on employment history the month before being hired. If no past employer is found, the worker is defined as coming from either unemployment or outside the labor force. Job status for separations is based on employment history the month after separation, with job being defined as earning a positive wage at an establishment. If no employer is found, the worker is defined as going to either unemployment or outside the labor force. All specifications include controls for municipal infrastructure (municipal road networks (in kilometers) per capita, average travel time to municipal center (in hours) and public spending on infrastructure), and fixed effects for time and municipality. Heteroskedastic robust standard errors are clustered on the regional level. **$p < 0.05$, ***$p < 0.01$.

Turning to separation rates, we decompose separation growth into separations where (i) workers move to another firm and (ii) separation into non-employment. Despite a lack of statistical precision, panels C-D show that the majority of separating workers move to other firms.[37] We elaborate on this finding by classifying workers as highly skilled if a worker has above median years of schooling within their past industry and lower skilled if his level of education is below the median. In Appendix Table A5, we show that hiring and separation growth is concentrated among low-skilled workers. By contrast, the skill biased technical change hypothesis would imply that the increase in hires was primarily driven by high-skill workers. Instead, our evidence points towards increasing churn of low-skilled workers as a likely mechanism, which is consistent with the predictions from a model with endogenous job destruction and on-the-job search. Another interpretation is that employers, on average, hire more high-wage workers through social connections (see e.g., Montgomery, 1991 and Eliason *et al.*, 2019). As a result, low skilled job seekers gained relatively more from job platforms than high skilled job seekers.

7 Aggregate Effects

This section provide complementary evidence using variation in broadband internet expansions across labor market regions. This approach accounts for potential spillover effects from an enlargement of the effective

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[37]Note the important distinction between firms and establishments. Both in recall hires and in separations, we exclude re-hiring of a worker within a firm's internal labor market (e.g., establishments within the same firm).

size of a labor market and allows us to estimate the aggregate implications of the broadband internet expansion. The section concludes with a discussion of the implications of our findings for the steady state unemployment rates.

7.1 Regional Approach

By focusing on regional-variation in broadband availability, we can estimate the general equilibrium effects of broadband availability on labor market outcomes. The basic idea follows from Kroft & Pope (2014), who argue that the regional approach captures search externalities across units within a region that may not be captured by studies that focus on worker- or firm-level outcomes. The main assumption is that a regional labor market is sufficiently broad, so there are minimal spillovers in job search and hiring beyond its borders. We use commuting zones based on natural geographic boundaries, such as mountains and fjords, in addition to commuting statistics (Bhuller, 2009). Thus, it is reassuring to find that the entire effect on re-employment we documented in Section 5 is concentrated within the commuting zone (CZ) of the worker and the employer. These results are presented in Appendix Table A8.

To implement the regional approach, we estimate a modified version of Equation (1). In order to estimate equilibrium effects of broadband availability, we aggregate data into year by CZ cells and modify our regression equation to include CZ and calendar year fixed effects. Our variable of interest is now the *regional* broadband availability rate. To recover estimates of population-level parameters, we use weighted least squares regressions with the size of the labor force (the number of job seekers) as weights for employer (worker) outcomes. As in the individual-level analysis, the baseline specification includes regional averages of population-weighted municipal infrastructure characteristics. The parameter of interest captures the impact of regional broadband availability rate on regional job matching. Absent other feedback effects, Kroft & Pope (2014) argue that the regional evidence is informative about the aggregate implications of the broadband internet expansion.

7.2 Regional Evidence

We start by confirming that our main result on recruitment difficulties holds at the regional level. The point estimate is reported in panel A.1 and shows that when the availability rate goes from zero to full in a region, the fraction of establishments that report problems while recruiting falls by about 4 percentage points. This effect is slightly stronger than the effect we estimated at the individual establishment-level.

In Section 5, we documented a significant reduction in the duration of vacancies and an increase in the vacancy flow following expansions in broadband availability. These two results have opposite implications for how the overall stock of vacancies should respond to improved access to broadband internet. To assess the net impact on vacancies, we calculate the stock of vacancies in a CZ at the end of the year, and divide by the labor force. Panel A.2 of Table 11 shows that we are unable to reject that there is no impact. While the estimate is somewhat imprecisely estimated, it suggests that the improved matching efficiency and a stronger incentive to post vacancies offset each other at the aggregate level.

Table 11: Region-Level Analysis.

Dependent Variable:	A. Firms		B. Workers	
	A.1 Recruitment Problems	A.2 Vacancy Rate	B.1 Job Finding Rate	B.2 Subsequent Unemployment Rate
	(1)	(2)	(3)	(4)
Broadband Availability	-0.041**	0.002	0.040**	-0.025**
(Standard Error)	(0.018)	(0.002)	(0.018)	(0.010)
[p-value]	[0.024]	[0.247]	[0.029]	[0.019]
Dep. Mean	0.215	0.015	0.677	0.195
Obs. ($R \times T$)	687	506	598	598

Notes: This table displays estimation results of broadband internet availability rate on the fraction of establishments reporting experiencing recruitment problems (column 1, see Table 5), on normalized days of vacancies at the establishment level (column 2), on the probability a job seeker finds a job after 2 years (column 3), and the probability a job seeker is unemployed again one year after finding a job (column 4). All specifications controls for region and year fixed effects. Local labor markets are defined based on the classification of Norway into 46 regions by Bhuller (2009) based on commuting statistics. Heteroskedastic robust standard errors are clustered on the regional level. *$p < 0.10$, **$p < 0.05$.

Next, we turn to re-employment and unemployment risk at the regional level. We estimate that moving from no to full coverage in a region increases the re-employment rate by 4 percentage points, or nearly 6 percent relative to the baseline mean. This result is reported in panel B.1 of Table 11. Our final outcome of interest is the subsequent flow into unemployment. This outcome reflects the tenure effects we documented in Section 5; it is equal to one if a person who finds a new job after a spell of unemployment is subsequently observed as a job seeker, and zero otherwise. The average risk of entering a new spell of unemployment is 19.5 percent. We find that broadband internet coverage reduces this probability substantially. Panel B.2 in Table 11 documents a statistically significant reduction of 2.5 percentage points, which corresponds to a 12 percent decrease relative to the baseline mean.

Local Multipliers.

One may still worry that overall demand effects due to improvements in productivity from ICT could be driving the main results. This hypothesis states that even though a plumber does not use internet for work purposes, demand for his services is increasing because of higher levels of economic activity at the regional level. While such "local multipliers" are hard to preclude, we can assess the likelihood that they explain our results by focusing on late expansions. The idea is that the aggregate demand effects have materialized at the time the policy induced expansions reach the "last" municipalities, and that if demand effects are crucial, the impact among late expansions should be smaller than the overall impacts. We implement this test by focusing on municipalities whose neighboring municipalities have higher than the national median broadband coverage rate, and redo the main empirical analysis from Section 5. Appendix Table A9 show that if anything, the effects are larger, suggesting that our conclusions are robust to possible local multiplier effects.

7.3 Implications for the Beveridge Curve

Having established that broadband internet availability affects job finding rates and the risk of unemployment at the regional level, a natural question is: What are the implications for the Beveridge curve? Figure 6 illustrates the co-movement between unemployment and vacancy rates – or the Beveridge curve – in Norway over the period 2001 to 2016. Empirically, the joint movement of unemployment and vacancies is informative about the functioning of the labor market. For example, changes in the intensity of the reallocation process or matching technology may cause the two quantities to move in parallel, while movements in aggregate activity lead to opposite movements in job creation and job destruction (Blanchard *et al.* , 1989). In normal times, it, therefore, displays an inverse relationship, which is indeed the case in Norway during the early 2000s: the vacancy rate was moving upwards while the unemployment rate was falling. Note that there seems to have been an inward shift of the Beveridge curve, beginning in 2006, and leading up to the Great Recession. To what extent can the expansion in broadband internet account for this inward shift?

Figure 6: The Beveridge Curve in Norway, 2001-2016.
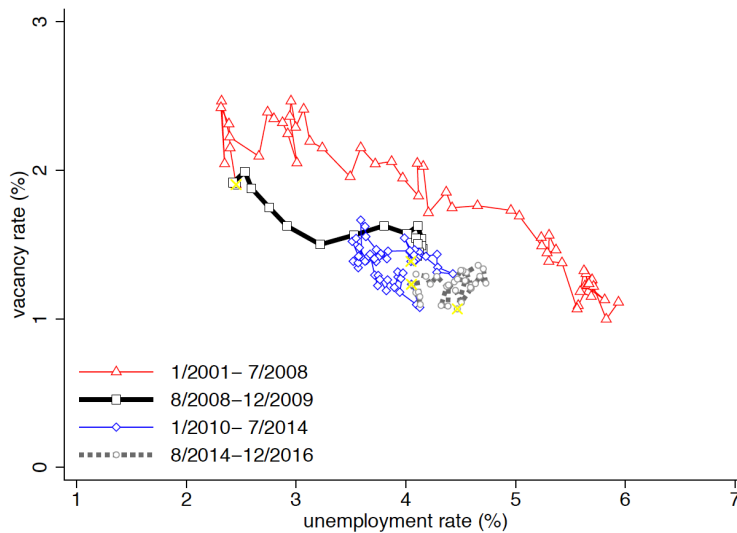
Notes: This figure shows the Beveridge curve for Norway using administrative data of vacancies and unemployed job seekers. The number of vacancies and unemployed are divided by the labor force, and are seasonally adjusted.

To illustrate the implications of our findings for steady state unemployment rates, our calculations in Appendix D use the fact that flows in and out of unemployment must be equal in an equilibrium. We can calculate the counterfactual flows in a scenario with no broadband coverage using our estimated impacts. Next, to calculate the unemployment rate that would be consistent with the counterfactual unemployment risk and matching efficiency, we make the following assumptions. We ignore on-the-job search and entry and exit from the labor force, and assume that, conditional on broadband internet coverage, all workers face the same constant unemployment risk.[38] We parameterize a Cobb-Douglas matching function and use our estimates from Table 11 to compute the counterfactual separation and vacancy rate with no broadband coverage. Finally, our estimate on the regional job finding rate allows us to infer the impact of broadband

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[38]We find no impact of broadband availability on the probability of entering the labor force, and do not find any evidence that it affects the probability of leaving the labor force. These results are available upon request.

coverage on total matching efficiency. We then numerically solve for the level of unemployment that would equalize the flows in and out of unemployment. Assuming that 2012 represents a point on the Beveridge curve, our calculation implies that the counterfactual steady state unemployment rate would be 5 percentage points, nearly 1 percentage point higher than the actual rate in 2012. If we disregard the impact on separation rates, the counterfactual steady-state unemployment rate is 4.4 percentage points, still 10 percent higher than the actual rate in 2012. In terms of evaluating the broadband policy, our calculations suggest that important benefits of the policy would be missed if we omit the effects on labor market matching.

8   Conclusion

The goal of this paper was to understand how broadband internet has affected the labor market's ability to match workers to vacant jobs. We were able to offer the first evidence of the impacts on labor market matching due to two unique features of Norwegian labor markets. The first was a staggered expansion in broadband internet infrastructure that generated plausibly exogenous variation in the availability of high-speed internet to firms and workers. This allowed us to address the fact that use of broadband internet is not random but likely explained by factors that are unobservable to the researcher and correlated with labor market success. The second key feature was the availability of a wide range of large-scale surveys and administrative data sets covering establishments, vacancies, and workers. Using these data sources, we compared labor markets with high versus low coverage rates and assessed several margins of firm recruitment, job search behavior, and match quality.

We began our empirical analysis by documenting substantial increases in the use of broadband internet among both firms and households following the staggered roll-out of internet access points. Notably, we found that broadband coverage led to a large increase in the use of online job search and recruitment (e.g., posting on online platforms). Guided by the theoretical predictions from standard search and matching models, our empirical analysis delivered three main results. First, broadband internet has significantly improved the search and matching process: The average duration of a vacancy fell by 9 percent and the share of establishments that experienced problems while recruiting fell by 13 percent. As a response to faster filling rates, we found that firms posted more vacancies. Second, we uncovered important benefits of broadband availability for job seekers. We confirmed prior evidence from other countries showing that internet use increases the job-finding rates of unemployed workers and expanded on it by documenting large increases in starting wages and tenure in new jobs. Our third empirical contribution was to show that improved information about available jobs is a likely mechanism through which the internet affects labor market matching.

We discussed the implications of our findings for policy. The first implication pertains to the interpretation of the falling rates of worker mobility in the U.S. This trend has led to a growing concern about underlying reasons for the weakened labor market fluidity. Our results suggest that online job search and recruitment may have improved match quality and this improvement reduced the need to switch employers in search for a better match. Thus, our findings are consistent with a more optimistic view on recent trends in job mobility. Second, our evidence offers an explanation of the inward shift in the Beveridge curve observed in several countries from the 1990s to the early 2000s. Our evidence suggests that without the

near-universal internet adoption rates, the unemployment rate after the Great Recession could have reached even higher levels. The improved access to information about job openings may have further lowered the natural rate of unemployment, which is relevant for conducting monetary policy. Our calculations suggest that the steady-state unemployment rate would have been as much as 25 percent higher in the absence of broadband internet. Finally, and perhaps somewhat more speculative, our evidence suggests a reduced scope for government-provided job matching services.

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A   Appendix: Additional Tables and Figures

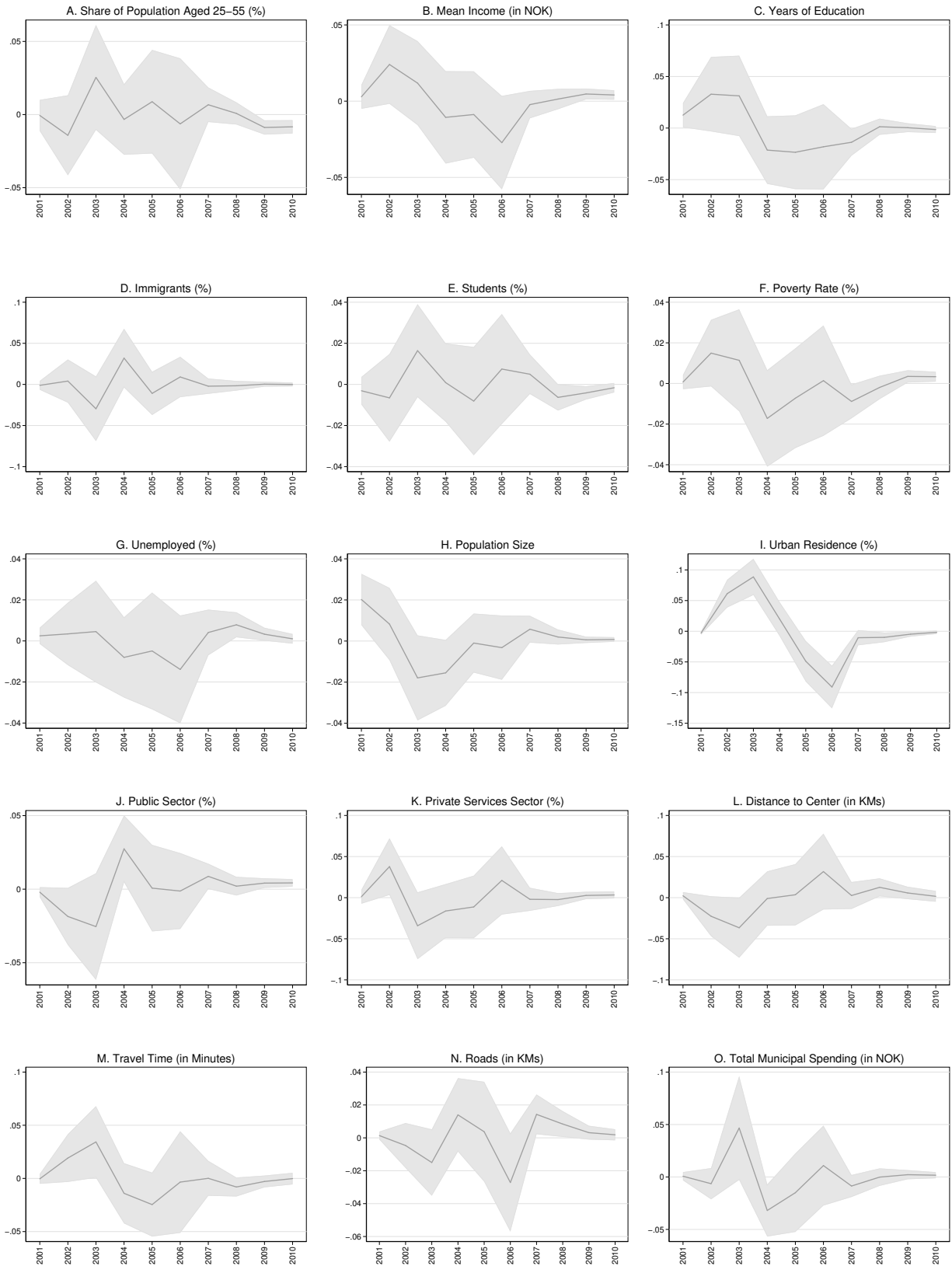Figure A1: Indicator for Recruitment Problems in the Recruitment Survey.
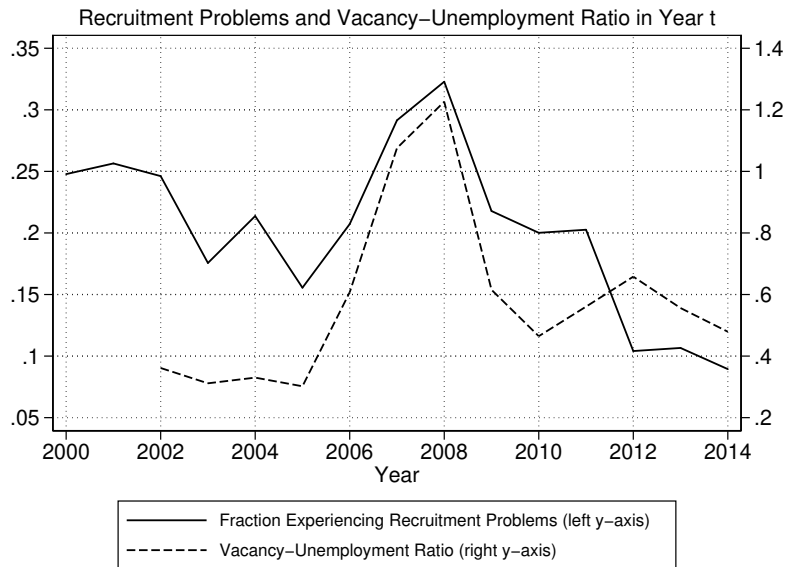
Notes: The figure shows for each year the fraction of establishments experiencing recruitment problems along the yaxis to the left, and the aggregate vacancy-unemployment ratio along the yaxis to the right. The fraction of establishments reporting a recruitment problem is from the Annual Survey of Establishments' Recruitment Behavior performed by the National Public Employment Agency (NAV), and the vacancy-unemployment ratio is from the administrative data of job seekers and vacancies maintained by the same agency (see Appendix B.1).

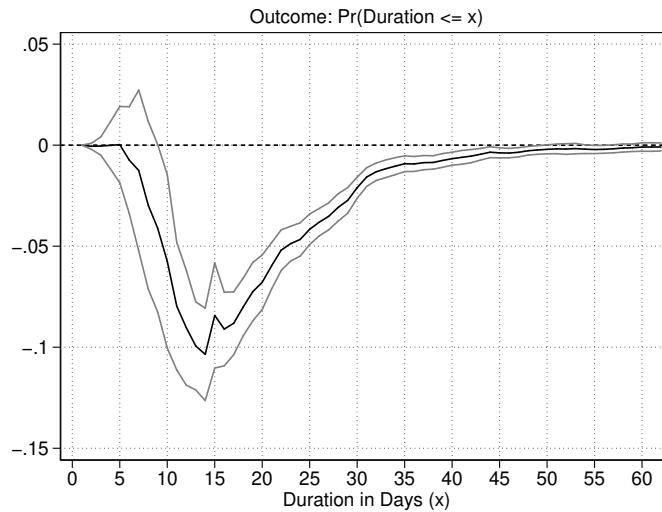Figure A2: The Geographical Dispersion of Broadband Internet Availability Rates across Norway.
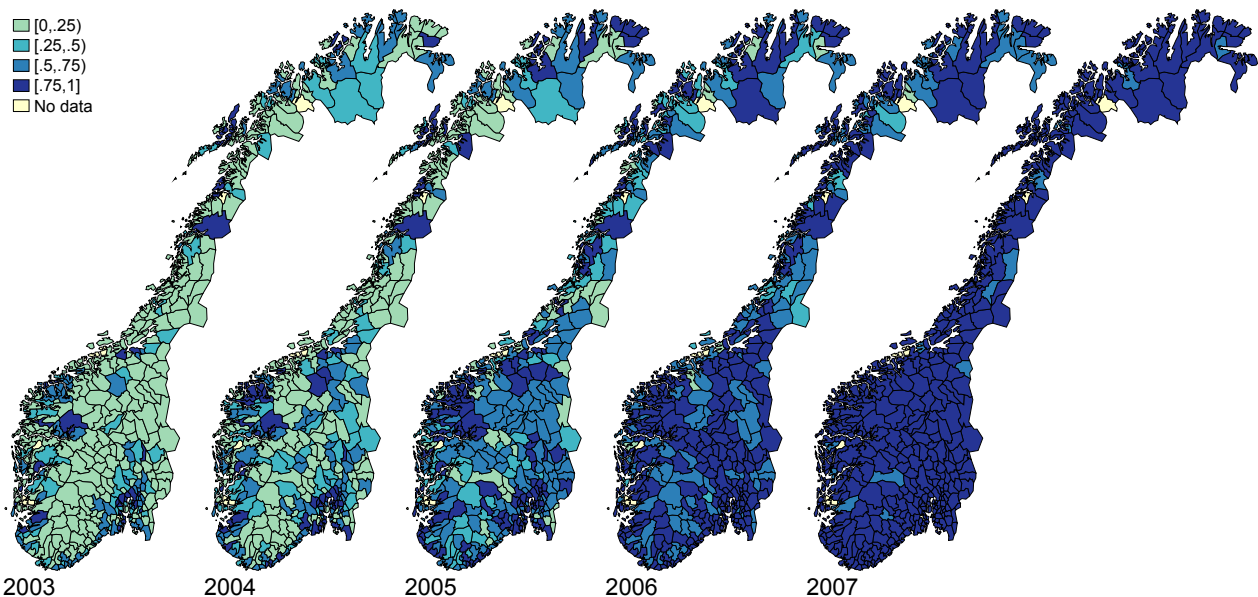
Notes: The figures show the geographical distribution of broadband internet availability rates across Norway in each year from 2003-2007 based on data from the Norwegian Communications Authority (NKOM). For each municipality and year, broadband internet availability rate is plotted, with different colors indicating different levels of coverage.

Figure A3: The Expansion of Broadband Internet by Baseline Municipality Characteristics.

Figure A4: Vacancy Duration.

Outcome: Pr(Duration <= x)

Table A1: Firms' and Workers' Internet Access and Online Activities – Using Analytical Weights.

	A. Firms in the ICT Use Survey		B. Working-age Individuals in the Media Use Survey	
	(1) Unweighted	(2) Analytical Weights	(3) Unweighted	(4) Analytical Weights
Dependent Variable:	1. Has Broadband Internet Access		1. Has Broadband Internet Access	
Broadband Availability	0.301***	0.301***	0.282***	0.267***
(Standard Error)	(0.025)	(0.025)	(0.027)	(0.027)
Base Dep. Mean	0.380	0.380	0.059	0.059
Dependent Variable:	2. Online Job Board Use Rate		2. Uses Internet for Browsing Ads	
Broadband Availability	0.171***	0.171***	0.091**	0.091**
(Standard Error)	(0.038)	(0.038)	(0.044)	(0.043)
Base Dep. Mean	0.284	0.284	0.022	0.022
Obs. ($B{\times}T / N{\times}T$)	50,269	50,269	10,959	10,119

Figure A5: Placebo Tests.

(a) Establishments – Recruitment Problems

(b) Establishments – Vacancy Flow

(c) Establishments – Vacancy Duration
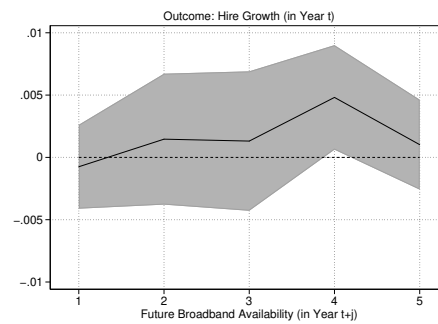
(d) Establishments – Hire Growth
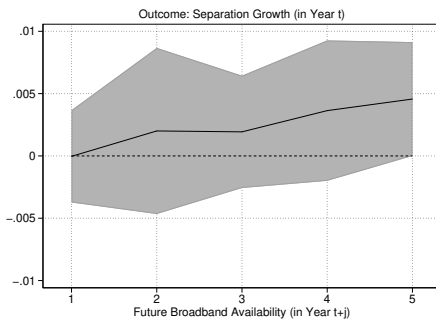
(e) Establishments – Separation Growth
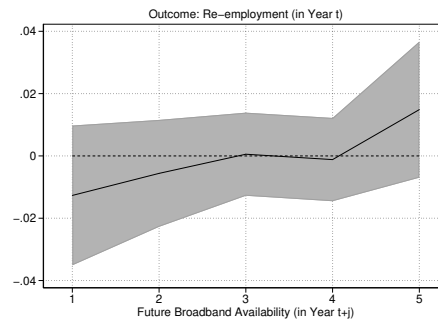
(f) Workers – Re-employment
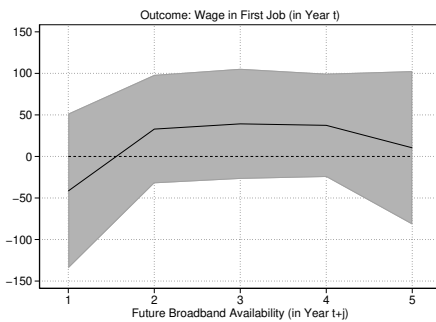
(g) Workers – Wage in First Job
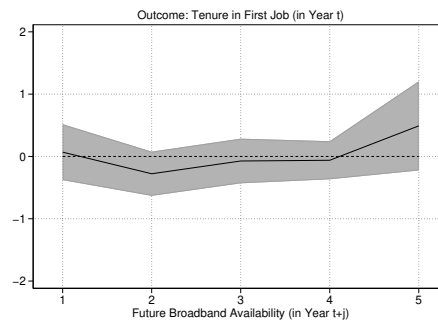
(h) Workers – Tenure in First Job

Note: The figures shows the estimated effect and associated 90% confidence intervals of future broadband availability in years 1-5 after each outcome is measured. The specification includes municipality and time fixed effects, controls for past broadband availability, as well as controls for municipal infrastructure (municipal road networks (in kilometers) per capita, average travel time to municipal center (in hours) and public spending on infrastructure) and all additional controls listed in Table 8, column (4). Heteroskedastic robust standard errors are clustered on the regional level.

Table A2: On the Job Search.

Dependent Variable:	On the Job Search		
Panel:	A. Searching for a Job	B. Duration of Search (Weeks, Conditional)	C. Total Time Searching (Weeks, Unconditional)
Broadband Availability	-0.013**	3.949**	0.241
(Standard Error)	(0.006)	(1.760)	(0.173)
[p-value]	[0.035]	[0.030]	[0.169]
Dep. Mean	0.093	20.0	1.9
Obs. ($N \times T$)	143,069	13,346	143,069

Notes: This table displays estimation results of probability of searching for a job (panel A) and number of weeks spent on on-the-job search if searching (panel B) and overall time spent on search (panel C) on broadband internet availability rate in year t-1, with t-1 $\in$ [2000,2012]. This estimation uses data from the Quarterly Labor Force Surveys, where the sample is conditional on being employed. For years 2000-2005, the sample consists of respondents from second quarter, while for years 2006-2014 the sample consists of respondents from all quarters but only second quarter responses are kept. All specifications include controls for municipal infrastructure (municipal road networks (in kilometers) per capita, average travel time to municipal center (in hours) and public spending on infrastructure), and fixed effects for time and municipality. Heteroskedastic robust standard errors are clustered on the regional level. **$p < 0.05$.

Table A3: Non-ICT Intensive Occupations.

Panel	A. Hiring Firms		B. Job Seekers	
Dependent Variable:	Vacancy Duration (1)	Vacancy Flow (2)	Tenure (3)	Wage (4)
Broadband Availability	-1.273**	0.025***	0.409***	117***
(Standard Error)	(0.609)	(0.004)	(0.137)	(40)
[p-value]	[0.042]	[0.000]	[0.005]	[0.005]
Dep. Mean	11.9	0.133	7.1	1,910
Obs. ($N \times T$)	214,243	1,611,573	778,896	875,930

Notes: Panel A displays estimation results of mean duration in days of a vacancy posted during year t (column 1), posting at least one vacancy during year t (column 2) on broadband internet availability rate in year t. Both variables are from the vacancy register, and duration is conditional on an establishment having posted a vacancy. Panel B displays estimation results of tenure length in the first firm measured in months (column 3) and starting monthly wage level measured in 2014-USD (column 4) on broadband internet availability rate in year t-1, with t-1 $\in$ [2000,2012]. In column 4, monthly wage is rebased to 2014-NOK using the CPI and then converted to USD (1 USD = 8 NOK). In column 3, we drop observations with tenure equal or greater than 48 months due to censoring. Tenure and wages are not conditional on finding a job in either year t or year t+1, and is set to zero for non-job outcomes. ICT-Intensive is defined as a (three-digit) occupation where the incidence of using internet for work related purposes (from the ICT Survey) is greater than the median. All specifications include controls for municipal infrastructure (municipal road networks (in kilometers) per capita, average travel time to municipal center (in hours) and public spending on infrastructure), and fixed effects for time and municipality. Heteroskedastic robust standard errors are clustered on the regional level. **$p < 0.05$, ***$p < 0.01$.
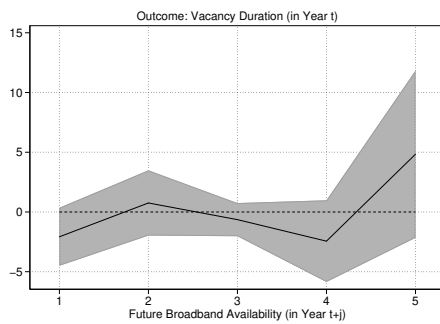
Table A4: Worker-Level Evidence By Workers' Age and Gender.

	All	Males			Females		
		25-35	35-45	45-55	25-35	35-45	45-55
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
A. Broadband Internet Use							
Has Broadband Internet Access	0.282***	0.144**	0.451***	0.204***	0.316***	0.213***	0.261***
	(0.027)	(0.071)	(0.048)	(0.064)	(0.067)	(0.057)	(0.087)
Number of Observations ($N \times T$)	10,939	1,810	2,087	1,712	1,784	2,142	1,636
B. Workers' Job Search and Match Quality							
Re-Employment	0.024***	0.002	0.001	0.012	0.041***	0.036***	0.035
	(0.008)	(0.008)	(0.007)	(0.009)	(0.011)	(0.013)	(0.024)
Tenure in First Job (unconditional)	0.531***	0.410**	0.366**	0.639***	0.635***	0.467***	0.411
	(0.116)	(0.181)	(0.149)	(0.214)	(0.175)	(0.165)	(0.259)
Wage in First Job (unconditional)	201***	152***	210***	207***	116***	147**	208
	(54)	(36)	(64)	(61)	(33)	(58)	(124)
Number of Observations ($N \times T$)	1,339,779	340,297	259,155	180,469	360,222	264,631	151,189

Notes: Panel A displays estimation results from the Media Use Survey on the probability of broadband internet access on broadband internet availability rate in year t-1, with t-1 $\in$ [2001,2014]. Panel B displays estimation results for previously unemployed workers on probability of re-employment within the next two years, tenure length in the first establishment measured in months and starting monthly wage level measured in 2014-USD on broadband internet availability rate in year t-1, with t-1 $\in$ [2000,2012]. All specifications include controls for municipal infrastructure (municipal road networks (municipal center in hours) and public spending on infrastructure), and fixed effects for municipality and year. Heteroskedastic robust standard errors are clustered on the regional level. **$p < 0.05$, ***$p < 0.01$.

Table A5: Decomposing Firms' Hire and Separation Growth By Worker Skill Types.

Dependent Variable:	A. Hire Growth High-Skilled	B. Hire Growth Low-Skilled
Broadband Availability	0.001*	0.004***
(Standard Error)	(0.001)	(0.001)
[*p*-value]	[0.057]	[0.004]
Dep. Mean	0.040	0.089
Dependent Variable:	C. Separation Growth High-Skilled	D. Separation Growth Low-Skilled
Broadband Availability	0.001	0.004**
(Standard Error)	(0.001)	(0.002)
[*p*-value]	[0.300]	[0.043]
Dep. Mean	0.036	0.078
Obs. (*B*×*T*)	1,821,902	1,821,902

Notes: This table displays estimation results of hire growth and separation growth in year *t*, with hires being a high-type worker (panel A), hires being a low-type worker (panel B), separations being a high-type worker (panel C) and separations being a low-type worker (panel D), on broadband internet availability rate in year *t*, with *t* ∈ [2000,2014]. High-type is defined as the worker having an above-median education length (with the distribution of education length being industry-specific and defined in year *t*-1), and the worker is defined as low-type otherwise. All specifications include controls for municipal infrastructure (municipal road networks (in kilometers) per capita, average travel time to municipal center (in hours) and public spending on infrastructure), and fixed effects for time and municipality. Heteroskedastic robust standard errors are clustered on the regional level. **p < 0.10, **p < 0.05, ***p < 0.01.*

Table A6: Residential Mobility.

Dependent Variable:	Probability of Relocating to a Different Local Labor Market		
Panel:	A. All Workers	B. Employed	C. Unemployed
Broadband Availability	-0.001	-0.002	0.004
(Standard Error)	(0.001)	(0.002)	(0.004)
[*p*-value]	[0.347]	[0.227]	[0.244]
Dep. Mean	0.041	0.040	0.056
Obs. (*N*×*T*)	24,248,439	18,961,171	1,339,779

Notes: This table displays estimation results of the cumulative probability of relocating from year *t*-1 to year *t* or *t*+1 among all workers (panel A), relocating among employed workers who transfer to a new job (panel B), and relocating among the sample of unemployed workers who find work (panel C) on broadband internet availability rate in year *t*-1, with *t*-1 ∈[2000,2012]. Employment is defined as at least one month of employment and unemployment is defined as at least one month of unemployment (either full-time or part-time), both measured in year *t*-1. Local labor markets are defined based on the classification of Norway into 46 regions by Bhuller (2009) based on commuting patterns. All specifications include controls for municipal infrastructure (municipal road networks (in kilometers) per capita, average travel time to municipal center (in hours) and public spending on infrastructure), and fixed effects for time and municipality. Heteroskedastic robust standard errors are clustered on the regional level.

Table A7: Distance Between Employer and Newly Hired Workers.

Dependent Variable:	Mean Distance between Employer and Newly Hired Workers		
Panel:	A. All Hires	B. Hires from Job Status	C. Hires from Unemployment
Broadband Availability	0.677***	0.470	0.640***
(Standard Error)	(0.220)	(0.341)	(0.182)
[p-value]	[0.004]	[0.175]	[0.001]
Dep. Mean	9.0	9.3	8.8
Obs. ($B \times T$)	766,672	413,367	645,482

Notes: This table displays estimation results of mean distance in kilometers between the location of operation of the employer (establishment) and the residential location of its all new hires (panel A), hires who were previously in another job (panel B) and hires who were previously unemployment (panel C) on broadband internet availability rate in year *t*, with *t* ∈ [2000,2014]. All specifications include controls for municipal infrastructure (municipal road networks (in kilometers) per capita, average travel time to municipal center (in hours) and public spending on infrastructure), and fixed effects for time and municipality. In panels A-C, we limit the sample (*B×T* = 1,821,902) to only include establishments hiring at least one worker within the calendar year (by past employment status). We further also limit the samples to observations where we could match both workers' residential address and employer's address at the location of operation to exact geographic coordinates and construct reliable distance measures. Since matching of workplace addresses to geographic coordinates was done based on fuzzy matching on text strings, we tried to minimize measurement errors in geographic distance by excluding matches with a distance above 30 miles (approx. 50 kilometers). Heteroskedastic robust standard errors are clustered on the regional level. ***p < 0.01.

Table A8: Unemployed Workers' Re-Employment – By the Commuting Zone of the Employer.

Dependent Variable:	A. Re-employment	B. Employer is in same CZ	C. Employer is in different CZ
Broadband Availability	0.016***	0.019***	-0.002
(Standard Error)	(0.006)	(0.005)	(0.003)
[p-value]	[0.006]	[0.001]	[0.456]
Dep. Mean	0.659	0.533	0.126
Obs. ($N \times T$)	1,339,779	1,339,779	1,339,779

Notes: This table displays estimation results of availability of broadband internet in year *t*-1 on the cumulative probability of re-employment (panel A), employment with establishments in the same commuting zone (CZ) as the worker (panel B), employment with establishments in the a different CZ as the worker (panel C) in year *t* or *t*+1, with *t*-1 ∈ [2000,2012]. Employment is defined as at least one month of employment the following two years after the installation of broadband internet access points. All specifications include controls for municipal infrastructure (municipal road networks (in kilometers) per capita, average travel time to municipal center (in hours) and public spending on infrastructure), and fixed effects for time, municipality and 4-digit code for past occupation. Heteroskedastic robust standard errors are clustered on the regional level. ***p < 0.01.

Table A9: Neighboring Municipalities With High Coverage.

Panel:	A. Hiring Firms		B. Job Seekers	
Dependent Variable:	Vacancy Duration (1)	Vacancy Flow (2)	Tenure (3)	Wage (4)
Broadband Availability	-1.236**	0.029***	0.616***	216***
(Standard Error)	(0.474)	(0.008)	(0.115)	(57)
[p-value]	[0.012]	[0.001]	[0.000]	[0.000]
Dep. Mean	15.0	0.208	7.7	2,123
Obs. ($N \times T$)	5,166	5,172	4,449	4,449

Notes: Panel A displays estimation results (weights = number of establishments in the municipality in year *t*) of municipality mean duration of vacancies posted during year *t* (conditional on posting) in days (column 1), average probability of posting at least one vacancy during year *t* (column 2) on broadband internet availability rate in year *t*, with *t* ∈ [2002,2014]. Panel B displays estimation results (weights = number of unemployed in the municipality in year *t*-1) of municipality average tenure (column 3) and average starting monthly wage (column 4) in new employment spells on broadband internet availability rate in year *t*-1, with *t*-1 ∈ [2000,2012]. Sample consists of municipalities with at least one neighboring municipality (i.e., within same CZ) with broadband availability rate higher than the national median in the same year. Fixed effects include time and municipality fixed effects. Firm characteristics indicate vector of lagged controls for mean establishment age, mean establishment size, and mean establishment composition (average level of education of workers in the establishment and average annual wage rebased to 2014-NOK). All specifications include controls for municipal infrastructure (municipal road networks (in kilometers) per capita, average travel time to municipal center (in hours) and public spending on infrastructure). Heteroskedastic robust standard errors are clustered on the Bhuller region level. **p < 0.05, ***p < 0.01.

B Appendix: Data Sources and Quality

B.1 Data Sources

Administrative Employer-Empoyee Register. Workers' earnings and employment histories, and transitions between jobs and occupations come from the Norwegian Matched Employer-Employee Register maintained by Statistics Norway. This data set covers virtually all employment contracts from 1995 to 2014. Every worker-level contract is reported by the employer to the authorities at the end of the year, and includes information on the dates of alterations to the contract, and the corresponding wage, industry and occupational codes, geographic location and tenure at the establishment. From this source, we construct time series of monthly earnings for each worker, and the transitions between establishments and occupations.

Administrative Job-Seeker/Unemployment Register. Information on participation in the unemployment insurance (UI) program comes from the job-seeker register, which has complete records for all individuals who entered or exited this program between 1992 and 2014. This information is maintained by Statistics Norway and builds on administrative records kept by the National Public Employment Agency (NAV). The data includes every job-seeker, both the fully unemployed and those who have a part-time job but are looking for full-time work, as well as participants in active labor market programs. To assist workers in job search, caseworkers in the employment agency keep a record of details about workers' occupational experience, and the occupations job seekers want to work in.

Administrative Register of Job Vacancies. The public employment agency maintains a database of job vacancies used for statistical purposes and by caseworkers to match unemployed workers to potential employers. Individual vacancies are either manually collected from job boards and help-wanted ads, or are reported directly by employers.[39] These vacancies are then classified by the number of positions the establishment is trying to fill, the workplace location (e.g., zip code) and the corresponding four-digit occupational code. Occupational codes are based on the International Standard Classification of Occupations (ISCO). The vacancy data is available from 2002 and onward.

Administrative Population Registers. To capture complete information on workers' geographic location, education, annual earnings, and household income, social security data is merged with longitudinal administrative registers provided by Statistics Norway and covering every Norwegian resident from 1967 to 2014. These administrative data sources contain individual demographic information (including sex, age, zip codes,

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[39]The Norwegian Labor Market Act (*Loven om arbeidsmarkedstjenester §7-1*) requires employers to report vacant positions to the public employment agency. The public employment agency employs data collectors that manually record vacancies from various alternative sources. As a result, the quality of the vacancy register naturally depends on the degree to which establishments comply with the reporting requirements and the accuracy of manual recording performed by data collectors. A natural question is then to what extent are data recorded in the vacancy register representative of all job openings. To assess the representativeness of our data we collected additional data on job openings from Statistics Norway that is based on representative surveys of establishments from 2010 to 2016. Our comparisons reveal that data on vacancies from the public employment agency tracks the time variation in aggregate job openings from the survey data on vacancies remarkably well (see Appendix Figure B1).

and years of education) and, since 1993, all sources of annual income, including earnings, self employment income, capital income, and cash transfers. From the early 2000s, we have geographic coordinates of the residential location for almost all workers and the workplace location for a large fraction of establishments.

Survey of Firms' ICT Use. Since 1999, Statistics Norway has surveyed firms' ICT use using repeated cross-sections. About 4,000 firms are drawn from stratified random samples by firm size and industry from the population of firms. Crucial to our analysis, the surveys include information on the use of dial-up or broadband internet by firms. The surveys also collect information about online activities, including whether a firm has a marketing website and other measures of firms' digital presence and online search behavior. We received extracts from these data sets for years 1999 to 2014, which contain responses from around 3,600 firms each year. Statistics Norway mandates the collection of this information for the purpose of preparing official statistics on firms' ICT use and can threaten to impose coercive fines in case of non-response. As a result, the average response rate is nearly 95 percent.

Survey of Establishments' Vacancies. Since 2010, Statistics Norway has conducted quarterly surveys of establishments' vacancy posting behavior. These surveys are used primarily for statistical reporting purposes, and are designed as repeated cross-sections, with a sample of around 8,000 representative establishments drawn from the population of registered establishments. The definition of a vacant position in this survey is that it can start within 30 days, recruitment must be from outside the firm, and full-time, part-time, permanent, temporary, and short-term job openings are included. The survey arguably provides the most reliable data on the aggregate level of vacancies, and includes the number of vacant positions and establishment identifiers. Since this survey starts only in 2010, which is after the period of broadband expansions in Norway, we only use data from this survey for comparisons and to perform a quality assessment of the public employment agency's register of job vacancies (discussed above and in Section B.2).

Survey of Establishments' Recruitment Behavior. Since 1994, the public employment agency has conducted annual surveys of establishments' recruitment efforts. These surveys are used for various policy analyses and in forecasts of labor market trends across local labor markets and industries, and are designed as repeated cross-sections, with a sample of around 20,000 representative establishments drawn from the population of registered establishments. The data include establishment-level information on expected changes in labor demand, planned vacancy posting and questions about the recruitment challenges an establishment is facing. For our analysis, we received extracts of the surveys for the years 1996 to 2014 with responses from around 14,000 establishments in each year – where an average response rate of 70 percent. The data includes establishment and firm identifiers allowing us to link the survey information to the various other firm-level data sources mentioned above.

Survey of Media Use. Since 1991, Statistics Norway has surveyed individuals' media use annually. These surveys are designed as repeated cross-sections, with representative survey samples of around 2,000-3,000 individuals drawn from the population aged 7-79. Each individual is interviewed about a wide array of topics related to media use behavior, including questions on whether the individual had access to dial-up or

broadband internet, used the internet for work-related purposes, and a number of other measures of online search activities. We received anonymized extracts from these survey data sets from Statistics Norway for years 2000 to 2013, with an average response rate of 65 percent over these years. Even though these data sets are anonymized, identifiers for municipality of residence and time of survey were retained, which allows us to use this information in our research design.

Quarterly Labor Force Survey. Since 1972, Statistics Norway has published quarterly labor force surveys. These surveys are primarily cross-sectional (with a rotational panel design with interviews across up to eight consecutive quarters) covering around 20,000 individual respondents in each quarter drawn from the working-age population of individuals aged 15-74. Each individual is interviewed about a wide array of topics related to labor market, including questions on time spent on job search for working individuals, which allowed us to construct indicators for on-the-job search. We received extracts from these surveys from Statistics Norway from 1996 to 2016, which we were allowed to link to our worker-level analytical samples.

B.2 Data Quality: Vacancies

The Register of Job Vacancies is a data set covering years 2002 to 2018 and is based on employer-filled reports of vacant positions sent to the public employment agency. The quality of this vacancy register would naturally depend on the degree to which firms comply with the reporting requirements. To assess the quality and representatives of the public employment agency's vacancy data, we first (i) aggregate vacancies using ad-level data, to occupation, municipality and month in which job vacancy was created, (ii) create stocks of vacancy stocks based on the duration of each vacancy, and next, (iii) compare the vacancy stocks to two alternative sources of vacancy data.

First, we use a representative sample performed by Statistics Norway, which includes vacancies for 8,000 establishments, i.e., almost 5 percent of all establishments (see details in Section B.1). Next, we also collected vacancy data from the largest Norwegian online job-board (Finn.no), which has had an online market share at around 95 percent (Anand & Hood, 2007). Unfortunately, the online job board data does not include establishment identifies for all online vacancy postings, limiting the scope for a direct use of this data set in our main analysis.

Figure B1 displays the aggregate trends of quarterly vacancy stocks, starting in 2010, the first year the survey data are available. The stock of vacancies is divided by the labor force, comprising every worker aged between 25 to 66 who is either employed or unemployed but actively looking for work. The time pattern shows a clear seasonality in the vacancy postings: the survey shows a distinct peak in the second quarter, while the two other sources have peaks that vary between the first two quarters of the year. Importantly, the graph shows that the three sources track each other well over time, and that the relative differences between the sources are quite stable over time.[40]

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[40]The aggregate numbers from NAV and Finn are approximately 20 percent below the survey at their respective peaks.

Figure B1: Trends in Vacancy Stocks Across Three Sources of Data on Vacancies.
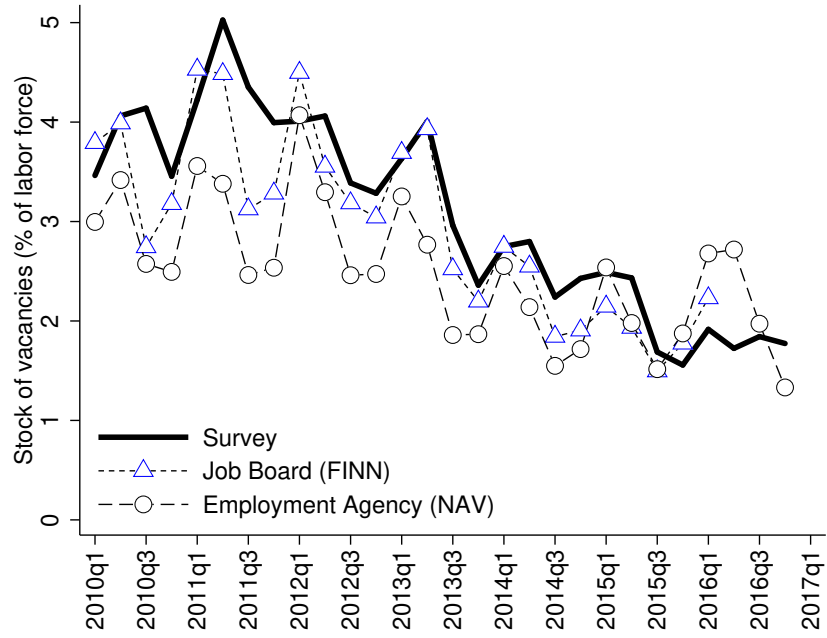
Notes: This figure shows the aggregate trend of vacancy rates using three data sources on vacant jobs. The total number of vacancies is divided by the labor force.

C   Appendix: Search and Matching Models

This appendix section presents the implications of improved matching efficiency and lower recruitment costs in the basic search and matching framework as presented in Pissarides (2000). We also provide Python codes that numerically solve the models on this website.

C.1   Basic Model

We begin with the model from Chapter 1 in Pissarides, and summarize it briefly here. Agents maximize the present value of income discounted at rate r. An individual i receives unemployment benefits b_t if he is unemployed at time t, and earns labor income w_{it} from a firm j if he is employed. Firms maximize the present value of profits. Each firm combines labor with their technology, so that a unit of labor is transformed into p_t units of output. Firms face a recruitment cost per period a job is unfilled, which varies with the economic circumstance $p_t c_t$.

As individuals search for firms with vacant jobs, and firms with vacant jobs search for qualified workers, positive levels of both unemployment and vacancies coexist without immediate hiring. The hiring process is proxied by a matching function that produces hires using job vacancies and job seekers as inputs,

$$H_t = A_t v_t^{\alpha} u_t^{1-\alpha} \tag{C1}$$

where u_t is the number of job seekers, v_t is the number of vacant jobs, and A_t is the efficiency of the search and matching process. We assume that the matching function has a Cobb-Douglas structure with constant returns to scale. The parameter α captures the elasticity of the matching function with respect to vacancies. The probability that a given worker is matched with a vacant job is then given by $A_t q^w(\theta_t) = A_t (v_t/u_t)^{\alpha}$, where $\theta_t = v_t/u_t$ is the labor market tightness from the worker's perspetive. The probability to find a job is scaled by the efficiency parameter A_t.

The terms of the employment contract are determined by a Nash bargaining solution (see pages 15-18 in Pissarides, 2000). The outside option of the worker is the value of unemployment, U, and the threat point of the firm is the value of a vacant job V. The bargaining power is assumed constant, and equal to η for workers and $1 - \eta$ for firms. Given this assumption, the Nash bargaining solution assigns a fraction η of the match surplus to the worker. The match surplus is the value of an occupied job J, and the value of employment for a worker W, net of the the firm and worker's outside options.

Steady State and Value Functions

As all workers face the same constant unemployment risk λ, the change in the level of unemployment from one period to the next can then be described by the flow into unemployment $\lambda(1-u)$, and the flow out of unemployment $Aq^w(\theta)u$. In a steady state, the two flows are equal, which gives

$$u = \frac{\lambda}{\lambda + Aq^w(\theta)}. \tag{C2}$$

This equation characterizes the Beveridge curve; that is, the unemployment and vacancies that equalize the flow in and flow out of unemployment. The Beveridge curve is downward-sloping and convex to the origin, and yields values of unemployment that are consistent with given values of unemployment risk, matching technology and labor market tightness.

Figure C1: Comparative Statics: Improvements in Matching Technology.

(a) Wages and Labor Market Tightness   (b) Vacancies and Unemployment Rates
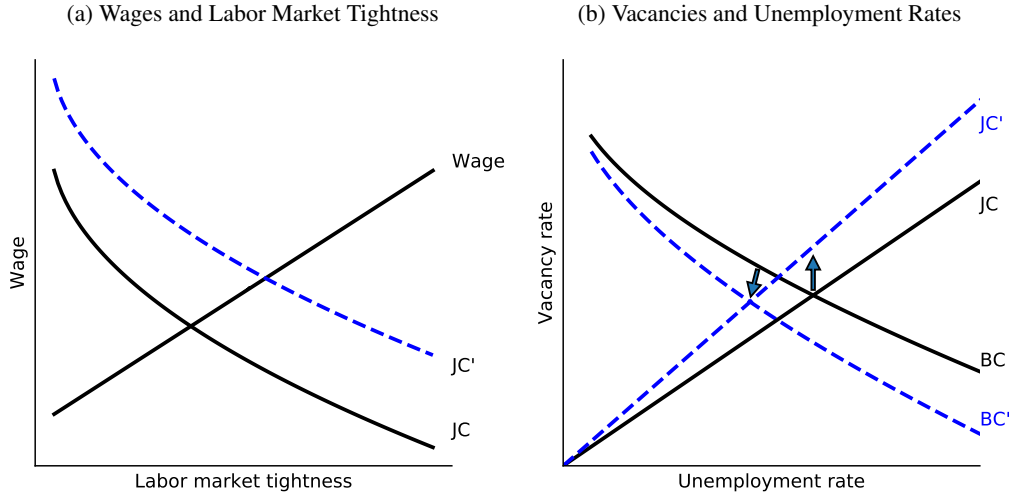
Notes: Figure C1a illustrates the shift in the Job Creation curve (JC to JC') from Equation (C3) and the upward sloping wage curve. Figure C1b illustrates the shift in the Job Creation curve (JC to JC') and Beveridge curve (BC to BC') from Equation (D1).

In a steady state equilibrium, unemployed workers search for a job while receiving unemployment benefits (which include non-pecuniary benefits such as leisure) and an expected return from job search. The net flow value of search is $rU = b + A\theta q(\theta)(W - U)$, and the flow value of accepting an offer is $rW = w + \lambda(U - W)$. Firms receive a flow value of profits for active jobs according to $rJ = p - w - \lambda J$. The value of a vacancy equals $rV = -pc + Aq(\theta)(J - V)$, where $Aq(\theta) = A(u/v)^{1-\alpha} = A\theta q^w(\theta)$ is the job-filling rate. In profit-maximizing equilibrium, the expected value of a vacancy is driven to zero by free entry of new vacancies. Combining the zero profit condition with the value of a filled job gives the job creation condition, or demand curve

$$p - w - \frac{(r+\lambda)pc}{Aq(\theta)} = 0. \tag{C3}$$

The job creation curve is upward-sloping in the vacancy-unemployment space (i.e., JC in Figure C1b), and downward-sloping in the wage and labor market tightness space (i.e., JC in Figure C1a). The last equilibrium condition concerns wage setting, and is given by

$$w = (1 - \eta)b + \eta p(1 + c\theta). \tag{C4}$$

The wage is increasing in labor market tightness, and job creation is falling in labor market tightness.

The equilibrium wage is uniquely determined by their intersection in Figure C1a. Similarly, the steady state unemployment and vacancy rates are illustrated by the downward-sloping Beveridge curve denoted BC in Figure C1b. Here, the job creation curve is the solid upward-sloping line, and the intersection of the JC- and BC-line determines the equilibrium unemployment and vacancy rates.

C.1.1   Improvements in the Matching Technology

We now turn to the model predictions from a shift towards online job search. We think of online search and recruitment as an increase in the matching efficiency A – which may operate through improved access to information about vacancies for workers, and firms ability to announce their jobs to a larger pool of applicants. An improvement in the matching efficiency leads to higher filling rate and lower average costs of recruitment. This induces firms to post more vacancies. This follows directly from the labor demand equation C3, and leads to a counter-clockwise shift of the job creation curve in Figure C1b.

Tightness (θ): We begin by showing that the vacancy-unemployment ratio increases. Combining the demand curve $p - w - \frac{(r+\lambda)pc}{Aq(\theta)} = 0$, and the wage equation $w = (1-\eta)b + \eta p(1+c\theta)$, we have $(\frac{(r+\lambda)}{Aq(\theta)} + \eta\theta)pc = (p-b)(1-\eta)$. The right hand side is unaffected by a change in A. This means that the vacancy-unemployment ratio must go up in the new equilibrium to maintain equality.

Wage (w): Faster job matching increases the threat point of the unemployed worker. This leads to a higher equilibrium wage due to the bargaining protocol, and the assumption that the bargaining weights are unaffected. Since the tightness goes up, the wage must also go up. The argument can also be made graphically: the wage curve is increasing in labor market tightness, and the job creation is falling in labor market tightness. Faster filling rates leads to an outward shift in the job creation curve, represented by the shift from JC to JC' in Figure C1a. The new equilibrium wage can be traced along the wage curve, which is unambiguously higher. The new equilibrium unemployment rate is determined by the intersection of the JC' and BC' line.

Vacancy Duration (D_v): Because the filling rate is increasing in A, but decreasing in θ, we infer from the job creation curve that since wages go up, the vacancy filling rate must go up, $Aq(\theta)\uparrow$. This leads to a reduction in the vacancy duration $\mathbb{E}[D_v]\downarrow= 1/[Aq(\theta)\uparrow]$.

Job Finding Rate ($Aq^w(\theta)$): Because firms fill a vacancy faster, firms respond by posting more vacancies due to the free entry condition. Then workers are more likely to find a job both because of the increase in match efficiency and because this increase induces more firms to search per unemployed worker: $A\uparrow (\theta\uparrow)^{\alpha}$.

C.1.2   Lower Costs of Recruiting

We now turn to the model predictions from a reduction in the hiring costs. A reduction in the cost induces firms to post more vacancies. A reduction in the cost induces firms to post more vacancies. This follows directly from the labor demand equation C3.

Tightness (θ): We have $(\frac{(r+\lambda)}{Aq(\theta)} + \eta\theta)pc = (p-b)(1-\eta)$, where the right hand side is unchanged. This means that the fall in c must be offset by an increase in θ. This is true since we know that $\partial q(\theta)/\partial\theta = \partial\theta^{\alpha-1}/\partial\theta < 0$.

Wage (w): Using the intersection between the job creation and wage equation, we can rewrite it so that $\theta cq(\theta) = c\theta^{\alpha} = K$ where $K = (p-b)(1-\eta)/p\eta - (r+\lambda)/\eta$ is unaffected by assumption. As $c \downarrow$ and $\alpha < 1$, then θ must increase more than c for the equality to hold. Hence, $c\theta \uparrow$, which means that $w \uparrow$.

Vacancy Duration (D_v): The filling rate goes down from an increase in θ. This leads to a increase in the expected vacancy duration $\mathbb{E}[D_v] \uparrow = 1/[Aq(\theta) \downarrow]$.

Job Finding Rate ($Aq^w(\theta)$): Job finding rates go up because there are more vacancies per job seeker, $\partial \theta^{\alpha}/\partial \theta > 0$.

C.2 Endogenous Recruitment Intensity

In this subsection, we extend the model to allow firms to endogenously choose recruitment intensity, see Chapter 5 in Pissarides (2000) for details. In the basic model, the cost of vacancy is outside of the firm's control. In this extension, firms affect the cost by choosing the amount of advertising for job j: $c = c(a_j)$, where $c'(a_j) > 0$ and $c''(a_j) > 0$. By choosing the level of advertising, the firm affects the vacancy filling rate, now written as $q(\theta) = \frac{a_j}{av}(av)^{\alpha}u^{1-\alpha}$. The average advertisement in the economy is a, and the firm chooses the level of advertising to maximize the value of the vacant job j. The value of a vacancy is $rV_j = -pc(a_j) + Aq(a_j;\theta)(J - V_j)$.

C.2.1 Improvements in the Matching Technology

Optimal advertising is given by the first order condition, where the marginal gain is equal to the marginal cost: $\frac{\partial Aq(a_j,\theta)}{\partial a_j}(J - V_j) = pc'(a_j)$. The change in the matching following a change in advertisement equals $\frac{\partial Aq(a_j;\theta)}{\partial a_j} = \frac{Aq(a_j,\theta)}{a}$. Then, if we set the value of a vacancy equal to zero (free entry condition) we have that $pc(a_j)/Aq(a_j;\theta) = J$. Combined with the first order condition, $J = pc'(a_j)/\frac{Aq(a_j,\theta)}{a}$ we get $c'(a_j)a/c(a_j) = 1$. This means that the elasticity of the cost of advertising is constant. This implies that the expected effects of an increase in the matching efficiency is qualitatively the same as in the basic model.

C.2.2 Lower Costs of Recruiting

Under the assumption that $c'(a) > 0$, lowering the cost of advertising implies that the optimal level goes down $a \downarrow$ in order to keep $c'(a)a \downarrow = c(a) \downarrow$.

Tightness (θ): We have $(\frac{(r+\lambda)}{A\theta^{\alpha-1}} + \eta\theta) = (p-b)(1-\eta)/pc(a)$, where the left hand side (LHS) goes up because $c(a) \downarrow$. Therefore, the right-hand side, $\frac{(r+\lambda)}{A}\theta^{1-\alpha} + \eta\theta$ goes up through $\theta \uparrow$.

Wage (w): The wage equation is $w = (1-\eta)b + \eta p(1 + c(a)\theta)$. To determine the wage effect, we need to establish the direction of $c(a)\theta$. In this extension, we can combine the wage equation with the demand curve to find $\frac{p(r+\lambda)c(a)}{Aa^{\alpha}\theta^{1-\alpha}} + p\eta c(a)\theta = (p-b)(1-\eta)$. Rearranging this slightly, and substituting $\gamma = c(a)\theta$ we find $\gamma^{1-\alpha}(\frac{c(a)}{a})^{\alpha}\frac{p(r+\lambda)}{A} + \gamma p\eta = (p-b)(1-\eta)$. As with the baseline model the right hand side of this equation is constant in equilibrium. Further, we know that $c'(a) = \frac{c(a)}{a}$ by the argument in C.2.1, and so $a \downarrow$ implies $c'(a) \downarrow$ and thus $(\frac{c(a)}{a})^{\alpha}$ must decease. Therefore, if γ is constant, then the left hand side of our earlier expression is decreasing, which cannot hold in equilibrium, and so, because the left hand side is increasing in γ, it must be that $\gamma = c(a)\theta$ increases in equilibrium. We then know that wages must increase in equilibrium.

Intuitively, this must be the case, because the firms' reaction to cut search effort due to a cost decrease in searching is a second order effect, which should never dominate the first order cost decrease, and so we are left with a muted version of the baseline model, where firms reduction in search effort works against the initial decrease in search costs to cause a less dramatic equilibrium shift.

Vacancy Duration (D_v): The vacancy filling rate $q(\theta) = Aa^\alpha \theta^{\alpha-1}$ goes down both from $\theta \uparrow$ and from $a \downarrow$. This leads to a increase in the expected vacancy duration $\mathbb{E}[D_v] \uparrow = 1/\left[A(a)^\alpha \theta^{\alpha-1} \downarrow\right]$.

Job Finding Rate ($Aq^w(\theta)$): To establish the effect on job finding rates, we need to determine the net effect of $a \downarrow$ and $\theta \uparrow$ on $q^w(\theta, a) = a^\alpha \theta^\alpha$. The solution of the Nash bargaining assigns a fraction η of the total surplus to a worker: $W_i - U = \eta(J_i - V + W_i - U)$. This expression can be converted into a wage equation $w_i = rU + \eta(p - U)$.[41] Since $w \uparrow$ then $U \uparrow$, and $\frac{w}{U} \downarrow = r + \eta(p/U \uparrow -1)$. We next use the flow values of employment and unemployment to write the permanent income of unemployed as $rU = \frac{(r+\lambda)b + Aa^\alpha \theta^\alpha w}{r+\lambda + Aa^\alpha \theta^\alpha}$. Dividing by w gives $r\frac{U}{w} \uparrow = \frac{(r+\lambda)b/w + Aa^\alpha \theta^\alpha}{r+\lambda + Aa^\alpha \theta^\alpha}$. Because the value of unemployment is assumed to be less than the equilibrium wage (else the model would be trivial and workers would reject all job offers) b/w is less than 1, and $b/w \downarrow$, then $Aa^\alpha \theta^\alpha \uparrow$.

C.3 Endogenous Job Destruction and On-the-Job Search

In this subsection, we extend the model to allow firms and workers to endogenously choose to destroy an existing match and for workers to search for a new job while working, see Chapter 4.2 in Pissarides (2000) for details. New matches begin with a fixed match efficiency equal to the highest possible level, which we will normalize to 1. Firm-worker matched pairs then draw new match efficiency Q distributed according to a cumulative distribution function $G(Q)$ at a rate λ. Finally, workers will also be given the option to search while working in an identical manner to unemployed agents. Firms can observe if workers search and, in equilibrium, will pay a searching worker less than a non-searching working because the searching worker increases the separation probability. Given this set-up, two cutoff rules describe the optimal decision rules that both workers and firms agree upon. All match quality draws below some threshold R will result in the firm and worker agreeing to dissolve the match. Match qualities between R and a second cutoff S will result in a match where workers continue to search for other employment. Finally, match qualities between S and 1 will result in a match where workers choose not to search.

C.3.1 Improvements in the Matching Technology

Tightness (θ): In equilibrium, the job destruction condition can be written as $R + \lambda \Omega(R, \theta) = \frac{b+\sigma}{p}$, where $\Omega(R, \theta) = \frac{1}{r+\lambda+A\theta^\alpha} \int_R^S (s - R)dG(s) + \frac{1}{r+\lambda} \int_s^1 (s - R)dG(s) - \frac{\lambda(1-\eta)p}{r+\lambda}\left(\frac{\eta}{1-\eta}c\theta - \frac{\sigma}{p}\right)(1 - G(S))$. Intuitively, this relation determines the reservation match efficiency R in equilibrium by setting the net profit R from this match plus the option value of a match to the firm $\Omega(R, \theta)$ equal to the opportunity cost of holding a job with on-the-job search for the worker. Pissarides (2000) demonstrates that $\frac{\partial R + \lambda \Omega(R,\theta)}{\partial R} > 0$ and $\frac{\partial \Omega}{\partial \theta} < 0$. Further, it is easy to see that $\frac{\partial \Omega}{\partial A} < 0$. Then, the right hand side of $R + \lambda \Omega(R, \theta) = \frac{b+\sigma}{p}$ remains constant, and so as A increases either R must increase or θ must decrease (or both). Further, the job creation condition

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[41]See page 16 in Pissarides (2000).

for this model implies $(1-\eta)\frac{1-R}{r+\lambda} = \frac{c}{A\theta^{\alpha-1}} + \frac{\eta c\theta - (1-\eta)\frac{\sigma}{p}}{r+\lambda}$. Then as A increases, the right hand side of this equality decreases. Therefore, either θ must increase or R must increase (or both). Together, these two sets of conditions imply that the reservation match efficiency R must increase, regardless of the direction θ moves.

We proceed by substituting the reservation efficiency optimality condition for workers $rW^s(R) = rU$ and the value function for unemployed workers $rU = b + A\theta^{\alpha}[W^{ns}(1) - U]$ into the value function for a worker with the cutoff match efficiency $rW^s(R) = w^s(R) - \sigma + \lambda \int_R^1 W(s)dG(s) + \lambda G(R)U - \lambda W^s(R) + A\theta^{\alpha}[W^{ns}(1) - W^s(R)]$, where $W(x) = max(W^{ns}(x), W^s(X))$, $W^s(x)$ is the value function for an employed worker who searches on the job with match efficiency x, and $W^{ns}(x)$ is the value function for an employed worker who doesn't search on the job with match efficiency x. After some rearrangement, we find $U\lambda[1 - G(R)] = w^s(R) - \sigma - b + \lambda \int_R^1 W(s)dG(s)$. Substituting the Nash sharing rule for new jobs $rU = b + \frac{\eta}{1-\eta}pc\theta$ and the equilibrium wage equation for searching workers $w^s(x) = (1-\eta)(b+\sigma) + \eta px$ into our equation, we find $\lambda(b + \frac{\eta}{1-\eta}pc\theta) = \frac{r\eta(pR-b-\sigma)}{1-G(R)} + \frac{r\lambda \int_R^1 W(s)dG(s)}{1-G(R)} = \frac{r\eta(pR-b-\sigma)}{1-G(R)} + r\lambda\mathbb{E}[W(s)|s \geq R]$. Then, since both A and R increasing imply that the far right hand side of this equality increases. Then, it must be that θ increases to maintain our derived equality.

Job Finding Rate ($q^w(\theta)$): The job finding rate is $A\theta^{\alpha}$, so an increase in θ and A increases the job finding rate.

Wage (w). The discussion of wages will be split into two parts. First, wages for workers who search for a job in equilibrium are equal to $w^s(x) = (1-\eta)(b+\sigma) + \eta px$. These wages are unchanged in the new equilibrium because the searching worker's wage is independent of outside market conditions.

Next, wages for workers who do not search in equilibrium are equal to $w^{ns}(x) = (1-\eta)b + \eta p(x+c\theta)$. We have previously shown that θ increases in this model if A increases, and so it must be that wages for non-searching workers increase. Therefore, the average wage of all workers increases after A increases.

Vacancy Duration (D_v): Rearranging the job creation condition $(1-\eta)\frac{1-R}{r+\lambda} = \frac{c}{A\theta^{\alpha-1}} + \frac{\eta c\theta - (1-\eta)\frac{\sigma}{p}}{r+\lambda}$ slightly we find $(1-\eta)(1-R) - \eta c\theta = \frac{c(r+\lambda)}{A\theta^{\alpha-1}} + (1-\eta)\frac{\sigma}{p}$. The right hand side of this expression decreases as both R and θ increase. Therefore, because the job filling rate $A\theta^{\alpha-1}$ is the only endogenous term on the right hand side, $A\theta^{\alpha-1}$ must increase to maintain equality in equilibrium. Then if the job filling rate increases as A increases, the vacancy duration must decrease.

Tenure ($1/E[\mathbb{P}(Leave\,Job)]$): First, the expected tenure of a worker is the inverse of the expected probability of separation, which in turn can be written as the weighted average of the probability of leaving job conditional on search behavior. If we normalize the mass of workers to 1, let the mass of on-the-job searchers be e, and the mass of unemployed workers be u, then we find that $\mathbb{E}[\mathbb{P}(Leave\,Job)] = \frac{e}{1-u}(\lambda G(R) + A\theta^{\alpha}) + \frac{1-u-e}{1-u}(\lambda G(R))$. We have shown that the reservation match quality R and the labor market tightness θ increase as A increases. Therefore, both $G(R)$ and $A\theta^{\alpha}$ are increasing as A increases and the expected probability of leaving a job increases, resulting in a decreasing average tenure.

Separation Rates in Transition: We have already shown that the reservation match quality R increases after an increase in A. Then, as an economy transitions from a low A steady state to a high A steady state, existing matches that have a match quality within the region $(Q_r^{lowA}, Q_r^{highA})$ will no longer be optimal for both firms and workers, given their new outside options, and so agents will choose to terminate the match

earlier than the stochastic job destruction rate would suggest. Therefore, the model predicts higher separation rates in transition to a high match efficiency steady state.

C.3.2 Lower Costs of Recruiting

Tightness. Following the discussion from Section C.3.1, we find that $\frac{\partial \Omega}{\partial c} > 0$, $\frac{\partial \Omega}{\partial \theta} < 0$, $\frac{\partial R + \lambda \Omega(R,\theta)}{\partial R} > 0$, and $R + \lambda \Omega(R,\theta) = \frac{b+\sigma}{p}$ together imply that either R decreases, θ increases, or both are true. Further, $(1 - \eta)\frac{1-R}{r+\lambda} = \frac{c}{A\theta^{\alpha-1}} + \frac{\eta c\theta - (1-\eta)\frac{\sigma}{p}}{r+\lambda}$ directly implies that either R or θ, or both must increase. Then, we can conclude that regardless the effect on R, θ must increase. Further, by defining an auxiliary variable $\gamma = c\theta$ we can conclude that either R decreases, γ increases, or both are true from $R + \lambda \Omega(R,\theta) = \frac{b+\sigma}{p}$ and either R or γ, or both must increase from $(1 - \eta)\frac{1-R}{r+\lambda} = \frac{\gamma^{1-\alpha}c^{\alpha}}{A} + \frac{\eta\gamma - (1-\eta)\frac{\sigma}{p}}{r+\lambda}$. Therefore, we can further conclude that $c\theta$ increases if c decreases.

Vacancy Duration (D_v): Vacancy duration is the inverse of job filling rate, $A\theta^{\alpha-1}$. Then, an increase in θ implies the job filling rate decreases and the vacancy duration increases.

Job Finding Rate ($q^w(\theta)$): The job finding rate is $A\theta^{\alpha}$, so an increase in θ increases the job finding rate.

Wage (w): The discussion of wages will be split into two parts. First, wages for workers who search for a job in equilibrium are equal to $w^s(x) = (1 - \eta)(b + \sigma) + \eta px$. These wages are unchanged in the new equilibrium because the searching worker's wage is independent of outside market conditions.

Next, wages for workers who do not search in equilibrium are equal to $w^{ns}(x) = (1 - \eta)b + \eta p(x + c\theta)$. We have previously shown that $c\theta$ increases in this model if c decreases, and so it must be that wages for non-searching workers increase if c decreases. Therefore, the average wage of all workers increases after c decreases.

Tenure ($1/E[\mathbb{P}(Leave\,Job)]$): First, the expected tenure of a worker is the inverse of the expected probability of separation, which in turn can be written as the weighted average of the probability of leaving job conditional on search behavior. If we normalize the mass of workers to 1, let the mass of on-the-job searchers be e, and the mass of unemployed workers be u, then we find that $E[\mathbb{P}(Leave\,Job)] = \frac{e}{1-u}(\lambda G(R) + A\theta^{\alpha}) + \frac{1-u-e}{1-u}(\lambda G(R))$. Below we show that the reservation match quality R increases as c decreases. Therefore, both $G(R)$ and $A\theta^{\alpha}$ are increasing as c decreases and the expected probability of leaving a job increases, leading to a fall in the average tenure.

Separation Rates in Transition: The separation rates in the transition between steady states are a function of the reservation match quality, here denoted R. The job destruction condition implies the value to firms of a match of reservation quality is $J^s(R) = 0$ in equilibrium, where $J^s(x)$ is the value to a firm of a match of quality x and whose worker searches on the job. Expanding $J^s(R)$ we find $0 = pR - w^s(R) + \lambda \int_R^1 max(J^s(s), J^{ns}(s))dG(s)$. The value of a non-searching worker must decrease for all match qualities because wages for matched workers go up. Then the value of the expected match conditional on drawing a new match quality must decrease for the firm. As discussed in the wage prediction, the wage paid to searching workers does not change if c decreases, and so $w^s(R)$ is constant across equilibrium. Therefore, the right hand side of this equation decreases if c decreases and R remains constant, implying that the reservation match quality increases if c decreases. Then, as an economy transitions from a high c steady state to a low

c steady state, existing matches that have a match quality within the region (R^{highc}, R^{lowc}) will no longer be optimal for both firms and workers, given their new outside options, and so agents will choose to terminate the match earlier than the stochastic job destruction rate would suggest. Therefore, the model predicts higher separation rates in transition to a high match efficiency steady state.

D Appendix: Quantifying the Steady State Unemployment Rate

For the regional analysis presented in Section 7, we consider local labor markets, indexed by r, each with $u_{r,t}$ job seekers and $v_{r,t}$ vacant jobs in year t. Under the same set of assumptions and adopting the same notation as in Section C.1, we can derive the regional flow into unemployment as $\lambda_{r,t}(1-u_{r,t})$, the regional flow out of unemployment as $f_{r,t} = A_{r,t}(v_{r,t}/u_{r,t})^\alpha$. We now let the regional unemployment risk $\lambda_{r,t}$ depend on the regional availability rate of broadband $z_{r,t}$, i.e., $\lambda_{r,t} = \tilde{\lambda}e^{\delta_\lambda z_{r,t}}$. Similarly, we let the regional matching efficiency $A_{r,t} = \tilde{A}_t e^{\delta_f z_{r,t}} e^{a_{r,t}}$, where $\tilde{A}_t$ is an aggregate time-varying component, $e^{\delta_f z_{r,t}}$ is a component that varies by the regional broadband availability rate and $e^{a_{r,t}}$ is an unobserved regional time-varying component. We further let the regional stock of vacancies be $v_{r,t} = \tilde{v}_t e^{\delta_v z_{r,t}}$. Equipped with these expressions and equating the flows in and out of unemployment, we determine the steady state rate of unemployment for any given value of the broadband availability rate $z_{r,t} = z$ and at $a_{r,t} = 0$ as follows:

$$u = \frac{\tilde{\lambda}e^{\delta_\lambda z}}{\tilde{\lambda}e^{\delta_\lambda z} + \tilde{A}_t e^{\delta_f z}(\tilde{v}_t e^{\delta_v z}/u)^\alpha}, \tag{D1}$$

which corresponds to the Beveridge curve – that is, values of unemployment that are consistent with given values of unemployment risk, matching technology and labor market tightness. The parameter δ_λ gives how the risk of unemployment varies with broadband availability, δ_f gives how job finding rates depend on broadband availability, and δ_v gives how vacancy rates depend on broadband availability. In this derivation, we assume that the matching function has a constant returns to scale Cobb-Douglas technology and, for simplicity, the elasticity of hires with respect to vacancies α is assumed to be independent of broadband availability.

Estimating the Elasticity of the Matching Function.

Estimating α empirically is challenging due to the equilibrium responses to matching efficiency shocks: An unobserved matching efficiency shock affects both hires and vacancies. We address this challenge by following Borowczyk-Martins *et al.* (2013), who impose an error structure and use lagged values of the dependent variable as instruments for labor market tightness. We use aggregated data at the monthly level from 2001 to 2016, and employ the GMM procedure proposed by Borowczyk-Martins *et al.* (2013). The GMM procedure involves deciding on the number of autoregressive and moving error parts.

Treating $\tilde{A}_t$ as an unobserved error term, the estimating regression equation, in logs, is

$$\ln f_t = \kappa + \alpha \ln(v_t/u_t) + \tau_t + \varepsilon_t \tag{D2}$$

where τ_t are month dummies, and f_t is the aggregate job-finding rate. We assume that ε_t follows an ARMA(p,q) process

$$\varepsilon_t = \sum_{l=1}^{p} \rho_l \varepsilon_{t-l} + \sum_{l=1}^{q} \sigma_l \omega_t \tag{D3}$$

where ω_t a serially uncorrelated shock. Using (D3) we can rewrite (D2) as

$$\ln f_t = \nu + \sum_{l=1}^{p} \rho_l \ln f_{t-l} + \alpha \ln(v_t/u_t) - \sum_{l=1}^{p} \xi_l \ln(v_{t-1}/u_{t-1}) + \sum_{l=1}^{p} \rho_l \varepsilon_{t-l} + \sum_{l=1}^{q} \sigma_l \omega_t \tag{D4}$$

with the restrictions

$$\nu = \left(1 - \sum_{l=1}^{p} \rho_l\right) \kappa \text{ and } \forall l : \xi_l = \alpha \rho_l \tag{D5}$$

This implies that lagged values (beyond order $l = q+1$) of $(\ln f_{t-l}, \ln(v_{t-1}/u_{t-1}))$ are valid instruments. Following Borowczyk-Martins *et al.* (2013), we estimate an over-identified version of (D4), for different values for (p,q) over a grid $(p,q) \in [1,...,\bar{p}] \times [1,...,\bar{q}]$. We first select the highest p for which we get significant estimates of ρ_l up to order l. Table D1 reports the estimation results over the grid $(p,q) \in [1,...,2] \times [0,...,10]$. We follow the identification protocol of Borowczyk-Martins *et al.* (2013), and observe that for $p > 1$ the autocorrelation coefficients ρ_l are no longer statistically significant. As estimates of α seem stable around 0.35, our preferred estimate of the elasticity is 0.35. This estimate suggests that a 10 percent increase in vacancies increases hires by 3.5 percent.

Table D1: Matching Function Estimates Using GMM.

p	q	sd(κ)	κ	sd(α)	α	sd(ρ_1)	ρ_1	sd(ρ_2)	ρ_2
1	0	0.061	-2.139	0.041	0.372	0.072	0.406	.	.
1	1	0.179	-2.194	0.137	0.329	0.217	1.211	.	.
1	2	0.158	-2.154	0.120	0.353	0.191	1.248	.	.
1	3	0.147	-2.123	0.113	0.397	0.128	0.750	.	.
1	4	0.389	-2.123	0.294	0.361	0.200	1.080	.	.
1	5	0.158	-2.165	0.122	0.344	0.216	1.256	.	.
1	6	0.145	-2.115	0.113	0.401	0.140	0.720	.	.
1	7	0.458	-2.094	0.331	0.389	0.234	1.072	.	.
1	8	0.155	-2.154	0.120	0.354	0.236	1.290	.	.
1	9	0.118	-2.133	0.091	0.382	0.142	0.624	.	.
1	10	0.193	-2.157	0.151	0.349	0.275	1.225	.	.
2	0	0.070	-2.152	0.049	0.366	0.097	0.323	0.188	0.224
2	1	0.196	-2.189	0.149	0.345	0.441	0.473	0.178	0.346
2	2	0.231	-2.145	0.177	0.357	0.626	1.349	0.774	-0.172
2	3	0.208	-2.090	0.174	0.433	0.605	0.342	0.707	0.490
2	4	1.735	-1.397	1.450	1.087	0.450	0.693	0.431	0.274
2	5	0.133	-2.140	0.103	0.361	2.123	-0.245	2.209	1.541
2	6	0.157	-2.121	0.115	0.398	0.857	0.964	1.043	-0.293
2	7	1.093	-2.727	0.838	-0.063	0.401	0.794	0.376	0.172
2	8	0.101	-2.144	0.073	0.367	0.644	0.371	0.673	0.995
2	9	0.549	-1.776	0.408	0.713	0.365	-0.007	0.377	0.917
2	10	0.425	-2.642	0.324	-0.026	0.293	0.434	0.264	0.511

Notes: Included instruments are lags of $\ln\theta_{t-l}$ for $l = q+1$ to $l = q+p+1$ and lags of $\ln f_{t-l}$ for $l = q+1$.

Quantifying the Steady State Unemployment Rate.

We proceed in four steps: First, we take the log of the job finding rate $f_{r,t}$ in region r and year t, that is the log of $\tilde{A}e^{\delta_f z_{r,t}}(v_{r,t}/u_{r,t})^\alpha$. We then move the vacancy-unemployment ratio to the left-hand-side, and regress $\ln(f_{r,t}) - 0.35 \cdot \ln(v_{r,t}/u_{r,t})$ on a constant and $z_{r,t}$ to identify the parameters δ_f and $\tilde{A}$ using OLS.[42] Second, we tune the separation rate $\tilde{\lambda}$ so that the steady state unemployment rate in 2012 is equal to the observed unemployment rate. This amounts to multiplying the observed flow of new full-time job seekers with 0.55, and subtracting the average labor force withdrawal rate. This gives us an unemployment rate of u_{2012}=4.05%. Third, we obtain the counterfactual flows in and out of unemployment. We infer the counterfactual separation rate by multiplying $\tilde{\lambda}$ by one minus the estimated impact from Table 11. Relative to its mean, this reduction corresponds to approximately 10 percent. The counterfactual vacancy rate is unaffected; that is, $\delta_v = 0$, so that the counterfactual job finding rate is $\tilde{A}_{2012}e^0(v_{2012}/u)^\alpha$. Finally, we numerically solve for the unemployment rate u that solves equation (D1). We find that the steady state unemployment rate is 4.98%. If we ignore the impact on separation rate, the steady state unemployment rate would be 4.34%.

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[42]Our estimate of δ_f is .048 (se =.026).