

Costly Commuting and the Job Ladder

[preliminary]

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Abstract

I study the interaction between commuting and employment in the data and within a spatial model of on-the-job search. I document the correlation between commuting time, job-to-job transitions, and earnings empirically. The theoretical model features a labor market in which individuals must commute in order to work, explicitly taking into account the distributions across both space and employment states. Wages and rent are jointly determined endogenously, giving rise to sorting across jobs and space. The rate of job-to-job transitions and wage gains within and between jobs depend crucially on the spatial elements of the model. Decomposing wage growth following job-to-job transitions into commuting and productivity changes suggests that dispersion in commuting can reconcile the coexistence of high dispersion in wage growth and a more concentrated productivity distribution.

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1 Introduction

The locations of jobs, and the commute they require workers to endure, affects the functioning of labor markets. The connection between jobs and locations has been known since the island model of [Lucas and Prescott \(1974\)](#). This relationship has been further studied by explicitly modeling the interaction of commuting and labor markets, beginning with [Oswald \(1997\)](#) and [Van Ommeren et al. \(1999\)](#) and more recently in [Rupert and Wasmer \(2012\)](#), [Halket and Vasudev \(2014\)](#), and [Van Vuuren \(2018\)](#), among others. An important weakness in most of the literature is that it has been unable to study the link between residential and job-to-job mobility with endogenous prices in both rental and labor markets. Both of these margins are crucial determinants of location and job decisions, and by studying them jointly this paper argues that commuting costs are an important determinant in the functioning of local economies, in terms of individual and aggregate labor market and spatial outcomes. It is of first-order importance to study the interaction between commuting and job search to meaningfully analyze the labor-market implications of local and national policy.

In this paper I build a spatial on-the-job search model to quantitatively assess these implications. In doing so, this paper contributes to the literature on observed wage dispersion and non-wage amenities. There is a large and growing literature on non-wage amenities that attempts to enrich the framework through which workers climb the job ladder. Differently from most of these papers, which assume that such amenities are valued in the same way by different workers (an early example being [Hwang et al. \(1998\)](#)), I show in the data and build a model in which workers' values of such amenities are observable and heterogeneous. [Sorkin](#) (forthcoming) shows that non-wage aspects of the job have the potential to improve these models' performance in this regard. I focus on a specific non-wage amenity, commuting time, and infer productivity from observed changes in the wage and commute. I show that the model requires a narrower productivity distribution than the previous literature in order to achieve reasonable wage dispersion. Following [Hall and Mueller](#) (forthcoming), I compare workers' reported reservation and accepted wages to provide evidence of the existence of a compensating differential for commuting time.

Empirically, I explore the relationship between commuting, wages, and productivity. Data from the British Household Panel Survey (BHPS) shows that individual earnings and job histories are strongly linked to commuting time. In the aggregate, commuting flows are strongly correlated with both productivity measured in gross value added per worker and in proximity to the center of London's economic activity, the City of London. In addition, average wages and commutes are positively correlated. At the individual level, I show

evidence on compensating differentials both using reservation wage data as discussed in the previous paragraph, as well as by showing that the majority of job-to-job transitions involving wage cuts are accompanied by a simultaneous decrease in commuting time.

Studying the trade-off between wages and commutes in a model of on-the-job search is important for two reasons. First, job-to-job transitions account for a large share of total hires as well as total wage growth (see [Topel and Ward 1992](#)). Models of on-the-job search imply that workers move from lower paying, or less productive, jobs to more productive ones. Additionally, as highlighted by [Hornstein et al. \(2011\)](#), it is essential to model on-the-job search to better match the frictional wage dispersion seen in the data. This distribution is key when one tries to measure the costs of unemployment and life-cycle earnings profiles. Second, the strength of the relationship between job-to-job transitions and productivity is affected by the cost of commuting and housing. When workers trade off wages and the disutility of commuting, changes in both productivity and other aspects of the job interact to determine wage growth. By ignoring such non-wage characteristics, and in particular the commuting costs that this paper will focus on, this will lead to biased estimates of the gains in match quality generated by job-to-job transitions. Most search and matching models of the labor market model job-to-job transitions and wages as functions primarily of match productivity, and struggle to reconcile the long right tail of the observed wage distribution with plausible distributions of productivity ([Postel-Vinay and Robin 2006](#)). I discipline the model to match the wage and commuting distributions and show that the implied productivity distribution is indeed affected by the spatial elements of the model.

Unlike other amenities, such as job security, flexible working hours, or health care, which are fixed or determined by a worker's contract, commute time can vary for identical workers, introducing heterogeneity into workers' preferences across jobs. Because workers do not all live in the same place, they do not share a common ranking of jobs. Therefore, identical workers may value the same job differently simply because of where they live. Typically, models with heterogeneous values for non-wage amenities have used preference heterogeneity to explain these differences. By considering the commute, it is possible to measure these differences in the data. This heterogeneity in worker values through commuting costs is reflected in the surplus of a match, which depends not only on its productivity, but also on the cost of a worker's commute and housing. It follows that the costs of commuting are affected by the configuration of the labor market, suggesting the importance of endogenous location choices of both workers and firms.

I build a model of on-the-job search with heterogeneous workers and firms with endogenous location choice and rent prices. By combining these features with the wage bar-

gaining and renegotiation processes of [Cahuc et al. \(2006\)](#), the model remains tractable, resulting in frictional wage dispersion across otherwise identical workers. In the model, workers and firms are ex-ante heterogeneous in their fixed type, or productivity. Workers may move at a cost while firms commit to a location for a given job after posting a vacancy. A worker's location decision introduces a trade-off between her potential commuting costs and the price of rent to live in a given location. Match surplus reflects both the rent and commuting costs, as well as productivity, leading to some highly productive matches being rejected when such costs are high. Because wages are determined by the match surplus, which itself is a function of productivity and location, the model is not observationally equivalent to one in which only wages net of commuting costs matter for workers. Further, the quantitative model allows for the worker to remain in the same match after receiving moving or productivity shocks, further distinguishing the commuting dimension from productivity.

I show that the patterns in the data arise endogenously in the model. In particular, workers are compensated for longer commutes with higher wages. When workers can move, policies that affect costs related to the spatial dimension will directly affect the dynamics of the labor market and residential sorting patterns. With heterogeneous productivities of workers and firms, these policies can increase aggregate productivity. The model allows me to understand the links between the costs of living, proxied by rent, and the configuration of the labor market. Using tools introduced in the theory literature on existence of Walrasian equilibria with indivisibilities, most importantly that by [Kaneko and Yamamoto \(1986\)](#) and [Azevedo et al. \(2013\)](#), I prove that a steady state equilibrium exists. The main theoretical contribution of this model therefore allows me to study the connection between endogenous rent prices and labor market outcomes. Recent work by [Halket and Vasudev \(2014\)](#) uses similar techniques to prove existence of a spatial equilibrium, but their focus is on homeownership and the choice of housing quantity, while abstracting from search frictions in the labor market. Conversely, I am most interested in the effects of commuting on the wage and firm productivity distribution, and thus assume a much simpler housing market.

There is a large branch of literature studying the costliness of search across labor markets. [Gautier and Teulings \(2009\)](#) study the job search problem across labor markets of different sizes to explain observed wage differentials across large and small metropolitan areas. [Head and Lloyd-Ellis \(2012\)](#) build a model with frictional housing and labor markets to study the effects of wages on migration across cities. [Battu et al. \(2008\)](#) empirically evaluate the link between unemployment-employment and job-to-job transitions and housing in the UK, focusing on migration across labor markets in response to labor mar-

ket transitions. Unlike these papers, I focus on movement within cities due to commuting rather than migration costs. In this way, I allow workers to change jobs without moving, a common feature in the data, while also considering the endogenous determination of matches and the configuration of workers and firms within the labor market.

Another strand of the literature models job search in the presence of spatial frictions for unemployed workers only. [Manning and Petrongolo \(2017\)](#) study spatial job search using a directed search model without on-the-job search. In their framework, applying to jobs is costly and workers will accept any job to which they optimally choose to apply. In the data, [Rupert et al. \(2009\)](#) show that 14.7% of workers cite commuting as their main reason for rejecting their most recent job offer. [Rupert and Wasmer \(2012\)](#) study the unemployed worker's trade-off between commuting and wages in a random search model, but abstract from differences in spatial costs and acceptance rates. My model employs a random search framework with both off- and on-the-job search and endogenous spatial costs to take into account the most important channels affecting the job ladder across space, namely demand for well-located housing and offices and the potential to find better matches while employed.

A highly related paper is that by [Van Vuuren \(2018\)](#). His paper differs from mine in several ways. First, all firms in his model are located in the city center, simplifying the commute as a function only of the distance of the worker from the center. He also introduces endogenous rent prices determined only by workers' location decisions and without moving costs using the bid-rent approach. Finally, he proposes an alternative mechanism in which the arrival rate of job offers is a function of distance between a worker and vacancy. In this model, matches are not created not because workers living far from a potential job reject offers due to commuting costs, but because the offers never arrive. His focus is on the location decisions of young college graduates, while mine is on wage growth and understanding the "productivity ladder".

The paper proceeds as follows. Section 2 discusses some preliminary motivating evidence from the UK suggesting a link between commuting, job-to-job transitions, and earnings. The model is introduced in Section 3. Section 4 extends the model for the quantitative analysis, discusses its estimation, and explores counterfactuals related to changes in the spatial dimension of the model and their effects on the labor market. Section ?? considers alternative specifications to examine the robustness of the results. Section 5 concludes.

2 Motivation

This section discusses motivating evidence pointing to the importance of introducing commuting into a model of on-the-job search using the British Household Panel Survey (BHPS) for residents of England between 1992 and 2009. The BHPS is an annual panel survey with information on individuals' commute times, employment histories, housing, and wages. I restrict attention to individuals who appear in at least two years of the survey and who are between the ages of 24 and 55 (inclusive). I include workers reporting annual labor income and hours and a one-way commute up to 90 minutes¹, to exclude individuals with so-called “mega-commutes”². Reported (one-way) commutes are multiplied by 2 to determine the daily round-trip commute. I exclude those who are self-employed. Annual labor income is deflated by annual CPI in the UK from the Office for National Statistics (ONS). For individuals in the sample used in this section, the average number of years in the survey is 8. I begin by showing graphical evidence related to patterns in commuting and wages. The aggregated data shows that workers who earn more commute more on average, and that commuting flows are highly correlated with local productivity. I then document micro-level evidence pointing to the link between commute time and wages in both static and dynamic contexts to highlight the connection to individual workers' job histories.

2.1 Graphical Evidence for the Importance of Commuting

To motivate the micro-level estimates below, Figure 1 shows the average commuting time for employed respondents by income decile, as measured by the real hourly wage in a given year. Each dot corresponds to the average commuting time of individuals in a given decile of the income distribution in a given year. The solid line shows the average over all years for each decile, with shaded areas indicating the 5th and 95th percentiles. The figure shows that on average, commute time and its variance increase with wages.

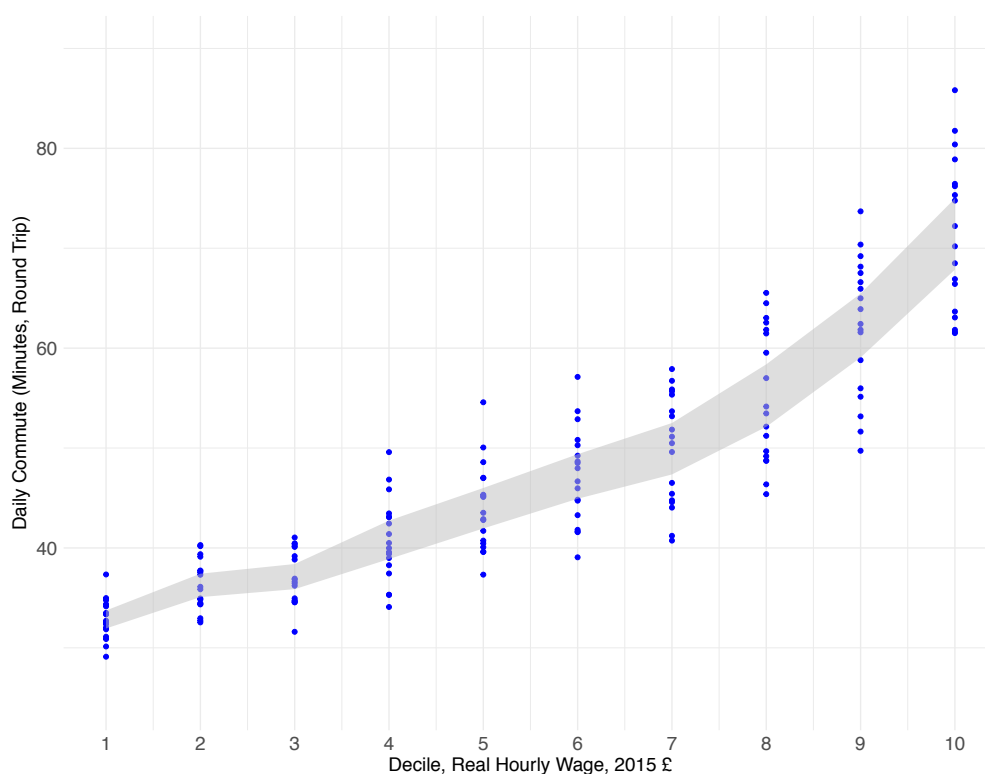
Further, the pattern of commuting flows across space highlights the importance of productivity. Figure 2 shows the change in population between residents and workers in each Local Authority District³ (LAD) in England and Wales as a function of proximity to the City

¹In the baseline regressions, I include workers reporting a commute of 0 minutes to take into consideration people working from home. Restricting the sample to those reporting a strictly positive commute does not significantly change the results.

²The Census Bureau defines a “mega-commuter” as a worker travelling more than 90 minutes to work, one-way, see [Rapino and Fields \(2013\)](#). In the BHPS data, these individuals represent less than 0.6% of the sample

³LADs are a unit of regional classification, with populations ranging from 2,300 to 1 million, and land area between 1 and 1,936 square miles.

Figure 1: Average Commute Time

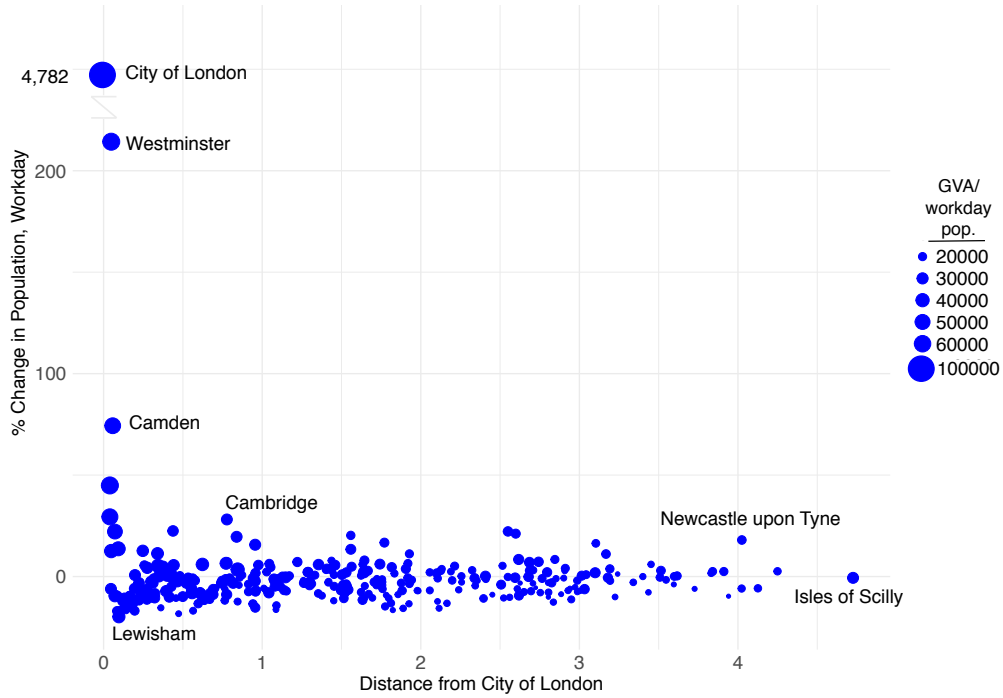


Data: BHPS 1992-2009. Average commute time for full-time employed respondents aged 24-55 in the regions of Inner and Outer London and South East England, with daily commute less than 180 minutes. Shaded areas denote the 5th and 95th percentiles by decile in each year. Real hourly wage deciles are computed annually.

of London. The City sees an increase of over 4,000% in population during the workday (growing from roughly 6,000 residents to over 300,000 workers in firms located in the area). The size of each point in the scatter plot corresponds to the ratio of 2011 gross value added to the workday population in each LAD.

The evidence in this section shows that individual workers' commuting time and income are strongly positively correlated in the cross section, and that commuting flows are strongly correlated with productivity and spatially concentrated in inner London. This subsection thus confirms that commuting is a pervasive feature of the UK labor force, strongly correlated with average productivity and wages. The next section documents the links at the worker level between commuting, wage growth, and transitions both from job-to-job and from unemployment.

Figure 2: Commuting: Concentration and Productivity



Notes: Source: ONS. Vertical axis: workday to residential population in 2011 census by LAD. Horizontal axis: distance from City of London, computed as the euclidean distance in latitude and longitude from the centroid of each LAD to the centroid of the City of London. The size of each point in the scatterplot corresponds to the ratio of 2011 gross value added using the income approach to the workday population in each LAD.

2.2 Micro-Level Evidence

To understand the trade-offs faced by individual workers, I exploit the panel dimension of the BHPS data to study the importance of commuting time for unemployment to employment (UE) and job-to-job (EE) transitions.

The BHPS is one of the only publicly available data sets⁴ to contain information on reservation wages. The sample contains 3,490 observations for which individuals are unemployed, of which 73% report a reservation wage. Of these, 1,029 report a UE transition between $t - 1$ and t . The data therefore allow me to test whether there is a compensating differential for jobs that require a long commute, in the spirit of work by [Hall and Mueller](#) (Forthcoming) on non-wage job values. To do so, I consider workers who made an unemployment to employment transition in between years $t - 1$ and t , for whom both the wage and commute in year t are available and who reported their reservation wage in year $t - 1$. Table 1 shows the average ratio of the realized wage to reservation wage for workers

⁴The other being the German Socio Economic Panel.

Table 1: Increase in log Realized to Reservation Wage

Group	Commute Below Median	Commute Above Median
All	.034	.112
Less Than College	.025	.092
College Graduates	.052	.129
Men	.075	.110
Women	-.018	.116

Notes: BHPS Sample 1993-2009, annual. Universe: respondents aged 24-55 employed in year t and reporting a minimum weekly wage ("Reservation wage") while unemployed in year $t - 1$. Columns report the ratio of the realized to reservation wage, conditional on the new job requiring an above or below-median commuting time. In the sample, the median round trip commute is 43.1 minutes.

who accepted jobs with commutes below (center column) and above (right column) the median commute, roughly 43 minutes round trip. The rows of the table show the robust result that workers accepting jobs which require a longer commute have realized wages that are well above their reported reservation wages, and above those of workers accepting jobs requiring a shorter commute.

Given the apparent compensation earned for long commutes, I next show that decreases in the dis-amenity of commuting explain the prevalence of wage cuts following EE transitions. Much of the search literature has trouble explaining wage cuts since productivity and wages are strongly positively correlated, and most non-wage amenities are estimated to be augmenting rather than compensating. As shown above and Appendix D, commuting is rare in that it increases with wages. Table 2 shows that a significant share of workers reporting wage cuts in the year in which an EE transition takes place also report decreases in their commuting time relative to the previous year. Thus, the wage-commuting trade-off can help to explain the existence of wage cuts in the data. This pattern is robust: the share of workers taking wage cuts and commuting cuts is stable across genders and age groups (20's, 30's, etc.).

To construct Table 2 I identify those making a job-to-job transition with no more than two weeks of non-employment between the two employment spells. I compare wages and commutes to the wage and commute reported by the individual in the previous survey. "Up" and "Down" indicate differences from the last reported wage or commute of more than 10%, and "Same" indicates differences less than 10%. Each column of the tables shows, for a given accepted wage which was higher, lower, or the same as her previ-

ous wage, whether the worker’s commute was higher, lower, or the same as her previous commute. Appendix D contains similar tables showing that this result is robust when conditioning on occupation switchers or stayers.

Table 2: After Job-to-Job Transition

		<u>Wage</u>		
		Down	Same	Up
<u>Commute</u>	Down	0.31	0.06	0.15
	Same	0.03	0.02	0.10
	Up	0.09	0.04	0.20

Notes: BHPS Sample 1993-2009, annual. Universe: respondents aged 24-55 employed in year t who changed jobs since year $t - 1$ with no more than 2 weeks of unemployment between the two employment spells. "Up" and "Down" indicate differences from the last reported wage or commute of more than 10%, and "Same" indicates differences less than 10%.

Further evidence on the importance of commuting for wage growth and job-to-job transitions at the individual level is contained in Appendix D. In particular, there is a strong positive relationship between contemporaneous commutes and real wages at the individual level. Further, the probability of making a job-to-job transition depends positively on the commute to the previous job, even after controlling for the previous wage. Finally, to study the effect of commuting on earnings, I use workers present in several consecutive years of the sample to estimate the effect of the first commute reported after a nonemployment spell on earnings over the following 2 to 5 years. The results suggest that a 30-minute increase in a worker’s initial commute is associated with between 4% and 6% higher present value of earnings at all horizons. Importantly, all results are also robust to controlling for housing costs as well as the method of commuting.

3 Model

In this section I build a spatial random search model where match surplus is affected by worker and firm locations. In this section, I assume that all workers can move to a new location by paying a fixed moving cost. The goal of the model presented here is to consider how workers’ employment patterns affect and are affected by the spatial configuration of the labor market.

3.1 Set-Up

Time is continuous and agents are infinitely lived. The economy is populated by a continuum of workers of measure one and a continuum of firms of a positive measure. Workers exit the labor market at rate $\chi > 0$, and new workers enter at the same rate. All agents share a common discount rate r and are risk neutral. Each worker and each filled job is located in a “residence” of size 1. For simplicity, all locations are assumed to be rented and therefore have no asset value. There is a single, closed labor market within which all workers and firms are located. The labor market is defined by $2N + 1$ locations, $\ell \in \mathcal{L} \equiv \{-N, \dots, -1, 0, 1, \dots, N\}$, with location 0 defining the “center” and N the “periphery” of the labor market⁵. Each location contains total land⁶ L . Both workers and firms with filled jobs pay rent, $k_R(\ell)$, which is determined endogenously as discussed below.

There is a large mass of ex-ante potential entrant firms who choose whether to open a vacancy given expected profits. Entrants pay a flow cost to post a vacancy, and draw a location ℓ and productivity y from joint distribution g where $\sum_{\ell=0}^N \sum_{y=1}^Y g(\ell, y) = 1$ if a match is made. Once a job is filled, its location and productivity are fixed until the match is destroyed. Workers are ex-ante identical and can be employed or unemployed. Firms have access to a constant returns to scale technology and employed workers supply their labor inelastically. Output in the match is given by y .

In order to earn her wage, an employed worker must pay a flow commuting cost $\tau(\ell, \ell_F)$ proportional to the productivity of her match⁷. The worker’s commuting distance $|\ell - \ell_F|$ is determined by the location of the worker’s residence and of her workplace, ℓ and ℓ_F , respectively. To change her location ℓ , the worker must pay a fixed moving cost k_M .

When a worker is employed, she consumes her wage net of commuting and rental costs. Matches are destroyed exogenously at rate δ . When a match is destroyed, the worker becomes unemployed and the newly vacant firm becomes a potential entrant. Unemployed workers consume the flow value of unemployment b less rent costs. Employed workers consume their wage less commuting and rent costs. All workers have the outside option of leaving the labor market and consuming $\bar{u}$, which I normalize to zero. Wages are determined by fixed-wage contracts which are renegotiated with the agreement of both parties, following [Dey and Flinn \(2005\)](#) and [Cahuc et al. \(2006\)](#). The outcome of this

⁵Rather than having exogenous agglomeration economies, for instance by introducing a location-specific productivity distribution, defining location 0 as the center will give rise to endogenous productivity differences across locations via firm entry. Such agglomeration externalities are introduced in Section ??.

⁶I assume that LN is larger than the measure of workers. If LN were small, some workers would be forced to leave the economy in order for the market to clear. The model allows for this possibility by assuming that all workers have the outside option of leaving the labor market.

⁷The proportionality assumption is made to ensure that high-wage workers are sensitive to commuting costs, and to match the share of wage cuts in the calibrated model.

game is identical to the generalized Nash-bargaining solution, where the worker's share of the surplus is given by β .

In each instant, the search and matching process proceeds as follows. First, vacant firms decide whether to post a vacancy by paying cost c . Each vacancy then draws the paid (ℓ_F, y) and decides whether to remain in the market and potentially meet a worker or exit. Unemployed (employed) workers have the opportunity to search at rate λ_0 (λ_1). Given this opportunity, market tightness⁸ θ is given by the ratio of vacancies to applicants. Under the standard assumption of a constant returns to scale matching function, the probability that a worker meets a firm is denoted $p(\theta)$. The worker's matching probability p is a strictly increasing and strictly concave function with $p(0) = 0$ and $p(\infty) = 1$. Similarly, the probability that a vacancy meets a worker is given by $q(\theta) = p(\theta)/\theta$, a strictly decreasing function with $q(0) = 1$ and $q(\infty) = 0$. As in the standard [Cahuc et al. \(2006\)](#) model, a match is formed if, after drawing the location and productivity of the job, the worker accepts the offer, which occurs whenever its surplus exceeds that in the worker's current match. I discuss workers' acceptance decision in more detail in the next sections.

3.2 Contracts and Wage Determination

In this section, employment contracts consist of a wage and worker location, (w, ℓ) . Similar to search intensity in [Bagger and Lentz](#) (Forthcoming), I assume that the worker's location ℓ is contractible for tractability⁹, to ensure that the equilibrium can be characterized independently of the split of the surplus between firm and worker. The distance is chosen to maximize the value of the match, $M_{\ell_F}(y, \ell)$. I discuss this assumption at the end of the next section.

For a given firm location and productivity (ℓ_F, y) , worker location ℓ , and wage w , denote the value of a filled job to the firm as $J_{\ell_F}(w, y, \ell)$ and the expected value of a vacancy as V . Similarly, denote the value of an employed worker as $W_{\ell_F}(w, y, \ell)$ and an unemployed worker as $U(\ell)$. The match value is given by $M_{\ell_F}(y, \ell) = J_{\ell_F}(w, y, \ell) + W_{\ell_F}(w, y, \ell)$, and the total surplus is denoted $S_{\ell_F}(y, \ell) = M_{\ell_F}(y, \ell) - U(\ell) - V$. Wages are determined as follows. When a firm meets an unemployed worker, her wage $\phi_0(\ell_F, y, \ell)$ is set to satisfy

$$W_{\ell_F}(\phi_0, y, \ell) - U(\ell) = \beta S_{\ell_F}(y, \ell) \quad (1)$$

⁸I model tightness to evaluate the effects of spatial frictions on the inefficiencies present in models with endogenous entry.

⁹The lack of tractability when workers are able to choose their location independently comes from the fact that the worker's location choice affects the probability of renegotiation, whereas the location choice maximizing the match value does not.

Henceforth, I will drop the arguments of the wage functions whenever they are clear. I use a carat to denote the values of an outside offer (e.g. $(\hat{\ell}_F, \hat{y})$) and a prime to denote shocks to the current match (e.g. y'). When a worker is employed, she may negotiate her wage upon the arrival of an outside offer. Considering first the outside offers, suppose a worker's current surplus is given by $S_{\ell_F}(y, \ell)$ and associated worker value is $W_{\ell_F}(w, y, \ell)$. If she is contacted by a firm with which her surplus would be $S_{\hat{\ell}_F}(\hat{y}, \ell)$, there are three possibilities:

- (1) $S_{\ell_F}(y, \ell) < S_{\hat{\ell}_F}(\hat{y}, \ell)$
- (2) $W_{\ell_F}(w, y, \ell) - U(\ell) < S_{\hat{\ell}_F}(\hat{y}, \ell) < S_{\ell_F}(y, \ell)$
- (3) $S_{\hat{\ell}_F}(\hat{y}, \ell) < W_{\ell_F}(w, y, \ell) - U(\ell) < S_{\ell_F}(y, \ell)$

In case (1), the worker will be poached by the new firm, with wage $w = \phi_1(\hat{\ell}_F, \hat{y}, \ell_F, y, \ell)$ satisfying:

$$W_{\hat{\ell}_F}(\phi_1, \hat{y}, \ell) - U(\ell) = S_{\ell_F}(y, \ell) + \beta(S_{\hat{\ell}_F}(\hat{y}, \ell) - S_{\ell_F}(y, \ell)) \quad (2)$$

In this case, the firms enter into Bertrand competition, and the worker extracts the full surplus of her previous match and a share β of the gains in surplus between the poaching firm and her previous employer. Following the terminology of [Postel-Vinay and Turon \(2010\)](#), the surplus $S_{\ell_F}(y, \ell)$ becomes the worker's new "negotiation baseline." In case (2), the worker remains at her current firm, but renegotiates her wage to $w = \phi_2(\ell_F, y, \hat{\ell}_F, \hat{y}, \ell)$ with the outside offer becoming her negotiation baseline:

$$W_{\ell_F}(\phi_2, y, \ell) - U(\ell) = S_{\hat{\ell}_F}(\hat{y}, \ell) \quad (3)$$

Finally, in case (3), the outside offer is too low to warrant renegotiation between the worker and her current firm, therefore she remains at the same wage in her current match.

Wages in this model are determined by the current and next-best match surplus, which are functions of the worker's commuting costs. Thus, otherwise identical workers are compensated for their commutes through wages, a potentially counter-factual assumption. However, wage posting models are known to be intractable in models such as this; [Albrecht et al. \(2018\)](#) show that when firms do not know workers' non-wage amenity value of the match, the wage posting model of [Burdett and Mortensen \(1998\)](#) will no longer have a non-degenerate wage offer distribution, and thus no incentive for workers to engage in on-the-job search. Although one may argue that wages offered to new hires should not vary by commuting cost, in this model with renegotiation firms will compensate their worker in order to avoid her being poached by an outside offer. Thus, observed wages after at least

one renegotiation will vary for otherwise identical workers due to differences in threat points reflecting heterogeneous commuting costs.

3.3 Value Functions

Turning to the value functions, the value for an unemployed worker is given by the following expression:

$$U(\ell) = \max_{\ell' \in \mathcal{L}} \{\tilde{U}(\ell') - k_M \mathbb{1}\{\ell \neq \ell'\}\} \quad (4)$$

where

$$(r + \chi)\tilde{U}(\ell) = b - k_R(\ell) + \lambda_0 p(\theta) \beta \sum_{\ell_F, y} \max\{S_{\ell_F}(y, \ell), 0\} g(\ell_F, y) \quad (5)$$

At rate λ_0 the worker gets the opportunity to search, and with probability $p(\theta)g(\ell_F, y)$ she meets a job with productivity y located at ℓ_F . If the offer is acceptable, the worker receives a share β of the surplus. Denote the unemployed worker's optimal location choice by the policy function $\ell_u(\ell)$.

Next, consider an employed worker living in ℓ in current firm (ℓ_F, y) earning wage w . The value function for this worker is given by:

$$W_{\ell_F}(w, y, \ell) = \tilde{W}_{\ell_F}(w, y, \ell_e(\ell_F, y, \ell)) - k_M \mathbb{1}\{\ell \neq \ell_e(\ell_F, y, \ell)\} \quad (6)$$

where $\ell_e(\ell_F, y, \ell)$ is the optimal location of the worker defined by the worker's contract. I verify below that this location is independent of the worker's current wage. If the worker's current location differs from the location in her contract, the worker must pay moving cost k_M . Define the sets $B_1(\ell_F, y, \ell) = \{(\hat{\ell}_F, \hat{y}) \in \mathcal{L} \times Y : S_{\hat{\ell}_F}(\hat{y}, \ell) > S_{\ell_F}(y, \ell)\}$, and $B_2(w, \ell_F, y, \ell) = \{(\hat{\ell}_F, \hat{y}) \in \mathcal{L} \times Y : W_{\ell_F}(w, y, \ell) - U(\ell) < S_{\hat{\ell}_F}(\hat{y}, \ell) < S_{\ell_F}(y, \ell)\}$. The flow value for a worker living in an arbitrary ℓ , in current firm (ℓ_F, y) earning wage w , is given by:

$$\begin{aligned} (r + \chi)\tilde{W}_{\ell_F}(w, y, \ell) &= w - k_R(\ell) - \tau(\ell, \ell_F)y + \delta(U(\ell) - W_{\ell_F}(w, y, \ell)) \\ &+ \lambda_1 p(\theta) \sum_{(\hat{\ell}_F, \hat{y}) \in B_1(\ell_F, y, \ell)} (\beta S_{\hat{\ell}_F}(\hat{y}, \ell) + (1 - \beta)S_{\ell_F}(y, \ell) - W_{\ell_F}(w, y, \ell) + U(\ell)) g(\hat{\ell}_F, \hat{y}) \\ &+ \lambda_1 p(\theta) \sum_{(\hat{\ell}_F, \hat{y}) \in B_2(w, \ell_F, y, \ell)} (S_{\hat{\ell}_F}(\hat{y}, \ell) - W_{\ell_F}(w, y, \ell) + U(\ell)) g(\hat{\ell}_F, \hat{y}) \end{aligned} \quad (7)$$

The first three terms of the right hand side are the wage, rent, and commuting cost. The worker exogenously separates from her match at rate δ . The last two lines report the payoffs to the employed worker when an outside offer arrives. The worker separates if

the surplus of the new offer is strictly larger than her current surplus, that is, $(\hat{\ell}_F, \hat{y}) \in B_1(\ell_F, y, \ell)$. The worker and firm renegotiate if the surplus of the outside offer exceeds the worker's current negotiation baseline, that is, $(\hat{\ell}_F, \hat{y}) \in B_2(w, \ell_F, y, \ell)$.

Before turning to the values of a vacancy and filled job, denote the mass of employed workers currently in a match (ℓ_F, y) living at ℓ as $e_{\ell_F}(y, \ell)$ and the mass of unemployed workers living at ℓ as $u(\ell)$. The flow cost of maintaining a vacancy in any location is $c \geq 0$. In equilibrium, vacancies will be posted as long as the expected value is weakly larger than c . Since vacancies are identical, the free entry condition is given by

$$\begin{aligned} c \geq & q(\theta) \sum_{\ell_F, y} \sum_{\ell \in \mathcal{L}} [\lambda_0 u(\ell)(1 - \beta) \max\{0, S_{\ell_F}(y, \ell)\} \\ & + \lambda_1(1 - \beta) \sum_{\hat{\ell}_F \in \mathcal{L}} \sum_{\hat{y} \in Y} \max\{0, S_{\ell_F}(y, \ell) - S_{\hat{\ell}_F}(\hat{y}, \ell)\} e_{\hat{\ell}_F}(\hat{y}, \ell)] g(\ell_F, y) \end{aligned} \quad (8)$$

If vacancies are posted, the distribution of vacancies is given by the exogenous distribution $g(\ell, y)$, whereas the distribution of filled jobs is endogenous given workers' acceptance decisions. Vacant firms do not pay rent; only once a job becomes filled do they pay rent in order to produce. Given free entry, the expected value of a vacancy is zero.

Finally, the value of a filled job to the firm is given by:

$$J_{\ell_F}(w, y, \ell) = \tilde{J}_{\ell_F}(w, y, \ell_e(\ell_F, y, \ell))$$

where

$$\begin{aligned} (r + \chi + \delta) \tilde{J}_{\ell_F}(w, y, \ell) = & y - w - k_R(\ell_F) - \lambda_1 p(\theta) J_{\ell_F}(w, y, \ell) \sum_{(\hat{\ell}_F, \hat{y}) \in B_1(\ell_F, y, \ell)} g(\hat{\ell}_F, \hat{y}) \\ & + \lambda_1 p(\theta) \sum_{(\hat{\ell}_F, \hat{y}) \in B_2(w, \ell_F, y, \ell)} (S_{\ell_F}(y, \ell) - S_{\hat{\ell}_F}(\hat{y}, \ell) - J_{\ell_F}(w, y, \ell)) g(\hat{\ell}_F, \hat{y}) \end{aligned} \quad (9)$$

Flow profits vary for firms in the same location due to heterogeneous productivities y and wages due to different worker histories. When an outside offer arrives, the firm and worker will separate if the offer has a higher surplus than the current match, shown by the term on the second line, and will renegotiate if the outside offer's surplus is lower than the current match, shown on the third line.

Combining (7) and (9), the match value is given by the following expression, which is

maximized by choosing the worker's optimal location ℓ' :

$$M_{\ell_F}(y, \ell) = \max_{\ell' \in \mathcal{L}} \{ \tilde{M}_{\ell_F}(y, \ell') - k_M \mathbb{1}\{\ell \neq \ell'\} \} \quad (10)$$

where $\tilde{M}_{\ell_F}(y, \ell) = \tilde{J}_{\ell_F}(y, \ell) + \tilde{W}_{\ell_F}(y, \ell)$ denotes the match value, with:

$$\begin{aligned} (r + \chi) \tilde{M}_{\ell_F}(y, \ell) &= (1 - \tau(\ell, \ell_F))y - k_R(\ell_F) - k_R(\ell) + \delta(U(\ell) - M_{\ell_F}(y, \ell)) \\ &+ \lambda_1 p(\theta) \beta \sum_{\hat{\ell}_F, \hat{y}} \max \{ 0, M_{\hat{\ell}_F}(\hat{y}, \ell) - M_{\ell_F}(y, \ell) \} g(\hat{\ell}_F, \hat{y}) \end{aligned} \quad (11)$$

and $M_{\ell_F}(y, \ell)$ denotes the match value at the optimal worker location that solves (10). The surplus is given by

$$S_{\ell_F}(y, \ell) = M_{\ell_F}(y, \ell) - U(\ell).$$

The worker's wage out of unemployment is chosen such that $W_{\ell_F}(w, y, \ell) - U(\ell) = \beta S_{\ell_F}(y, \ell)$ and out of employment such that $W_{\hat{\ell}_F}(w, \hat{y}, \ell) - U(\ell) = S_{\ell_F}(y, \ell) + \beta(S_{\hat{\ell}_F}(\hat{y}, \ell) - S_{\ell_F}(y, \ell))$. Denote these wage functions $w_U(\ell_F, y, \ell)$ and $w(\hat{\ell}_F, \hat{y}, \ell_F, y, \ell)$, respectively. Job-to-job transitions are determined by the probability that the worker living in ℓ meets a firm with type $(\hat{\ell}_F, \hat{y}) \in B_1(\ell_F, y, \ell)$ for each current match (ℓ_F, y) . Transitions out of unemployment by workers living in ℓ are determined by the probability that the worker meets a firm with match value $(\hat{\ell}_F, \hat{y}) \in B_1(u, \ell)$.

Discussion on Contractability of Location

The assumption of a worker's location being determined in her contract may seem questionable, however many contracts do specify a "mobility clause" defining the maximum distance the worker is expected to live from the workplace. The reason for this assumption here is technical, since the worker's location affects the match value through commuting and rent costs, but the worker's choice of location will generally not coincide with the match value-maximizing choice. This is because the worker's location affects the set of offers resulting in wage renegotiation. Although these effects may be interesting from the perspective of measuring the inefficiencies of commuting costs, it is beyond the scope of this paper.

3.4 Worker Flows

Before defining the equilibrium, I now define the flows into and out of the worker distributions across employment states and space. The flow into employment for workers living

at ℓ employed in matches located at ℓ_F with firm productivity y is made up of two groups. The first is the unemployed who match with a firm (ℓ_F, y) . The second is the employed making job-to-job transitions, who were previously in a match with $\tilde{y} \neq y$ and/or $\tilde{\ell}_F \neq \ell_F$. In sum, the flow into such matches is given by:

$$e_{\ell_F}^+(y, \ell) = p(\theta)g(\ell_F, y) \sum_{\ell' \in \mathcal{L}} [\lambda_0 u(\ell') \mathbb{1}\{S_{\tilde{\ell}_F}(\tilde{y}, \ell') > 0\} + \lambda_1 \sum_{\tilde{\ell}_F \in \mathcal{L}} \sum_{\tilde{y} \in Y} \mathbb{1}\{S_{\tilde{\ell}_F}(\tilde{y}, \ell') < S_{\ell_F}(y, \ell')\} e_{\tilde{\ell}_F}(\tilde{y}, \ell')] \mathbb{1}\{\ell_e(\ell_F, y, \ell') = \ell\} \quad (12)$$

Similarly, the flow out of such matches is given by the employed previously in matches located at ℓ_F with firm productivity y , who separate either exogenously or endogenously by making a job-to-job transition:

$$e_{\ell_F}^-(y, \ell) = e_{\ell_F}(y, \ell) [\delta + \lambda_1 p(\theta) \sum_{\tilde{\ell}_F \in \mathcal{L}} \sum_{\tilde{y} \in Y} \mathbb{1}\{S_{\tilde{\ell}_F}(\tilde{y}, \ell) > S_{\ell_F}(y, \ell)\} g(\tilde{\ell}_F, \tilde{y})] \quad (13)$$

The flow into of unemployment of workers living at ℓ consists of those employed workers who exogenously separate:

$$u^+(\ell) = \delta \sum_{\ell' \in \mathcal{L}} \sum_{\ell_F \in \mathcal{L}} \sum_{y \in Y} e_{\ell_F}(y, \ell') \mathbb{1}\{\ell_u(\ell') = \ell\} \quad (14)$$

The flow of workers living at ℓ out of unemployment is simply those unemployed workers who successfully match:

$$u^-(\ell) = \lambda_0 p(\theta) u(\ell) \sum_{\ell_F \in \mathcal{L}} \sum_{y \in Y} \mathbb{1}\{S_{\ell_F}(y, \ell) > 0\} g(\ell_F, y) \quad (15)$$

Turning to the flows across space, first note that with a fixed moving cost workers will only move in this model when their employment state changes, that is, following an unemployment to employment or job-to-job transition. However, the model allows for workers' employment status to change without their moving (and vice versa). Thus, the flow of workers and active firms into a given location $\tilde{\ell}$ is comprised of the flow of new matches located at $\tilde{\ell}$, plus those newly hired workers not previously living at $\tilde{\ell}$ whose contract specifies that they live at $\tilde{\ell}$, and the newly unemployed who are located at $\tilde{\ell}$. This

inflow is given by:

$$\begin{aligned}
& \sum_{y \in Y} \left(\sum_{\ell \in \mathcal{L}} e_{\tilde{\ell}}^+(y, \ell) + \sum_{\ell_F \in \mathcal{L}} e_{\ell_F}^+(y, \tilde{\ell}) - p(\theta)g(\ell_F, y) [\lambda_0 u(\tilde{\ell}) \mathbb{1}\{S_{\ell_F}(y, \tilde{\ell}) > 0\} \right. \\
& \quad \left. + \lambda_1 \sum_{\tilde{\ell}_F \in \mathcal{L}} \sum_{\tilde{y} \in Y} \mathbb{1}\{S_{\tilde{\ell}_F}(\tilde{y}, \tilde{\ell}) < S_{\ell_F}(y, \tilde{\ell})\} e_{\tilde{\ell}_F}(\tilde{y}, \tilde{\ell})] \mathbb{1}\{\ell_e(\ell_F, y, \tilde{\ell}) = \tilde{\ell}\} \right) + u^+(\tilde{\ell}) \\
& \quad - \delta \sum_{\ell_F \in \mathcal{L}} \sum_{y \in Y} e_{\ell_F}(y, \tilde{\ell}) \mathbb{1}\{\ell_u(\tilde{\ell}) = \tilde{\ell}\} \quad (16)
\end{aligned}$$

Similarly, the flow of workers and firms out of location $\tilde{\ell}$ is made up of the firms whose matches were located at $\tilde{\ell}$ and are destroyed, plus the employed who lived at $\tilde{\ell}$ but whose match is destroyed, and the unemployed who lived at $\tilde{\ell}$ but who leave unemployment, excluding those workers who remain at $\tilde{\ell}$ after an employment transition. This flow is given by:

$$\begin{aligned}
& \sum_{y \in Y} \left(e_{\tilde{\ell}}^-(y, \ell) + \sum_{\ell_F \in \mathcal{L}} e_{\ell_F}^-(y, \tilde{\ell}) - e_{\ell_F}(y, \tilde{\ell}) [\delta \mathbb{1}\{\ell_u(\tilde{\ell}) = \tilde{\ell}\} \right. \\
& \quad \left. + \lambda_1 p(\theta) \sum_{\tilde{\ell}_F \in \mathcal{L}} \sum_{\tilde{y} \in Y} \mathbb{1}\{S_{\tilde{\ell}_F}(\tilde{y}, \tilde{\ell}) > S_{\ell_F}(y, \tilde{\ell})\} \mathbb{1}\{\ell_e(\tilde{\ell}_F, \tilde{y}, \tilde{\ell}) = \tilde{\ell}\} g(\tilde{\ell}_F, \tilde{y})] \right) + u^-(\tilde{\ell}) \\
& \quad - \lambda_0 p(\theta) u(\tilde{\ell}) \sum_{\ell_F \in \mathcal{L}} \sum_{y \in Y} \mathbb{1}\{S_{\ell_F}(y, \tilde{\ell}) > 0\} \mathbb{1}\{\ell_e(\ell_F, y, \tilde{\ell}) = \tilde{\ell}\} g(\ell_F, y) \quad (17)
\end{aligned}$$

3.5 Equilibrium

Given the analysis above, it remains to derive an equation for the rent costs given the spatial allocation of workers and firms. Each location ℓ contains area L . Land is endowed to a continuum of homogeneous absentee landlords in each location. Since workers can move at any time but the location of the filled job is fixed, it is more straightforward to consider the stock of available land, which I denote $\hat{L}(\ell)$, equal to the total land less that occupied by the existing filled jobs.

The representative landlord maximizes her utility by choosing how much of the available land to rent to agents living at ℓ , denoted $\psi(\ell)$. His maximization problem is written

$$\max_{\psi(\ell) \in [0, \hat{L}(\ell)]} \left\{ \nu(\hat{L}(\ell) - \psi(\ell), k_R(\ell)\psi(\ell)) \right\} \quad (18)$$

where the first argument is the amount of land the landlord consumes, and the second argument is the amount of resources he gets from renting $\psi(\ell)$ at price $k_R(\ell)$. I assume

that ν is twice continuously differentiable and strictly increasing in both of its arguments. The strictly positive derivative with respect to the first argument insures that the landlord will not rent any of his land at a price of zero.

Taking the rent price as given, the solution to the representative landlord's maximization problem is

$$\psi(\ell) \begin{cases} = 0 & \text{if } \nu_1 > k_R(\ell)\nu_2 \\ \in (0, \hat{L}(\ell)) & \text{if } \nu_1 = k_R(\ell)\nu_2 \\ = \hat{L}(\ell) & \text{if } \nu_1 < k_R(\ell)\nu_2 \end{cases}$$

Land demand is determined by the total mass of employed and unemployed workers living at and newly filled jobs located at ℓ . Equilibrium in the land market requires the supply of available land be weakly greater than the demand of for land:

$$\psi(\ell) \geq u(\ell) + \sum_{y \in Y} \left[\sum_{\ell_F \in \mathcal{L}} e_{\ell_F}(y, \ell) + \sum_{\tilde{\ell} \in \mathcal{L}} e_{\tilde{\ell}}^+(y, \tilde{\ell}) \right] \quad (19)$$

I now define a steady state equilibrium.

Definition 1. A steady state equilibrium consists of value functions $M_{\ell_F} : Y \times \mathcal{L} \rightarrow \mathbb{R}$ for each $\ell_F \in \mathcal{L}$ and $U : \mathcal{L} \rightarrow \mathbb{R}$, policy functions $\ell_e(\ell_F, y, \ell) \in \mathcal{L}$ and $\ell_u(\ell) \in \mathcal{L}$, market tightness $\theta \in \mathbb{R}_+$, a wage function when employed and unemployed, $w : \mathcal{L} \times Y \times \mathcal{L} \times Y \times \mathcal{L} \rightarrow \mathbb{R}_+$ and $w_U : \mathcal{L} \times Y \times \mathcal{L} \rightarrow \mathbb{R}_+$, a rent function $k_R : \mathcal{L} \rightarrow \mathbb{R}_+$, and distributions of vacancies, of workers across employment states, and of workers and firms across space such that

- (i) For each $\ell_F \in \mathcal{L}$, and $y \in Y$, $M_{\ell_F}(y, \ell)$ satisfies (10) and $\ell_e(\ell_F, y, \ell)$ is the associated policy function. For each $\ell \in \mathcal{L}$, $U(\ell)$ satisfies (4) and $\ell_u(\ell)$ is the associated policy function.
- (ii) When an outside offer arrives, wages $w(\hat{\ell}_F, \hat{y}, \ell_F, y, \ell)$ are determined by the surplus splitting equations (2) and (3). When an offer arrives to the unemployed worker, the wage $w_U(\ell_F, y, \ell)$ is determined by (1).
- (iii) Market tightness is given by (8).
- (iv) For each $(\ell, \ell_F, y) \in \mathcal{L} \times \mathcal{L} \times Y$, the distributions across employment states satisfy $e_{\ell_F}^+(y, \ell) = e_{\ell_F}^-(y, \ell)$ and $u^+(\ell) = u^-(\ell)$, given by (12)-(15). The distributions across space equate (16) and (17).
- (v) For each $\ell \in \mathcal{L}$, $\psi(\ell)$ satisfies (18) and rent $k_R(\ell)$ adjusts such that (19) holds.

I restrict attention to the steady state for tractability, since firms' vacancy posting decisions depend on the worker distributions, therefore the surplus will depend on all of the distributions. In equilibrium, this distribution is determined by the optimal location choice of vacancies. In steady state, equating the flows of employed and unemployed workers determines their distributions $e_{\ell_F}(y, \ell)$ and $u(\ell)$. Under the assumption that vacant firms do not enter into the flows across space, imposing steady state in the labor market implies the spatial steady state, that is, the equality of (16) and (17).

Existence

Proving existence of the equilibrium is nontrivial due to the dependence of the spatial distributions of workers and firms on the rent price. The complication arises here because the rent price function k_R implies steady state distributions of workers across firms and locations, and these distributions must also be consistent with the market clearing condition for land. The demand correspondence that takes prices and returns a vector of demands corresponding to the right hand side of (19) is clearly nonempty. However, it is not clear that the correspondence is upper hemicontinuous nor convex-valued, since the distributions of vacancies and workers may not respond continuously to changes in price and agents must choose one discrete location in which to rent.

The exogenous probability of drawing a given location in which to post makes the choice of vacancies continuous as a function of the price. If vacancies were able to choose their location freely, all would be posted in the location with the highest surplus, violating continuity. Regarding convexity, I use results from [Kaneko and Yamamoto \(1986\)](#), who show that an equilibrium price vector exists in an economy where agents may choose only one of many indivisible goods by first solving a “convexified” problem, and then showing that any solution to such a problem is also a solution to the original problem. As discussed below, their model takes household preferences, or types, as given, whereas here worker types depend crucially on prices. I extend the continuity arguments discussed above to prove the result in the present set up.

For any price vector $k_R \in \mathbb{R}^N$, the surplus equation simply extends the standard [Cahuc et al. \(2006\)](#) model, taking the spatial costs as given. Given the surplus value, the steady state flows of workers across employment states imply that for each $(\ell_F, y) \in \mathcal{L} \times Y$ and $\ell \in \mathcal{L}$,

$$e_{\ell_F}(y, \ell) = \frac{p(\theta)g(\ell_F, y)N_e(\ell_F, y, \ell)}{\delta + \lambda_1 p(\theta) \sum_{\tilde{\ell}_F \in \mathcal{L}} \sum_{\tilde{y} \in Y} \mathbb{1}\{S_{\tilde{\ell}_F}(\tilde{y}, \ell) > S_{\ell_F}(y, \ell)\} g(\tilde{\ell}_F, \tilde{y})}$$

where

$$N_e(\ell_F, y, \ell) = \sum_{\ell' \in \mathcal{L}} [\lambda_0 u(\ell') \mathbb{1}\{S_{\tilde{\ell}_F}(\tilde{y}, \ell') > 0\} + \lambda_1 \sum_{(\tilde{y}, \tilde{\ell}_F) \in B_1^{-1}(y, \ell_F, \ell')} e_{\tilde{\ell}_F}(\tilde{y}, \ell')] \mathbb{1}\{\ell_e(\ell_F, y, \ell') = \ell\}$$

and $B_1^{-1}(y, \ell_F, \ell') = \{(\tilde{\ell}_F, \tilde{y}) \in \mathcal{L} \times Y : S_{\tilde{\ell}_F}(\tilde{y}, \ell') < S_{\ell_F}(y, \ell')\}$.

Similarly, the mass of unemployed located at ℓ is

$$u(\ell) = \frac{\delta \sum_{\ell' \in \mathcal{L}} \sum_{\ell_F \in \mathcal{L}} \sum_{y \in Y} e_{\ell_F}(y, \ell') \mathbb{1}\{\ell_u(\ell') = \ell\}}{\lambda_0 p(\theta) \sum_{\ell_F \in \mathcal{L}} \sum_{y \in Y} \mathbb{1}\{S_{\ell_F}(y, \ell) > 0\} g(\ell_F, y)}$$

The steady state distributions are pinned down by the surplus value S and policy functions determining workers' locations. Proposition 1 states that there exists a bounded price vector k_R satisfying the conditions of a steady state equilibrium.

Proposition 1. *A steady state price vector k_R exists.*

The proof follows the arguments presented in [Kaneko and Yamamoto \(1986\)](#). The proof differs from the previous literature because not only do the demands for land change by worker type, but also the mass of each type of worker, that is, her employment status and current match, respond to changes in rent prices. Intuitively, when “types” are fixed, workers and firms are permanently matched. An increase in rent near the most productive jobs will make the surplus of such matches fall, and workers will respond by trading off their commuting and rent costs. When workers and firms can choose who to match with, such an increase in rent will not only cause changes in residential patterns of workers in existing firms, but also change the set of acceptable matches, the distribution of vacancies, and the unemployment rate. This causes the distributions of workers and firms, market tightness, match surplus, and wages all to change in response to prices. The proof thus hinges on showing that the steady state distributions respond continuously to the price. This key mechanism by which spillovers exist between labor and rental markets is a fundamental feature of this model.

I now characterize properties of the rent vector assuming ν is quasilinear in the resources that the landlord gets from selling the available land:

$$\nu(\hat{L}(\ell) - \psi(\ell), k_R(\ell)\psi(\ell)) = \nu(\hat{L}(\ell) - \psi(\ell)) + k_R(\ell)\psi(\ell)$$

where $\nu' > 0$, $\nu'' < 0$ and $\lim_{x \rightarrow 0} \nu'(x) = \infty$. Then the landlord's choice of supply is given

by the first order condition:

$$\psi(\ell) \begin{cases} = 0 & \text{if } \nu' > k_R(\ell) \\ \in (0, \hat{L}(\ell)) & \text{if } \nu' = k_R(\ell) \\ = \hat{L}(\ell) & \text{if } \nu' < k_R(\ell) \end{cases}$$

Since ν is strictly increasing and concave, there is a unique choice of ψ given k_R when the landlord's solution is interior, with $\psi(\ell)$ strictly increasing in k_R . Further, by the Inada condition on ν , landlords will never supply all available land and therefore we can rule out the final case in the landlord's first order condition.

If there is excess supply, that is, (19) is slack, the landlords are not consuming enough of the available land themselves. Thus, the price must fall, increasing demand and decreasing supply until (19) holds with equality. The market clearing price then satisfies

$$\nu' \left(L - u(\ell) - \sum_{y \in Y} \left[\sum_{\ell_F \in \mathcal{L}} e_{\ell_F}(y, \ell) - \sum_{\tilde{\ell} \in \mathcal{L}} e_{\ell}(\tilde{\ell}) \right] \right) = k_R(\ell) \quad (20)$$

where I have replaced $\hat{L}(\ell)$ with the total supply of land less continuing matches.

In the proof, I show that land demand is weakly decreasing in rent. The right hand side of (20) is strictly increasing in the price and the left hand side is weakly decreasing since the landlords must consume more land as demand from workers and newly created matches falls. Therefore, even though workers' demands exhibit inaction regions due to the presence of a fixed moving cost, strict concavity of the landlord's utility function and the Inada condition insure that there is a unique rent price satisfying (20).

4 Quantitative Model

In this section I extend the model before bringing it to the data. All details of the model, corresponding to Sections 3.2 through 3.5 are contained in Appendix B. To allow for different job search and location choices by skill, workers are assumed to be heterogeneous in their fixed skill, z , which is drawn from a finite set Z . Production in a match is a function of worker and firm productivity, where firm productivity y is assumed to be a match-specific productivity shock¹⁰, such that a continuing match in location ℓ_F draws a new $y \sim H$ at rate μ . Output in the match is $f(y, z)$, which is strictly increasing in both of its arguments.

¹⁰Unlike Lise, Meghir, and Robin (2016), I assume that productivity shocks are match- rather than job-specific.

In addition, employed workers face “moving shocks” at rate φ , which trigger a draw of the worker’s location from exogenous distribution $\Pi(\ell)$, where $\pi(\ell)$ denotes the probability that the worker draws $\ell \in \mathcal{L}$.

Wage negotiation is identical to that above when an outside offer arrives, and renegotiation after idiosyncratic productivity and moving shocks is modeled as in [Postel-Vinay and Turon \(2010\)](#) and [Lise et al. \(2016\)](#). Here, employed workers have three opportunities for wage negotiation: the arrival of an outside offer, a productivity shock, or a moving shock that affects the surplus of the match. Appendix B discusses the model and defines the equilibrium¹¹.

4.1 Quantitative Results

[IN PROGRESS]

I now calibrate the model of Section 4 to quantitatively evaluate the importance of the commuting channel. This section discusses the parametric assumptions and parameter values. Section 4.2 discusses the results. Section 4.3 performs several counterfactual exercises to examine the link between labor market and urban policies related to commuting and moving costs.

Looking first at the distributions and functional forms, the production function is specified as: $f(y, z) = yz$. Given worker skills, the distribution match productivity y determines the cross sectional distribution of wages. I set the number of worker productivity levels equal to 3, normalizing the lowest z to 1. I calibrate the remaining two values of z to match the relative wages between workers with some college and college degrees relative to those with less than a high school education. The number of firm types is 5.

A significant limitation of the data used in Section 2 is that there is no data on firm locations or productivity. In addition, since entry choices are endogenous and workers may change location by paying the moving cost, I assume that the initial location distribution is uniform and set the number of locations to 5. Finally, the market tightness function is assumed to take the standard form: $p(\theta) = \min\{1, \theta^\sigma\}$, where $\sigma = .5$, a standard value.

The discount rate r is set to match an annual interest rate of 0.05 and the death rate χ is chosen to match an average working lifetime¹² of 47 years. The unemployment benefit b is constant for all workers and is chosen to match a ratio of the value of nonemployment to the average wage of 0.4. The exogenous meeting rates λ_0 and λ_1 are set to match the average EU and EE rates in UK data estimated by [Gomes \(2012\)](#). Following [Lise et al.](#)

¹¹Existence of the equilibrium in the full quantitative model can be proven using the arguments presented in the proof of Proposition 1, and is available upon request.

¹²The working lifetime corresponds to ages 18-65.

Table 3: Parameter Values

Parameter	Description	Value
r	Monthly interest rate	.0041
χ	Death rate	.0018
δ	Separation rate	.0033
μ	Match productivity shock	.04
φ	HH moving shock	.008
λ_1	Relative search rate, E	.04
γ	Matching function elasticity	.5
b	Unemployment benefit	.46
β	Worker bargaining power	.3
τ_1	Commuting cost constant	.33
τ_2	Commuting cost exponent	.33
ϵ_y	$y_H, y_L = 1 \pm \epsilon_y$	.0061
κ_y	Pareto shape	1.67
σ_y	Pareto scale	.0015
k_M	Moving cost	.094
α_L	Landlord $\succsim$	.1
c	Vacancy flow cost	.2

(2016), worker bargaining power β is estimated using observed wage increases after a job-to-job transition. Transitions from employment to unemployment in the model may be either involuntary or voluntary, and are driven by the parameters δ , φ , and μ . All matches hit by the δ shock are destroyed, but only those that become unproductive after being hit by the μ or φ shocks are destroyed. A productivity shock that implies a positive surplus can also lead to wage renegotiation, thus, μ is identified by the within-job variance of wages together with λ_1 . The moving shock φ is identified by the share of moves resulting in an increased commute for workers staying in the same job. Given μ and φ , the average EU rate is used to pin down δ . The vacancy posting cost c is set to match the average job-finding probability for all workers, estimated using data by [Gomes \(2012\)](#).

The novel parameters of the model determine moving costs, commuting costs, and output. Together, those related to commuting and output will be used in the next section to back out the implied distribution of productivity growth. The commuting cost function

Table 4: Calibration Targets

Parameter	Primary Target	Data	Model
r	Annual interest rate	.05	.05
χ	Years in LF (18 to 65)	47	47
δ	EU rate (quarterly)	.014	.014
μ	Within-job wage growth (annual)	.012	.010
β	Between-job wage growth (annual)	.027	.039
φ	Share of movers, $\uparrow$ commute	.50	.48
λ_0	UE rate (quarterly)	.27	.24
λ_1	EE rate (quarterly)	.028	.031
γ	standard value	.5	.5
b	Share of average wage (Shimer, 2005)	.4	.4
τ_1	Share of Wage Cuts following J2J	.33	.34
τ_2	Regression coefficient, Δ commute	.33	.34
ϵ_y	Between wage variance	.0061	4.40
κ_y	50-10th pctile of wage distribution	1.67	1.25
σ_y	Within wage variance	.0011	1.25
k_M	Moving probability (annual)	.094	.081
α_L	Average Rent/Income	.27	.18
c	Job finding probability	.47	.47

τ is assumed to take the form

$$\tau(\ell, \ell_F) = \tau_1 |\ell - \ell_F|^{\tau_2}$$

where $\tau_1, \tau_2 > 0$ are constants.

I use four empirical moments which are informative about the commuting costs. First, the share of wage cuts following job-to-job transitions. In the model, nearly all wage cuts are driven by commuting cuts; in the data this figure is roughly 30%, as discussed in Section 2. Second, the coefficient β_1 from the regression

$$\Delta w_t = \beta_0 + \beta_1 \Delta \tau(\ell, \ell_F) + \beta_2 X_t + \epsilon_t$$

conditional on making a J2J transition, where $\Delta \tau(\ell, \ell_F)$ in the data is measured as the

change in commuting time after a J2J transition and X_t is a vector of covariates¹³. In the model, I run the same regression on simulated workers' transitions. The final two moments used to identify the commuting cost parameters are the standard deviation of the log of commuting time and the standard deviation of (log) commuting changes following a J2J transition¹⁴.

Turning to the three parameters determining the productivity distribution for match productivity y , I use 7 moments related to the distribution of all wages and of wage growth within and between jobs. In particular, in the data I compute the mean and standard deviation of wage changes between and within jobs, the 50-10th and 90-10th percentiles of the wage distribution for all employed workers, and the relative variance of wage growth between and within jobs. I compute the analogous moments in the simulated data generated by the model. Finally, I use the average annual moving rates for employed and unemployed individuals to pin down the moving cost k_M .

Finally, the endowment of land L is chosen such that there is enough land for twice the maximum mass of workers and firms: $L(\ell) = 4/N$. Landlords' preferences are assumed to be quasilinear:

$$\nu(L - \psi(\tilde{\ell}), k_R(\tilde{\ell})\psi(\tilde{\ell})) = \alpha_L \log(L - \psi(\tilde{\ell})) + k_R(\tilde{\ell})\psi(\tilde{\ell})$$

where $\alpha_L < 1$. The parameter α_L is chosen such that the endogenous rent function implies an average private rent to (net) income ratio of 0.35 reported by the English Housing Survey between 2010 and 2017.

Appendix C describes the numerical solution algorithm. For each set of parameter values, I solve the model and simulate 50,000 worker histories over 5,000 months. I then aggregate the results as necessary to quarterly or annual frequency to compute the model-implied moments. Calibrated parameter values are shown in Table 3 and moments used in the calibration are contained in Table 4.

4.2 Quantitative Results

[IN PROGRESS]

This section presents the results of the quantitative model. Beginning with partial

¹³These covariates are: an indicator for whether the worker's commuting method or residence changed in the past year, and lagged variables for full time, job tenure, rent or mortgage payments, homeownership, education, number of employment spells in the past year, whether the worker is married and the spouse is employed, age, number of children, and a quadratic term for labor market experience, and dummies for year, month, region, commuting method, occupation and industry.

¹⁴In the model, commuting is in levels.

Table 5: Estimated Parameters, Values

Parameter	Description	Value
τ_1	Commuting Cost Scale	.045 (SE)
τ_2	Commuting Cost Exponent	1.66 (SE)
a_1	Mismatch parameter	.1 (SE)
a_2	Shape of $f(y, z)$	.5 (SE)
k_M	Moving Cost	36 (SE)

Table 6: Estimated Parameters, Targets

Parameter	Primary Target	Data	Model
τ_1	Share of Wage Cuts following J2J	.33	.34
τ_2	Regression coefficient, Δ commute	.33	.34
a_1	Between/within wage variance	5.42	4.40
a_2	50-10th pctl of wage distribution	1.67	1.25
k_M	Moving probability (annual)	.094	.081

equilibrium, I set $k_R(\ell) = .3$ for all locations and solve for the steady state in the labor market given the parameter values in the previous section. The left panel of Figure 3 shows the area in (ℓ_F, y) space for which a given employed worker accepts, rejects, or renegotiates his current wage. The right panel of the figure shows the corresponding wage at the cutoff for which the worker either accepts or renegotiates, that is, the wage she will earn if the offer is just good enough to make a job-to-job transition or renegotiate, corresponding to the solid lines in the left panel.

The right panel shows the range of commutes for which the worker is willing to take a wage cut, all of which are at firm locations closer to the center and therefore with a shorter commute than the worker's current match. Because of the bargaining assumptions, workers will use offers with longer commutes and lower productivity to bid up their current wage, shown by the dark gray region in the left panel and the blue line in the right panel. Interestingly, the worker will use jobs with much lower productivity but shorter commutes to renegotiate, shown by the blue line near the bottom of the right panel.

Figure 3: Partial Equilibrium: Constant Rent

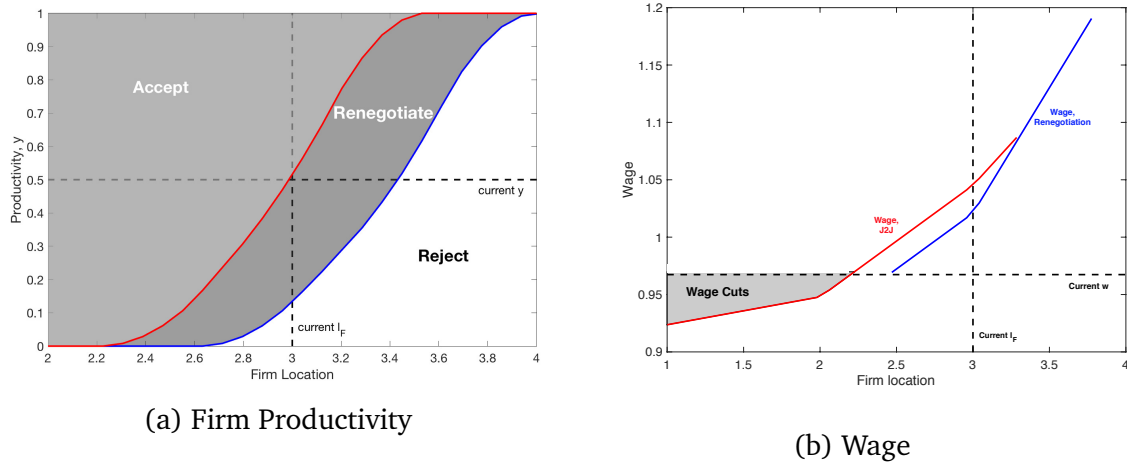
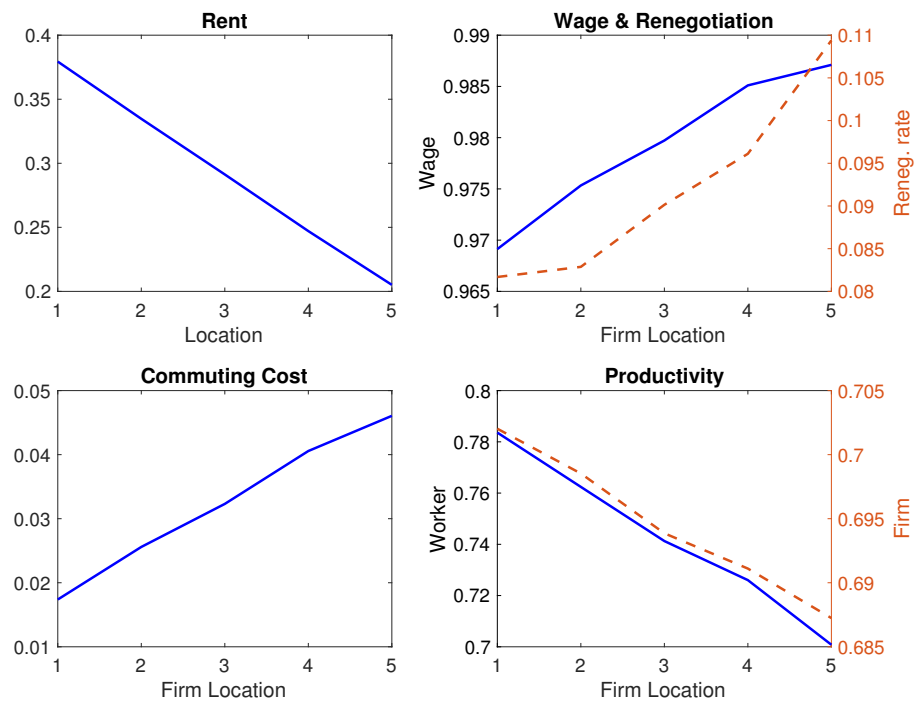


Figure 4: Spatial Effects: Aggregate



Moving to the general equilibrium, Figure 4 presents aggregate outcomes across the spatial dimension. The top right panel shows the downward sloping rent function: the center is more attractive to both workers and firms due to low commuting costs, pushing up land demand. Rent is linear because of the assumption of a constant amount of available land in each location and linear commuting costs. The horizontal axis in the remaining subplots corresponds to the location of the job. The top right panel shows average wages and renegotiation rates. As the firm is located farther from the center, wages increase because the fall in rent more than offsets the increase in commuting costs, and additionally the rate of renegotiation is higher for workers with longer commutes. These workers renegotiate more because the surplus in their current job is higher and therefore they have more room to renegotiate before making a job-to-job transition. The bottom right panel shows that commuting costs, as a share of output, are increasing in the distance of the firm from the center. Finally, the bottom right panel shows that there is some spatial sorting of highly skilled workers and high productivity firms closer to the center. Since rent is higher, and the surplus is increasing in firm and worker productivity, it is these matches which are profitable to operate in the center. Overall, the aggregate effects are qualitatively in line with the stylized facts presented in Section 2: workers who commute more have higher wages, and the center has the highest rent and productivity.

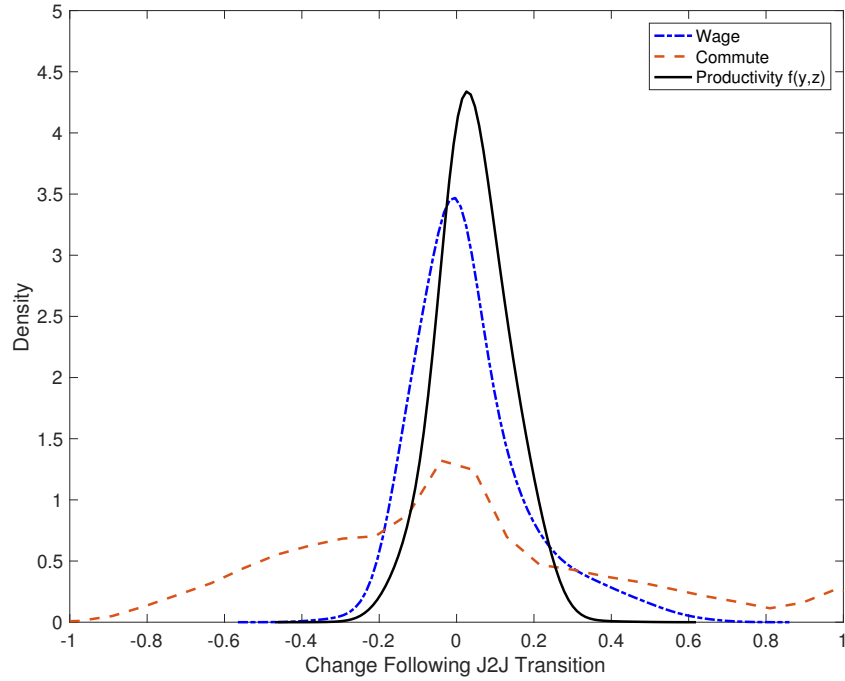
4.2.1 Estimating the Productivity Ladder

The goal of this section, given plausible values for wage dispersion and commuting costs, is to uncover the implied productivity ladder that workers climb through on-the-job search. The model implies that given the locations of workers and firms, which define the commute, and observed wage changes before and after job-to-job transitions, one can infer the change in output which driven by productivity differences across jobs.

In many models, the shape of the wage distribution is tightly linked to that of the productivity distribution. However, in the presence of non-productivity related job characteristics, changes in these aspects of the job may either dampen or amplify observed wage changes. Unlike models with non-wage amenities that augment the wage, here, commuting costs are compensated by wages and therefore introduce a second important dimension to the job ladder.

In the model, output is a function only of worker and firm productivities. Since the worker type is fixed, by observing wage and commuting changes the model allows us to infer the importance of moving to more (or less) productive firms as workers climb the job ladder. Figure 5 plots the changes in wages, commuting costs, and output following job-to-job transitions. The figure shows that the variance in wage changes is higher than that of

Figure 5: Implied Changes in Productivity



productivity changes because workers experience large changes in commuting costs when climbing the job ladder. The model predicts that the dispersion in productivity changes following job-to-job transitions is 57% of the dispersion in wages, with the remaining wage variation driven by changes in workers' commutes.

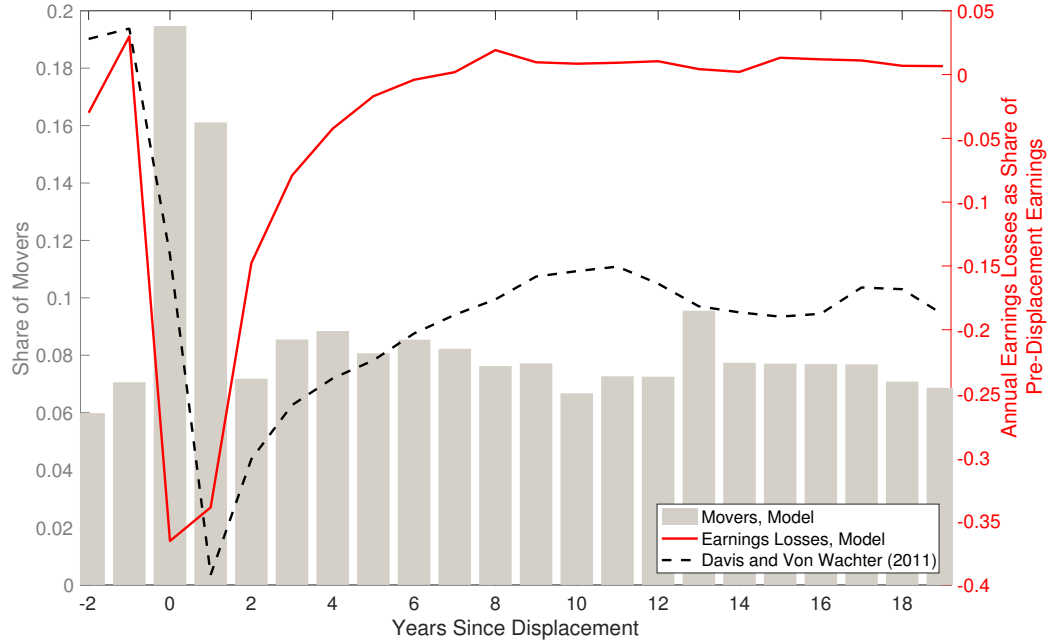
4.2.2 Wage Dispersion

This section studies the effect of spatial frictions on the cross-section of wages in the model. I compare dispersion by worker skill, experience, worker and firm location, and commute to the average dispersion in the economy. In a model without commuting costs, the location of workers and firms would play no role in wage dynamics, but here because of the interaction of spatial frictions with the job ladder, they are crucial.

4.2.3 Earnings Losses

This section compares the average earnings losses following a displacement into unemployment from the model simulations. To construct my measure of earnings losses, I simulate the individuals over time and identify workers who were employed for at least two years before transitioning from employment into unemployment in a period (month). I then

Figure 6: Simulated Earnings Losses



follow each worker over the next 20 years and compute earnings losses in each simulated year, as a fraction by the individual's average annual earnings in the two years prior to the displacement, conditional on survival over the 22 year sample. I define the displacement as occurring for each worker in the 6th month of the year of displacement (year 0).

Figure 6 shows the percentage losses relative to the average pre-employment wage in the two years before the transition into unemployment (solid line, right axis). The bar graph plots the share of these workers who change residence in each year, shown on the left axis. For comparison, the dashed line (right axis) shows the estimated earnings losses from [Davis and von Wachter \(2011\)](#) using Social Security Administration (SSA) data for workers with at least 3 years of tenure in the average US recession. Although untargeted, the model matches the trough of earnings losses in the first and second years following displacement, though the recovery is much faster. When workers have the ability to adjust on both the commuting and wage margins as they climb the job ladder, workers starting an employment spell with a long commute will trade off lower earnings for shorter commutes, making the earnings losses more persistent. Further, nearly 20% of newly unemployed workers move in the year of displacement or the next year, illustrating the importance of spatial frictions in the model's predictions.

4.3 Counterfactuals

In this section I use the model to perform several counterfactual exercises. First, what is the effect of a subsidy on commuting costs? Second, what is the effect of a change in technology allowing workers high productivity matches to work remotely? Third, what is the effect of an increase in the fixed moving cost? I compare steady states of the model corresponding to each of these questions relative to the benchmark model in the sections below.

4.3.1 Commuting Subsidy

This section studies the effect of a subsidy on commuting costs on individual and aggregate labor market and spatial outcomes. Suppose there is a benevolent government that raises funds via a lump-sum tax T paid by all employed workers, and transfers it as a proportional subsidy s to all employed workers' commuting costs. Under the subsidy, the flow value of the match is given by

$$\begin{aligned} (r + \chi)\tilde{M}_{\ell_F}(y, z, \ell) &= (1 - (1 - s)\tau(\ell, \ell_F))f(y, z) - k_R(\ell_F) - k_R(\ell) - T \\ &\quad + (\delta + \mu + \varphi)(U(z, \ell) - M_{\ell_F}(y, z, \ell)) + \mu \sum_{y' \in Y} \max\{0, M_{\ell_F}(y', z, \ell) - U(z, \ell)\}h(y') \\ &\quad + \varphi \sum_{\ell' \in \mathcal{L}} \max\{0, M_{\ell_F}(y, z, \ell') - U(z, \ell')\}\pi(\ell') + \lambda_1 p(\theta)\beta \sum_{(\hat{\ell}_F, \hat{y})} \max\{0, M_{\hat{\ell}_F}(\hat{y}, z, \ell) - M_{\ell_F}(y, z, \ell)\}g(\hat{\ell}_F, \hat{y}) \end{aligned}$$

The government's budget constraint is

$$T(1 - u) = s \int_{(\ell_F, y, z, \ell)} \tau(\ell, \ell_F)f(y, z)de_{\ell_F}(y, z, \ell)$$

Table 7 compares outcomes in the benchmark model with no subsidy to those in the model with a 20% and 50% subsidy on commuting.

4.3.2 Change in Technology: Working Remotely

[in progress]

4.3.3 Change in Moving Costs

[in progress]

Table 7: Effect of Commuting Subsidy

Model Moment	Benchmark ($s = 0$)	$s = 0.2$	$s = 0.5$
Avg Commuting Cost/Output	0.038	0.037	0.028
Average Output	1.25	1.26	1.26
Moving rate (annual)	0.075	0.075	0.075
EE rate (annual)	0.132	0.138	.0138
UE rate (annual)	0.581	0.581	0.583
Average Mismatch	0.109	0.108	0.109
Rent, Center	0.218	0.209	0.208
Rent, Periphery	0.116	0.121	0.110
Average Tax/Wage	0	0.017	0.048

5 Conclusion

[In progress...] In this paper I suggest a mechanism whereby commuting costs directly affect the shape of the job ladder and the speed with which workers climb it. I propose a tractable model that can address this link and that allows for endogenous wages and housing prices, both of which are crucial in the determination of the spatial configuration of workers and firms and aggregate productivity. I show several empirical patterns linking the commute to current and future labor market outcomes for individuals. These patterns are robust both across and within workers, as well as across UK metropolitan areas. Theoretically, I construct a model whereby wages and rent are endogenously determined, and in which workers and firms choose their locations and whether or not to match. Adopting a frequently used bargaining protocol, the model remains highly tractable but rich in its predictions. The framework generates the empirical patterns that I document in UK data, and predicts large effects of commuting costs on the implied productivity ladder, individual wage profiles, and aggregate labor market outcomes. The model can directly speak to crucial questions faced by policymakers, and introduces important trade-offs to evaluate infrastructure policies aimed at bringing workers and jobs together and maximizing productivity.

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A Proofs

A.1 Proof of Proposition 1

For the purposes of the proof, I define value functions, policy functions, and distributions as functions of the price vector k_R , e.g. $U(\ell; k_R)$. I assume that the distributions of workers, $u(\hat{\ell}; k_R)$ and $e_{\ell_F}(y, \hat{\ell}; k_R)$ are continuous in k_R .

Part 1a - Demand Correspondence

Define the demand correspondence for newly matched vacancies for each $i = 0, \dots, N$ and $y \in Y$ as

$$\begin{aligned} D_V(\ell_i, y; k_R) &= e^{i+1} p(\theta(k_R)) \sum_{\ell} [\lambda_0 u(\ell; k_R) \mathbb{1}\{S_{\ell_i}(y, \ell; k_R) > 0\} \\ &+ \lambda_1 \sum_{\hat{\ell}} \sum_{\hat{y}} \mathbb{1}\{S_{\ell_i}(y, \ell; k_R) > S_{\hat{\ell}}(\hat{y}, \ell; k_R)\} e_{\hat{\ell}}(\hat{y}, \ell; k_R)] \end{aligned}$$

where e^i is the i -th unit vector of dimension $N + 1$, and the second term is the probability a meeting occurs and the match is accepted. This demand correspondence defines the number of vacancies created in location $i - 1 = 0, \dots, N$.

Similarly, define the demand correspondence for the employed and unemployed, respectively, as

$$\begin{aligned} D_E(\ell_F, y, \hat{\ell}; k_R) &= \{x \in \{0, e^1, e^2, \dots, e^{N+1}\} : \beta S_{\ell_F}(y, \hat{\ell}; k_R) > \bar{u} \text{ and} \\ &x(\ell) \in \arg \max M_{\ell_F}(y, \hat{\ell}; k_R)\} \end{aligned}$$

for each $(\ell_F, y) \in \mathcal{L} \times Y$ and $\hat{\ell} \in \mathcal{L}$ and

$$D_U(\hat{\ell}; k_R) = \{x \in \{0, e^1, e^2, \dots, e^{N+1}\} : U(\hat{\ell}; k_R) \geq \bar{u} \text{ and } x(\ell) \in \arg \max U(\hat{\ell}; k_R)\}$$

for each $\hat{\ell} \in \mathcal{L}$. I denote the location choice implied by x as $x(\ell) \in \mathcal{L}$. Clearly, since all of the sets include 0, all three sets are nonempty. Define the aggregate demand correspondence $D(k_R)$ as

$$D(k_R) = \sum_{\hat{\ell}} \sum_{\hat{y}} D_V(\hat{\ell}, \hat{y}; k_R) g(\hat{\ell}, \hat{y}) + D_U(\hat{\ell}; k_R) u(\hat{\ell}; k_R) + \sum_{\ell_F} \sum_y D_E(\ell_F, y, \hat{\ell}; k_R) e_{\ell_F}(y, \hat{\ell}; k_R)$$

The first term is the demand correspondence for land for each vacancy which is created, multiplied by the mass of vacancies of each type $(\hat{\ell}, \hat{y})$. The second and third terms are the

demand correspondences, respectively, of the unemployed and employed workers living in $\hat{\ell}$ times their mass. Importantly, the mass of workers and firms in each location and of workers in each employment state depends on the price vector k_R .

It is clear that $M_{\ell_F}(y, \hat{\ell}; k_R)$ and $U(\ell; k_R)$ are continuous functions of k_R . By assumption, $u(\hat{\ell}; k_R)$ and $e_{\ell_F}(y, \hat{\ell}; k_R)$ are continuous, and by (8), it follows that θ is continuous in k_R . Thus, U , W , and J are all continuous in k_R . Given these results, I now prove each element of $D(k_R)$ is upper hemicontinuous (UHC).

(i) Unemployed: $D_U(\hat{\ell}; k_R)u(\hat{\ell}; k_R)$

Take an arbitrary $\hat{\ell} \in \mathcal{L}$. Take a sequence $k_R^n \rightarrow k_R^0$, $x^n \rightarrow x^0$ with $x^n \in D_U(\hat{\ell}; k_R^n)$ for all n .

Since S is continuous and $x^n \in \arg \max U(\hat{\ell}; k_R^n) \forall n$, it follows that x^0 must be feasible. Suppose $x^0 \notin \arg \max U(\hat{\ell}; k_R^0)$. Then since $D_U(\hat{\ell}; k_R^0)$ is nonempty, there exists $x' \in \{0, e^1, e^2, \dots, e^{N+1}\}$ with $x' \in \arg \max U(\hat{\ell}; k_R^0)$. Thus,

$$\tilde{U}(x'(\ell); k_R^0) - k_M \mathbb{1}\{x'(\ell) \neq \hat{\ell}\} > \tilde{U}(x^0(\ell); k_R^0) - k_M \mathbb{1}\{x^0(\ell) \neq \hat{\ell}\}$$

Since $x' \neq x^0$, it must be the case that $x'(\ell) \neq \hat{\ell}$ or $x^0(\ell) \neq \hat{\ell}$ or both. Then

$$\begin{aligned} & \tilde{U}(x'(\ell); k_R^0) - k_M \mathbb{1}\{x'(\ell) \neq \hat{\ell}\} - \tilde{U}(x^n(\ell); k_R^n) + k_M \mathbb{1}\{x^n(\ell) \neq \hat{\ell}\} \\ & > \tilde{U}(x^0(\ell); k_R^0) - k_M \mathbb{1}\{x^0(\ell) \neq \hat{\ell}\} - \tilde{U}(x^n(\ell); k_R^n) + k_M \mathbb{1}\{x^n(\ell) \neq \hat{\ell}\} \end{aligned}$$

For n large enough, the right hand side can be made arbitrarily close to zero, thus

$$\tilde{U}(x'(\ell); k_R^0) - k_M \mathbb{1}\{x'(\ell) \neq \hat{\ell}\} > \tilde{U}(x^n(\ell); k_R^n) - k_M \mathbb{1}\{x^n(\ell) \neq \hat{\ell}\}$$

But U is continuous in k_R , so

$$\tilde{U}(x'(\ell); k_R^n) - k_M \mathbb{1}\{x'(\ell) \neq \hat{\ell}\} > \tilde{U}(x^n(\ell); k_R^n) - k_M \mathbb{1}\{x^n(\ell) \neq \hat{\ell}\}$$

which is a contradiction since $x^n \in D_U(\hat{\ell}; k_R^n)$. Since $\hat{\ell} \in \mathcal{L}$ was arbitrary, it follows that $D_U(\ell; k_R)$ is UHC for all $\ell \in \mathcal{L}$, and given the guess that $u(\ell; k_R)$ is continuous, $D_U(\hat{\ell}; k_R)u(\hat{\ell}; k_R)$ is UHC.

(ii) Employed: $\sum_{\ell_F} \sum_y D_E(\ell_F, y, \hat{\ell}; k_R)e_{\ell_F}(y, \hat{\ell}; k_R)$

Similarly to the argument in part (i), consider an arbitrary $(\ell_F, y) \in \mathcal{L} \times Y$ and $\hat{\ell} \in \mathcal{L}$,

and let $k_R^n \rightarrow k_R^0$, $x^n \rightarrow x^0$ with $x^n \in D_E(\ell_F, y, \hat{\ell}; k_R^n)$ for all n . Clearly x^0 is feasible, but suppose there exists $x' \in D_E(\ell_F, y, \hat{\ell}; k_R^0)$. Then $x'(\ell) \in \arg \max M_{\ell_F}(y, \hat{\ell}; k_R^0)$. Since M is continuous $\exists N$ such that for $n > N$, $x^n(\ell) \in \arg \max M_{\ell_F}(y, \hat{\ell}; k_R^n)$, a contradiction.

Since (ℓ_F, y) and $\hat{\ell}$ were arbitrary, and using our guess $e_{\ell_F}(y, \hat{\ell}; k_R)$ is continuous in k_R , the above argument holds for all $(\ell_F, y) \in \mathcal{L} \times Y$ and $\hat{\ell} \in \mathcal{L}$, and thus $\sum_{\ell_F} \sum_y D_E(\ell_F, y, \hat{\ell}; k_R) e_{\ell_F}(y, \hat{\ell}; k_R)$ is upper hemicontinuous.

(iii) Vacancies: $\sum_{\hat{y}} D_V(\hat{\ell}, \hat{y}; k_R) g(\hat{\ell}, \hat{y})$

Consider an arbitrary $(\hat{\ell}, \hat{y}) \in \mathcal{L} \times Y$. Each

$$\begin{aligned} & p(\theta(k_R)) \sum_{\ell} [\lambda_0 u(\ell; k_R) \mathbb{1}\{S_{\ell_i}(y, \ell; k_R) > 0\} \\ & + \lambda_1 \sum_{\hat{\ell}} \sum_{\hat{y}} \mathbb{1}\{S_{\ell_i}(y, \ell; k_R) > S_{\hat{\ell}}(\hat{y}, \ell; k_R)\} e_{\hat{\ell}}(\hat{y}, \ell; k_R)] \end{aligned}$$

is continuous since θ and S are continuous under the assumption that u and e are continuous. Thus, D_V is UHC for all $(\hat{\ell}, \hat{y}) \in \mathcal{L} \times Y$, and $\sum_{\hat{y}} D_V(\hat{\ell}, \hat{y}; k_R) g(\hat{\ell}, \hat{y})$ is UHC.

Given the continuity of S and θ , it follows from the steady state conditions equating the flows into and out of employment and unemployment that $u(\hat{\ell}; k_R)$ and $e_{\ell_F}(y, \hat{\ell}; k_R)$ are continuous in k_R for each $\hat{\ell} \in \mathcal{L}$, verifying the guess. Thus, the aggregate demand correspondence $D(k_R)$ is nonempty and UHC.

Part 1b - Supply Correspondence

The supply of land at each location ℓ available to allocate to each group making up the demand correspondence above is given by the land choice of the landlord, $\psi(\ell)$, less the land occupied by continuing jobs, for whom the location is a state. In steady state, the amount of land occupied by continuing jobs is constant and equal to the mass of jobs located in ℓ less the mass of endogenously or exogenously destroyed matches. In each location $\ell \in \mathcal{L}$, the supply is given by

$$\Sigma(\ell, k_R) = \psi(\ell, k_R) - \sum_y \sum_{\hat{\ell}} (e_{\ell}(y, \hat{\ell}; k_R) - e_{\ell}^-(y, \hat{\ell}; k_R))$$

where $\Sigma(\ell, k_R) \geq 0$ if $k_R \geq 0$ and 0 otherwise since landlords will not rent at a negative price by assumption. The term $e_{\ell}^-(y, \hat{\ell}; k_R)$ corresponds to (13). The supply function in each location is clearly continuous in k_R given landlords' preferences and given that e_{ℓ} is

continuous in k_R . Thus, the aggregate supply correspondence is the vector

$$E(k_R) = [\Sigma(0, k_R), \dots, \Sigma(N, k_R)]$$

which is nonempty and upper hemicontinuous.

Part 2 - Excess Demand

Define the excess demand correspondence as

$$E(k_R) = D(k_R) - \Sigma(k_R)$$

It follows from Part 1 that the excess demand correspondence maintains the nonemptiness and upper hemicontinuity of the supply and demand correspondences. Define the set of prices as $P = [0, P_{max}]^{N+1}$, where

$$P_{max} = \max_{\ell_F, y, \ell} \left\{ \left(y + \delta U(\ell) + \lambda_1 \beta \sum_{\hat{\ell}_F, \hat{y}} \max \{0, M_{\hat{\ell}_F}(\hat{y}, \ell; k_R) - M_{\ell_F}(y, \ell; k_R)\} g(\hat{\ell}_F, \hat{y}) \right) / (r + \chi + \delta) \right\}$$

Letting the minimum and maximum values of $E(k_R)$ given the set P as $[\underline{E}, \overline{E}]$, the excess demand correspondence maps the convex set P into the convex set $C = [\underline{E}, \overline{E}]^{N+1}$ where $-\infty < \underline{E} < \overline{E} < \infty$.

Part 3 - Existence of a Fixed Point

This part of the proof uses results presented in [Kaneko and Yamamoto \(1986\)](#) (henceforth KY). By Lemma 4 in KY, the convex hull of $E(k_R)$, denoted $cov E(k_R)$ inherits the nonemptiness and upper hemicontinuity of $E(k_R)$. By Lemma 5 in KY, $cov E(k_R)$ is convex-valued. Further, denoting x as an element of $D(k_R)$, the following two results hold:

1. If $k_R(\ell) = 0$ for some $\ell \in \mathcal{L}$ and $x \in cov E(k_R)$, then $x(\ell) \geq 0$
2. If $k_R(\ell) = S_{max}$ for some $\ell \in \mathcal{L}$ and $x \in cov E(k_R)$, then $x(\ell) \leq 0$

To prove 1, notice that if $k_R(\ell) = 0$, $\Sigma(k_R, \ell) = 0$. Since $D(k_R)$ is nonempty, aggregate demand at ℓ must be weakly positive. To prove 2, since for $k_R(\ell) \geq 0$, supply is weakly positive and the surplus of all matches is weakly negative. Thus, no vacancies that draw ℓ will match, and no employed or unemployed workers will demand to locate in ℓ since the employed can at most extract their total match surplus and the unemployed have a lower value than the maximum match surplus. By Kakutani's fixed point theorem, there exists a price vector $k_R \in P$ such that $0 \in cov E(k_R)$.

Denote this solution by x_{ch} and σ_{ch} , where x_{ch}^i , $i = 0, \dots, N$ is given by the sum of each type of worker's demand for land in location i . There are N “types” of unemployed workers, and N^2Y “types” of employed workers, thus, the maximum number of types in each location is $M \equiv N + N^2Y$. I therefore denote $x_{ch}^{j,i}$ as the demand for land in location i by type $j = 1, \dots, M$. Similarly, σ_{ch}^i is the supply of land in each location i , after taking into account the demand for new vacancies. Note that in steady state, the demand for land by newly filled vacancies is equal to the inflow to employment. Thus,

$$\sigma_{ch}^i = \psi(i) - \sum_y \sum_{\hat{\ell}} e_i(y, \hat{\ell})$$

The market clearing condition for land can be written

$$\sum_{j=1}^M x_{ch}^{i,j} + \sigma_{ch}^i = L \quad \text{for all } i = 1, \dots, N$$

Since each worker can consume at most 1 unit of land:

$$\sum_{i=0}^N x_{ch}^{i,j} \leq 1 \quad \text{for all } j = 1, \dots, M$$

Since x_{ch} and σ_{ch} may not be integers, consider the system

$$\begin{aligned} \sum_{j=1}^M \hat{x}^{i,j} + \hat{\sigma}^i &= L \quad \text{for all } i = 1, \dots, N \\ \sum_{i=0}^N \hat{x}^{i,j} &\leq 1 \quad \text{for all } j = 1, \dots, M \end{aligned}$$

where $\hat{x}^{i,j} \in \mathbb{R}_+$ and $\hat{\sigma}^i \in \mathbb{R}_+$ for all $i \in N$ and $j \in M$.

Let $\mathbf{x} = [x^{0,1}, x^{1,1}, \dots, x^{N,1}, \dots, x^{0,M}, \dots, x^{N,M}]$ be an $1 \times (N+1)M$ vector and $\boldsymbol{\sigma} = [\sigma^0, \dots, \sigma^N]$ is a $1 \times (N+1)$ vector. The system above can be written as

$$A(\mathbf{x}, \boldsymbol{\sigma})' \begin{aligned} &\leq \begin{bmatrix} 1 \\ \vdots \\ 1 \\ L \\ \vdots \\ L \end{bmatrix} \\ &= \end{aligned}$$

where A is an $(N + 1)M \times (N + 1)(M + 1)$ matrix

$$A = \left[\begin{array}{ccc|ccc} 1 & \dots & 1 & & & \\ & & & \ddots & & \\ & & & & 1 & \dots & 1 \\ \hline 1 & & 1 & & & 1 & \\ & \ddots & & \ddots & & \ddots & \\ & & 1 & & 1 & & 1 \end{array} \right] \begin{array}{l} 0_{M \times (N+1)} \\ I_{N+1} \end{array}$$

and It follows directly from the proof of the Theorem in KY that the fixed point is also in $E(k_R)$, since any fixed point of the convex hull can be written in matrix form and shown to satisfy the unimodular property, implying that the solution is also an integer solution. Thus, an equilibrium price vector k_R exists.

B Quantitative Model

This Appendix contains the full exposition of the quantitative model used for the estimation and quantitative results.

B.1 Wage Determination

Denote the value of a filled job to the firm as $J_{\ell_F}(w, y, z, \ell)$. The value of an employed worker is $W_{\ell_F}(w, y, z, \ell)$ and of an unemployed worker is $U(z, \ell)$. The surplus is given by

$$S_{\ell_F}(y, z, \ell) = M_{\ell_F}(y, z, \ell) - U(z, \ell).$$

where $M_{\ell_F}(y, z, \ell)$ is the match value defined as the sum of the firm and employed worker's values. Renegotiation upon the arrival of an outside offer is identical to the main model, but now depends on the worker's productivity z and her location ℓ . The analogous expressions corresponding to 1, 2, and 3 are given by:

$$W_{\ell_F}(\phi_0, y, z, \ell) - U(z, \ell) = \beta S_{\ell_F}(y, z, \ell) \quad (21)$$

$$W_{\hat{\ell}_F}(\phi_1, \hat{y}, z, \ell) - U(z, \ell) = S_{\ell_F}(y, z, \ell) + \beta (S_{\hat{\ell}_F}(\hat{y}, z, \ell) - S_{\ell_F}(y, z, \ell)) \quad (22)$$

$$W_{\ell_F}(\phi_2, y, z, \ell) - U(z, \ell) = S_{\hat{\ell}_F}(\hat{y}, z, \ell) \quad (23)$$

Turning to wage renegotiation when the firm experiences an idiosyncratic productivity shock, consider a draw of y' in a firm with previous match surplus $S_{\ell_F}(y, z, \ell)$. There are four possibilities:

- (a) $S_{\ell_F}(y', z, \ell) < 0$
- (b) $S_{\ell_F}(y', z, \ell) > 0$, and $W_{\ell_F}(w, y', z, \ell) - U(z, \ell) < 0$
- (c) $S_{\ell_F}(y', z, \ell) > 0$, and $J_{\ell_F}(w, y', z, \ell) < 0$
- (d) $S_{\ell_F}(y', z, \ell) > 0$, $W_{\ell_F}(w, y', z, \ell) - U(z, \ell) > 0$ and $J_{\ell_F}(w, y', z, \ell) > 0$

In case (a), the match is endogenously destroyed due to a negative surplus. In case (b), the worker's surplus is negative under the old wage. Following [Postel-Vinay and Turon \(2010\)](#), the wage is reset to make the worker indifferent between remaining in the match or quitting into unemployment, $w = \psi_0(\ell_F, y', z, \ell)$ such that

$$W_{\ell_F}(\psi_0, y', z, \ell) - U(z, \ell) = 0 \quad (24)$$

In this case, the firm gets the full surplus: $J_{\ell_F}(\psi_0, y', z, \ell) = S_{\ell_F}(y', z, \ell)$. Conversely, in case (c), the wage is reset to make the firm indifferent between continuing in the match or becoming vacant: $w = \psi_1(\ell_F, y', z, \ell)$ such that

$$J_{\ell_F}(\psi_1, y', z, \ell) = 0 \quad (25)$$

In this case, the worker gets the full surplus: $W_{\ell_F}(\psi_0, y', z, \ell) - U(z, \ell) = S_{\ell_F}(y', z, \ell)$. Finally, in case (d), both the worker and firm have positive surplus under the new realization of productivity, and therefore the match will continue with no change in the wage.

Renegotiation after a moving shock occurs in the same way as with a productivity shock. Consider an employed worker previously living at ℓ who draws ℓ' after a moving shock arrives. There are four possibilities:

- (a) $S_{\ell_F}(y, z, \ell') < 0$
- (b) $S_{\ell_F}(y, z, \ell') > 0$, and $W_{\ell_F}(w, y, z, \ell') - U(z, \ell') < 0$
- (c) $S_{\ell_F}(y, z, \ell') > 0$, and $J_{\ell_F}(w, y, z, \ell') < 0$
- (d) $S_{\ell_F}(y, z, \ell') > 0$, $W_{\ell_F}(w, y, z, \ell') - U(z, \ell') > 0$ and $J_{\ell_F}(w, y, z, \ell') > 0$

In case (a), the match is endogenously destroyed due to a negative surplus. In case (b), the worker's surplus is negative under the old wage and is reset to make the worker indifferent between remaining in the match or quitting into unemployment, $w = \psi_0(\ell_F, y, z, \ell')$ such that

$$W_{\ell_F}(\psi_0, y, z, \ell') - U(z, \ell') = 0 \quad (26)$$

In this case, the firm gets the full surplus: $J_{\ell_F}(\psi_0, y, z, \ell') = S_{\ell_F}(y, z, \ell')$. Conversely, in case (c), the wage is reset to make the firm indifferent between continuing in the match or becoming vacant: $w = \psi_1(\ell_F, y, z, \ell')$ such that

$$J_{\ell_F}(\psi_1, y, z, \ell') = 0 \quad (27)$$

In this case, the worker gets the full surplus: $W_{\ell_F}(\psi_0, y, z, \ell') - U(z, \ell') = S_{\ell_F}(y, z, \ell')$. Finally, in case (d), both the worker and firm have positive surplus under the new realization of the worker's location, and therefore the match will continue with no change in the wage.

B.2 Value Functions

The flow utility for an unemployed worker is b . Her value function is given by

$$\begin{aligned} U(z, \ell) &= \max_{\ell' \in \mathcal{L}} \{ \tilde{U}(z, \ell') - k_M \mathbb{1}\{\ell \neq \ell'\} \} \\ \text{s.t. } &b \geq k_R(\ell') \end{aligned} \quad (28)$$

where

$$(r + \chi) \tilde{U}(z, \ell) = b - k_R(\ell) + \lambda_0 p(\theta) \beta \sum_{(\ell_F, y)} \max\{S_{\ell_F}(y, z, \ell), 0\} g(\ell_F, y) \quad (29)$$

where the set of acceptable offers is denoted $B_1(u, z, \ell) = \{(\ell_F, y) \in \mathcal{L} \times Y : S_{\ell_F}(y, z, \ell) > 0\}$. Denote the unemployed worker's optimal location choice by the policy function $\ell_u(z, \ell)$.

Define the sets $B_1(\ell_F, y, z, \ell)$, and $B_2(w, \ell_F, y, z, \ell)$ similarly to the main model. The value function for an employed worker with productivity z living in ℓ in current firm (ℓ_F, y) and earning wage w is given by:

$$W_{\ell_F}(w, y, z, \ell) = \tilde{W}_{\ell_F}(w, y, z, \ell_e(\ell_F, y, z, \ell)) - k_M \mathbb{1}\{\ell \neq \ell_e(\ell_F, y, z, \ell)\} \quad (30)$$

where $\ell_e(\ell_F, y, z, \ell)$ is the optimal location of the worker defined by the worker's contract

and

$$\begin{aligned}
& (r + \chi)\tilde{W}_{\ell_F}(w, y, z, \ell) = w - k_R(\ell) - \tau(\ell, \ell_F)f(y, z) + (\delta + \mu + \varphi)(U(z, \ell) - W_{\ell_F}(w, y, z, \ell)) \\
& + \mu \sum_{y' \in Y} \max\{\min\{W_{\ell_F}(w, y', z, \ell) - U(z, \ell), S_{\ell_F}(y', z, \ell)\}, 0\}h(y') \\
& + \varphi \sum_{\ell' \in \mathcal{L}} [\max\{\min\{W_{\ell_F}(w, y, z, \ell') - U(z, \ell'), S_{\ell_F}(y, z, \ell')\}, 0\} + U(z, \ell') - U(z, \ell)]\pi(\ell') \\
& + \lambda_1 p(\theta) \sum_{(\hat{\ell}_F, \hat{y}) \in B_1(\ell_F, y, z, \ell)} (\beta S_{\hat{\ell}_F}(\hat{y}, z, \ell) + (1 - \beta)S_{\ell_F}(y, z, \ell) - W_{\ell_F}(w, y, z, \ell) + U(z, \ell))g(\hat{\ell}_F, \hat{y}) \\
& + \lambda_1 p(\theta) \sum_{(\hat{\ell}_F, \hat{y}) \in B_2(w, \ell_F, y, z, \ell)} (S_{\hat{\ell}_F}(\hat{y}, z, \ell) - W_{\ell_F}(w, y, z, \ell) + U(z, \ell))g(\hat{\ell}_F, \hat{y}) \tag{31}
\end{aligned}$$

The first line is analogous to (7). At rate μ , the worker experiences a shock to the productivity of her job. At rate φ , the worker experiences a moving shock. If either of these two shocks results in a negative surplus, the worker and firm endogenously separate. Importantly, the threshold determining whether the shock is “low enough” to separate depends on the commute. The expression on the second line is the payoff to the worker after a productivity shock. In this case, the worker and firm renegotiate only if either the firm or worker’s surplus is negative under the new realization of productivity. Similarly, the third line shows the four possibilities for renegotiation when a moving shock arrives. The final two lines show the worker’s payoff upon the arrival of a job offer resulting in a job-to-job transition or renegotiation, respectively.

Let the mass of employed workers living at ℓ currently in a match (ℓ_F, y) with productivity z be denoted $e_{\ell_F}(y, z, \ell)$ and the mass of unemployed workers with productivity z living at ℓ be $u(z, \ell)$. The free entry condition is given by

$$\begin{aligned}
c & \geq q(\theta) \sum_{\ell_F, y} \sum_{\ell \in \mathcal{L}} \sum_{z \in Z} \left[\lambda_0 u(z, \ell)(1 - \beta) \max\{0, S_{\ell_F}(y, z, \ell)\} \right. \\
& \left. + \lambda_1 (1 - \beta) \sum_{\hat{\ell}_F \in \mathcal{L}} \sum_{\hat{y} \in Y} \max\{0, S_{\ell_F}(y, z, \ell) - S_{\hat{\ell}_F}(\hat{y}, z, \ell)\} e_{\hat{\ell}_F}(\hat{y}, z, \ell) \right] g(\ell_F, y) \tag{32}
\end{aligned}$$

Finally, the value of a filled job to the firm is:

$$J_{\ell_F}(w, y, z, \ell) = \tilde{J}_{\ell_F}(w, y, z, \ell_e(\ell_F, y, z, \ell))$$

where

$$\begin{aligned}
(r + \chi)\tilde{J}_{\ell_F}(w, y, z, \ell) &= f(y, z) - w - k_R(\ell_F) - (\mu + \delta + \varphi)J_{\ell_F}(w, y, z, \ell) \\
&+ \mu \sum_{y' \in Y} \max\{\min\{J_{\ell_F}(w, y', z, \ell), S_{\ell_F}(y', z, \ell)\}, 0\}h(y') \\
&+ \varphi \sum_{\ell' \in \mathcal{L}} \max\{\min\{J_{\ell_F}(w, y, z, \ell'), S_{\ell_F}(y, z, \ell')\}, 0\}\pi(\ell') \\
&+ \lambda_1 p(\theta) \sum_{(\hat{\ell}_F, \hat{y}) \in B_2(w, \ell_F, y, z, \ell)} (S_{\ell_F}(y, z, \ell) - S_{\hat{\ell}_F}(\hat{y}, z, \ell) - J_{\ell_F}(w, y, z, \ell))g(\hat{\ell}_F, \hat{y}) \\
&- \lambda_1 p(\theta) J_{\ell_F}(w, y, z, \ell) \sum_{(\hat{\ell}_F, \hat{y}) \in B_1(\ell_F, y, z, \ell)} g(\hat{\ell}_F, \hat{y})
\end{aligned} \tag{33}$$

Combining these expressions gives the match value:

$$\begin{aligned}
M_{\ell_F}(y, z, \ell) &= \max_{\ell' \in \mathcal{L}} \{\tilde{M}_{\ell_F}(y, z, \ell') - k_M \mathbb{1}\{\ell \neq \ell'\}\} \\
s.t. \quad &(1 - \tau(\ell', \ell_F))f(y, z) - k_R(\ell_F) - k_R(\ell') \geq 0
\end{aligned} \tag{34}$$

where $\tilde{M}_{\ell_F}(y, z, \ell) = \tilde{J}_{\ell_F}(y, z, \ell) + \tilde{W}_{\ell_F}(y, z, \ell)$ denotes the match value, with:

$$\begin{aligned}
(r + \chi)\tilde{M}_{\ell_F}(y, z, \ell) &= (1 - \tau(\ell, \ell_F))f(y, z) - k_R(\ell_F) - k_R(\ell) + (\delta + \mu + \varphi)(U(z, \ell) - M_{\ell_F}(y, z, \ell)) \\
&+ \mu \sum_{y' \in Y} \max\{0, M_{\ell_F}(y', z, \ell) - U(z, \ell)\}h(y') \\
&+ \varphi \sum_{\ell' \in \mathcal{L}} \max\{0, M_{\ell_F}(y, z, \ell') - U(z, \ell')\}\pi(\ell') \\
&+ \lambda_1 p(\theta)\beta \sum_{(\hat{\ell}_F, \hat{y})} \max\{0, M_{\hat{\ell}_F}(\hat{y}, z, \ell) - M_{\ell_F}(y, z, \ell)\}g(\hat{\ell}_F, \hat{y})
\end{aligned} \tag{35}$$

where the associated policy function for the worker's location is denoted $\ell_e(\ell_F, y, z, \ell)$. The surplus is given by $S_{\ell_F}(y, z, \ell) = M_{\ell_F}(y, z, \ell) - U(z, \ell)$.

B.3 Worker Flows

The flows into employment of workers of type z living at ℓ is given by

$$e_{\ell_F}^+(y, z, \ell) = e_{\ell_F, 1}^+(y, z, \ell) + e_{\ell_F, 2}^+(y, z, \ell) \tag{36}$$

where the first term indicates flows into employment where the firm location changes, and the second term indicates flows into employment where the firm location remains the

same:

$$e_{\ell_F,1}^+(y, z, \ell) = p(\theta)g(\ell_F, y) \sum_{\ell' \in \mathcal{L}} [\lambda_0 u(z, \ell') \mathbb{1}\{S_{\tilde{\ell}_F}(\tilde{y}, z, \ell') > 0\} \\ + \lambda_1 \sum_{\tilde{\ell}_F \in \mathcal{L}} \sum_{\tilde{y} \in Y} \mathbb{1}\{S_{\tilde{\ell}_F}(\tilde{y}, z, \ell') < S_{\ell_F}(y, z, \ell')\} e_{\tilde{\ell}_F}(\tilde{y}, z, \ell')] \mathbb{1}\{\ell_e(\ell_F, y, z, \ell') = \ell\}$$

denotes the new matches (ℓ_F, y, z, ℓ) that are created, and

$$e_{\ell_F,2}^+(y, z, \ell) = \varphi \sum_{\ell' \neq \ell} \sum_{\tilde{\ell}} e_{\ell_F}(y, z, \ell') \pi(\tilde{\ell}) \mathbb{1}\{S_{\ell_F}(y, z, \tilde{\ell}) > 0\} \mathbb{1}\{\ell_e(\ell_F, y, z, \tilde{\ell}) = \ell\} \\ + \mu h(y) \sum_{\tilde{y} \neq y} \sum_{\ell'} e_{\ell_F}(\tilde{y}, z, \ell') \mathbb{1}\{S_{\ell_F}(y, z, \ell') > 0\} \mathbb{1}\{\ell_e(\ell_F, y, z, \ell') = \ell\}$$

denotes the existing matches that become (ℓ_F, y, z, ℓ) . By assumption, workers change location only when one of the shocks is realized. Similarly, the flow out of employment in matches (ℓ_F, y, z, ℓ) can be decomposed into the flow out due to destroyed jobs and the flow out due to shocks, for which the match continues.

$$e_{\ell_F}^-(y, z) = e_{\ell_F,1}^-(y, z, \ell) + e_{\ell_F,2}^-(y, z, \ell) \quad (37)$$

where the two terms, respectively, are given by:

$$e_{\ell_F,1}^-(y, z, \ell) = e_{\ell_F}(y, z, \ell) \left(\delta + \mu \sum_{\tilde{y}} h(\tilde{y}) \mathbb{1}\{S_{\ell_F}(\tilde{y}, z, \ell) \leq 0\} + \varphi \sum_{\tilde{\ell}} \pi(\tilde{\ell}) \mathbb{1}\{S_{\ell_F}(y, z, \tilde{\ell}) \leq 0\} \right. \\ \left. + \lambda_1 p(\theta) \sum_{\tilde{\ell}_F} \sum_{\tilde{y}} \mathbb{1}\{S_{\tilde{\ell}_F}(\tilde{y}, z, \ell) > S_{\ell_F}(y, z, \ell)\} g(\tilde{\ell}_F, \tilde{y}) \right)$$

and

$$e_{\ell_F,2}^-(y, z, \ell) = e_{\ell_F}(y, z, \ell) \left(\mu \sum_{\tilde{y} \neq y} h(\tilde{y}) \mathbb{1}\{S_{\ell_F}(\tilde{y}, z, \ell) > 0\} \right. \\ \left. + \varphi \sum_{\tilde{\ell}} \pi(\tilde{\ell}) \mathbb{1}\{S_{\ell_F}(y, z, \tilde{\ell}) > 0\} \mathbb{1}\{\ell_e(\ell_F, y, z, \tilde{\ell}) \neq \ell\} \right)$$

I allow for workers experiencing the moving shock to move again before they are counted for the purposes of the above flow equations, to be consistent with the fact that the worker's location is determined by the value of the match. If not, the match value would change when a match continued after a moving shock to $\tilde{M}$ rather than M , compli-

cating the notation. This assumption will not significantly change the results since moving is subject to paying a cost.

The flows into and out of unemployment, respectively, are:

$$u^+(z, \ell) = \sum_{\ell'} \mathbb{1}\{\ell_U(z, \ell') = \ell\} \sum_{\ell_F} \sum_y \left[e_{\ell_F}(y, z, \ell') (\delta + \mu \sum_{\tilde{y}} h(\tilde{y}) \mathbb{1}\{S_{\ell_F}(\tilde{y}, z, \ell') \leq 0\}) \right. \\ \left. + \varphi \sum_{\tilde{\ell}} e_{\ell_F}(y, z, \tilde{\ell}) \pi(\ell') \mathbb{1}\{S_{\ell_F}(y, z, \ell') \leq 0\} \right] \quad (38)$$

$$u^-(z, \ell) = u(z, \ell) \lambda_0 p(\theta) \sum_{\ell_F} \sum_y g(\ell_F, y) \mathbb{1}\{S_{\ell_F}(y, z, \ell) > 0\} \quad (39)$$

Similarly, the flows across space are given by the inflow and outflow, respectively:

$$\sum_{z \in Z} \left(\sum_{y \in Y} \left[\sum_{\ell \in \mathcal{L}} e_{\tilde{\ell}, 1}^+(y, z, \ell) + \sum_{\ell_F \in \mathcal{L}} e_{\ell_F}^+(y, z, \tilde{\ell}) \right. \right. \\ - \mathbb{1}\{\ell_e(\ell_F, y, z, \tilde{\ell}) = \tilde{\ell}\} \left(\mu h(y) \sum_{\hat{y} \neq y} e_{\ell_F}(\hat{y}, z, \tilde{\ell}) \mathbb{1}\{S_{\ell_F}(y, z, \tilde{\ell}) > 0\} \right. \\ \left. \left. + p(\theta) g(\ell_F, y) [\lambda_0 u(z, \tilde{\ell}) \mathbb{1}\{S_{\ell_F}(y, z, \tilde{\ell}) > 0\} + \lambda_1 \sum_{\tilde{\ell}_F \in \mathcal{L}} \sum_{\tilde{y} \in Y} \mathbb{1}\{S_{\tilde{\ell}_F}(\tilde{y}, z, \tilde{\ell}) < S_{\ell_F}(y, z, \tilde{\ell})\} e_{\tilde{\ell}_F}(\tilde{y}, z, \tilde{\ell})] \right) \right] \\ \left. + u^+(z, \tilde{\ell}) - \delta \sum_{\ell_F \in \mathcal{L}} \sum_{y \in Y} e_{\ell_F}(y, z, \tilde{\ell}) \mathbb{1}\{\ell_u(z, \tilde{\ell}) = \tilde{\ell}\} \right) \quad (40)$$

$$\sum_{z \in Z} \left(\sum_{y \in Y} \left(\sum_{\ell \in \mathcal{L}} e_{\tilde{\ell}, 1}^-(y, z, \ell) + \sum_{\ell_F \in \mathcal{L}} e_{\ell_F}^-(y, z, \tilde{\ell}) - e_{\ell_F, 1}^-(y, z, \tilde{\ell}) \mathbb{1}\{\ell_u(z, \tilde{\ell}) = \tilde{\ell}\} \right. \right. \\ - e_{\ell_F}(y, z, \tilde{\ell}) \left[\mu \sum_{\hat{y} \neq y} h(\hat{y}) \mathbb{1}\{S_{\ell_F}(\hat{y}, z, \tilde{\ell}) > 0\} \mathbb{1}\{\ell_e(\ell_F, \hat{y}, z, \tilde{\ell}) = \tilde{\ell}\} \right. \\ - \lambda_1 p(\theta) \sum_{\tilde{\ell}_F \in \mathcal{L}} \sum_{\tilde{y} \in Y} \mathbb{1}\{S_{\tilde{\ell}_F}(\tilde{y}, z, \tilde{\ell}) > S_{\ell_F}(y, z, \tilde{\ell})\} \mathbb{1}\{\ell_e(\tilde{\ell}_F, \tilde{y}, z, \tilde{\ell}) = \tilde{\ell}\} g(\tilde{\ell}_F, \tilde{y}) \left. \right] \\ \left. + u^-(z, \tilde{\ell}) - \lambda_0 p(\theta) u(z, \tilde{\ell}) \sum_{\tilde{\ell}_F \in \mathcal{L}} \sum_{\tilde{y} \in Y} \mathbb{1}\{S_{\tilde{\ell}_F}(\tilde{y}, z, \tilde{\ell}) \geq 0\} \mathbb{1}\{\ell_e(\tilde{\ell}_F, \tilde{y}, z, \tilde{\ell}) = \tilde{\ell}\} g(\tilde{\ell}_F, \tilde{y}) \right) \quad (41)$$

B.4 Equilibrium

Equilibrium in the land market requires that for all $\tilde{\ell} \in \mathcal{L}$:

$$\chi(\tilde{\ell}) = \sum_{z \in Z} \left(u(z, \tilde{\ell}) + \sum_{y \in Y} \left[\sum_{\ell_F \in \mathcal{L}} e_{\ell_F}(y, z, \tilde{\ell}) + \sum_{\ell \in \mathcal{L}} e_{\tilde{\ell}}(y, z, \ell) \right] \right) \quad (42)$$

The equilibrium definition is given below.

Definition 2. A steady state equilibrium consists of value functions $M_{\ell_F} : Y \times Z \times \mathcal{L} \rightarrow \mathbb{R}$ for each $\ell_F \in \mathcal{L}$ and $U : Z \times \mathcal{L} \rightarrow \mathbb{R}$, policy functions $\ell_e(\ell_F, y, z, \ell) \in \mathcal{L}$ and $\ell_u(z, \ell) \in \mathcal{L}$, market tightness $\theta \in \mathbb{R}_+$, a wage function when employed and unemployed, $w : \mathcal{L} \times Y \times \mathcal{L} \times Y \times Z \times \mathcal{L} \rightarrow \mathbb{R}_+$ and $w_U : \mathcal{L} \times Y \times Z \times \mathcal{L} \rightarrow \mathbb{R}_+$, a rent function $k_R : \mathcal{L} \rightarrow \mathbb{R}_+$, and distributions of vacancies, of workers across employment states, and of workers and firms across space such that

- (i) For each $\ell_F \in \mathcal{L}$, and $(y, z, \ell) \in Y \times Y \times \mathcal{L}$, $M_{\ell_F}(y, z, \ell)$ satisfies (34) and $\ell_e(\ell_F, y, z, \ell)$ is the associated policy function. For each $(z, \ell) \in Z \times \mathcal{L}$, $U(z, \ell)$ satisfies (28) and $\ell_u(z, \ell)$ is the associated policy function.
- (ii) When an offer arrives to the unemployed worker, the wage $w_U(\ell_F, y, z, \ell)$ is determined by (21). When an outside offer arrives, wages $w(\hat{\ell}_F, \hat{y}, \ell_F, y, z, \ell)$ are determined by the surplus splitting equations (22) and (23). When a match-specific productivity shock is realized, wages are determined by (24) and (25). When a moving shock is realized, wages are determined by (26) and (27).
- (iii) Market tightness is given by (32).
- (iv) For each $\ell_F \in \mathcal{L}$, and $(y, z, \ell) \in Y \times Z \times \mathcal{L}$ the distributions across employment states satisfy $e_{\ell_F, i}^+(y, z, \ell) = e_{\ell_F, i}^-(y, z, \ell)$ for $i = 1, 2$ and for all $(\ell_F, y, z, \ell) \in \mathcal{L} \times Y \times Z \times \mathcal{L}$ and $u^+(z, \ell) = u^-(z, \ell)$ for all $(z, \ell) \in Z \times \mathcal{L}$, given by (36)-(39). The distributions across space equate (40) and (41).
- (v) For each $\ell \in \mathcal{L}$, $\chi(\ell)$ satisfies (18) and rent $k_R(\ell)$ adjusts such that (42) holds.

C Numerical Solution Algorithm

I solve the model in the following steps:

1. Guess a rent function, initial distributions of workers and vacancies, and initial value functions for U , W , V and S .

2. Given the rent function and distributions of workers, solve for the value functions U , W, V and S and optimal moving choices using (28)-(34) by iterating on the value functions until convergence.
3. Given the value functions computed in step 2, compute the worker distributions given steady state flow conditions (36)-(39), and the vacancy distribution given (32).
4. Given worker distributions, compute the difference between the left and right hand (denote the RHS $D(\ell)$) sides of (42) for each ℓ . Update the rent price as

$$k'_R(\ell) = k_R(\ell) + D(\ell) - \chi(\ell)$$

5. Using solutions for W , U , and S , compute wages satisfying (21)-(27)

D Robustness and Micro-Level Regressions

The first two tables in this section document the robustness of the wage cut result in Table 2 for occupation switchers and stayers separately.

Table 8: After Job-to-Job Transition, Occupation Switchers

		Wage		
		Down	Same	Up
<u>Commute</u>	Down	0.11	0.05	0.21
	Same	0.05	0.03	0.13
	Up	0.09	0.06	0.28

Notes: BHPS Sample 1993-2009, annual. Universe: respondents aged 24-55 employed in year t who changed jobs and occupation since year $t - 1$ with no more than 2 weeks of unemployment between the two employment spells. "Up" and "Down" indicate differences from the last reported wage or commute of more than 10%, and "Same" indicates differences less than 10%.

In Tables 10 and 11 I run regressions of the following form:

$$y_{it} = \beta x_{it} + \gamma Z_{it} + \delta M_t + \varepsilon_{it}$$

where i is the individual and t is the year of the interview, y_{it} is the variable of interest (the real log wage in year t or a dummy for a job-to-job transition between years $t - 1$ and t), x_{it} are the daily commute time in minutes (contemporaneous or lagged) and log hourly wage at $t - 1$ (in job-to-job transition regressions only), Z_{it} are a set of individual

Table 9: After Job-to-Job Transition, Occupation Stayers

		<u>Wage</u>		
		Down	Same	Up
<u>Commute</u>	Down	0.46	0.06	0.11
	Same	0.02	0.02	0.07
	Up	0.09	0.03	0.14

Notes: BHPS Sample 1993-2009, annual. Universe: respondents aged 24-55 employed in year t who changed jobs but not occupation since year $t - 1$ with no more than 2 weeks of unemployment between the two employment spells. "Up" and "Down" indicate differences from the last reported wage or commute of more than 10%, and "Same" indicates differences less than 10%.

and firm characteristics¹⁵ for the job at $t - 1$, and M_t are a set of region and time fixed effects. Regions correspond to Local Authority Districts, which is a highly disaggregated regional classification (roughly 350 LADs in the UK). Regressions of real log wages and the job-to-job transition dummy in the linear probability model also include individual fixed effects to control for unobservable heterogeneity. Robust standard errors are shown in parentheses.

The results reported in Table 10 suggest that minutes of commuting time is positively correlated with workers' contemporaneous hourly wage. Column 1 includes region, time, commuting method, industry, occupation and firm size fixed effects as regressors in addition to the contemporaneous commute. Column 2 includes individual fixed effects, and column 3 further includes the individual covariates contained in Z_{it} . After including individual fixed effects, the additional regressors in column 3 do not significantly affect the magnitude of the estimated correlation between the commute and wage. A 30 minute increase in commuting time is associated with roughly a 1.5% higher hourly wage.

Table 11 reports the marginal effects from a probit regression in which the dependent variable is equal to 1 if the individual made at least one job-to-job transition in the past year, with less than 14 days of nonemployment between the two jobs, and 0 if she remained employed in the same job according to her self-reported employment history. The first column regresses the job-to-job transition probability on the commute and wage in the

¹⁵The contemporaneous variables contained in Z_{it} in all of the regressions reported in Table 10 are a quadratic term in labor market experience, age, education, marital status, and number of children. The 1 year lagged variables contained in Z_{it} in all of the regressions reported in Table 10 are the years of tenure in current job, dummies for outright homeownership, mortgage holding, whether the individual moved in the past year, real housing expenditures, an annual regional house price index, whether the worker was unemployed in the past year, whether the worker made a job-to-job transition in the past year, the number of employment spells, whether the spouse or partner is employed, a government job dummy, union status, mode of commute, whether mode of commute has changed, firm size, and 1-digit industry and occupation dummies for the job in $t - 1$ and for the job in year t .

Table 10: Regressions of Wage on Contemporaneous Commute

	Real log Wage _t	Real log Wage _t	Real log Wage _t
Commute _t × 30	0.063*** (0.003)	0.015*** (0.003)	0.015*** (0.004)
Ind. characteristics			✓
Ind. FE		✓	✓
Region, Time, Commute Method, Size, Industry & Occupation FE	✓	✓	✓
R ²	.619	.626	.616
N obs	16,551	12,600	11,395
N ind		2,937	2,200

Notes: BHPS Sample 1992-2009, annual. Universe: respondents aged 24-55 working full-time in year t . Real log hourly wages are computed as the log of monthly labor income divided by $4.33 \times$ weekly hours worked, deflated by UK annual CPI. Individual characteristics include the annual regional house price index, a quadratic term in labor market experience, age, education, marital status, and number of children, 1-year lagged tenure, 1-year lagged dummies for outright homeownership, mortgage holding, whether the individual moved in the past year, real housing expenditures, whether the worker was unemployed in the past year, whether the worker made a job-to-job transition in the past year, the number of employment spells, whether the spouse or partner was employed last year, a government job dummy, union status, mode of commute, and 1-digit industry and occupation dummies for the job in $t - 1$ and for the job in year t . All regressions include region, month, year, 1-digit industry and occupation fixed effects. The second and third columns also include individual fixed effects. Robust standard errors are reported in parentheses. * denotes $p < .1$, ** $p < .05$, and *** $p < .01$.

previous year and fixed effects. The second column repeats the regression including the individual characteristics included in Z_{it} described above. The estimates suggest that the commute in year $t - 1$ has a small, positive relationship with the probability of a job-to-job transition between years $t - 1$ and t even after controlling for the wage in $t - 1$. The results in column 2 can be interpreted as follows: for a 30 minute increase in last year's commute, the probability of making a job-to=job transition in the current year increases by about 1.4 percentage points. In the sample used in the regressions, the effect of a 20 minute commute explains roughly 12% of the annual job-to-job transition rate.

To study the key relationship between earnings losses and initial commutes, I compute the present value of annual earnings over the 2 to 5 years following a nonemployment spell ending in full-time work. Using an annual interest rate of 5%, I compute the present value of annual labor income (inc) over the T years following a nonemployment spell in year $t - 1$ as $PV_{t,T} = \sum_{s=t}^{t+T} \frac{inc_s}{(1.05)^s}$. The present values are computed for all individuals in the sample reporting labor income (including zeros) each of the T following the nonemployment spell. Table 12 shows results from the regression of the log of $PV_{t,T}$ on the commute and log of

Table 11: Regressions of Job-to-Job Transition Probability on Lagged Commute and Wage

	J2J _t	J2J _t
Commute _{t-1} × 30	0.017*** (0.002)	0.014*** (0.002)
Real log Wage _{t-1}	-0.061*** (0.008)	-0.031*** (0.008)
Individual Characteristics		✓
Region, Time, Commute Method Size, Industry & Occ FE	✓	✓
Pseudo R ²	.074	.124
N obs	12,207	10,785

Notes: BHPS Sample 1992-2009, annual. Universe: respondents aged 24-55 working full-time in year t . Estimated marginal effects from a probit regression of J2J_t, equal to one if a worker made a job-to-job transition in the past year with no more than 2 weeks of nonemployment between jobs and 0 if she remained in the same job, on commute time and wages in the previous year. Real log hourly wages are computed as the log of monthly labor income divided by 4.33 × weekly hours worked, deflated by UK annual CPI. Controls for observables are included in column 2: see Table 10. Robust standard errors are reported in parentheses. * denotes $p < .1$, ** $p < .05$, and *** $p < .01$.

labor income and observable characteristics, all at time t . Log labor income in the year in which the employment spell begins is included to control for the worker's initial position in the wage ladder. All regressions also include fixed effects for the initial year, month, region, commuting method, firm size, and the industry and occupation of the initial job. The first column estimates the semielasticity of the present value of earnings over 2 years to the initial commute and initial log labor income. Identical regressions using the 3, 4 and 5-year present value of earnings as the dependent variable are shown in the second through fourth columns. A 30 minute increase in the initial commute is associated with a 5.1% higher present value of earnings over the next 2 years. At the 3 to 5-year horizons, the corresponding estimates increase to between 4.3% and 5.2%.

In Table 17 in Appendix D, I show similar regressions to those in Table 12, exploiting variation within individuals in the sample reporting more than one nonemployment spell. In particular, I look at workers with two or more employment spells beginning after a period of nonemployment and lasting at least 2 to 5 years, in order to include individual fixed effects into the earnings regressions. The estimates suggest a highly significant semielasticity when controlling for worker fixed effects at all horizons considered. A 30 minute increase in the commute is associated with between 4.7 and 6.6% higher present value of earnings over the next 2 to 5 years. These estimates, however, should not be taken

Table 12: Log Present Value of Earnings

	<u>2 Years</u>	<u>3 Years</u>	<u>4 Years</u>	<u>5 Years</u>
Initial Commute $\times 30$	0.051*** (0.011)	0.052*** (0.011)	0.043*** (0.012)	0.046*** (0.012)
Initial log Income	0.322*** (0.016)	0.296*** (0.016)	0.269*** (0.016)	0.256*** (0.017)
Region, Time, Commute Method, Industry, Occ FE	✓	✓	✓	✓
R^2	.738	.759	.762	.761
N obs	2,241	1,892	1,635	1,387

Notes: BHPS Sample 1992-2009, annual. Universe: respondents aged 24-55 reporting a nonemployment spell ending in full-time employment and appearing in the sample for the next T years. The present value of earnings over T years following a nonemployment spell as $\sum_{t=2}^{T+1} \frac{inc_t}{(1.05)^{t-1}}$. Controls for observables include the commute and log of annual labor income in the year in which the nonemployment spell ended, gender, age, a quadratic term in experience, education, marital status, number of children, dummies for whether homeownership and job has changed, and dummies in the year in which the nonemployment spell ended for: whether the spouse was employed, 1-digit industry and occupation, homeownership, housing expenditures and the annual regional house price index. Robust standard errors are reported in parentheses. * denotes $p < .1$, ** $p < .05$, and *** $p < .01$.

as conclusive, as the sample size of workers with multiple spells is small.

Table 13: Summary Statistics: Job-to-Job Transitions

	J2J	No J2J
N	9,048	36,096
Age	35.9	39.4
% Low Skilled/% High Skilled	11%/55%	17%/48%
% Male	45%	43%
Real Individual Labor Income	£12,970	£13,578
Weekly Hours	44.7	43.3
Commute (minutes R/T)	47.3	42.1
Years of Tenure	-	5.8
% Full Time	85%	78%
% Unemp last year	7%	4%
% Married	57%	65%
% Moved house last year	15%	8%
% Homeowners	79%	83%
% in London/ SE England	31%	27%

Table 14: Summary Statistics: Commuters

	Commute $\leq$ 30 min	30<Commute $\leq$ 180
N	22,870	22,274
Age	39.1	38.1
% Low Skilled/% High Skilled	20%/42%	11%/56%
% Male	38%	49%
Real Individual Labor Income	£11,173	£15,775
Weekly Hours	43.0	44.2
Commute (minutes R/T)	19.2	67.7
Years of Tenure	5.2	4.3
% Full Time	73%	86%
% Unemp last year	4%	5%
% Married	66%	60%
% J2J last year	18%	22%
% Moved house last year	8%	10%
% Homeowners	81%	84%
% in London/ SE England	24%	33%

Table 15: Regressions of Wage on Contemporaneous Commute, Regional Subsamples

	Excluding London Real log Wage _t	England only Real log Wage _t
Commute _t × 30	0.014*** (0.004)	0.015*** (0.004)
Ind. characteristics	✓	✓
Ind. FE	✓	✓
Region, Time, Commute Method, Size, Industry & Occupation FE	✓	✓
R ²	.612	.620
N obs	10,208	10,769
N ind	1,966	2,077

Notes: BHPS Sample 1992-2009, annual. Universe: respondents aged 24-55 working full-time in year t . Real log hourly wages are computed as the log of monthly labor income divided by $4.33 \times$ weekly hours worked, deflated by UK annual CPI. Individual characteristics include the annual regional house price index, a quadratic term in labor market experience, age, education, marital status, and number of children, 1-year lagged tenure, 1-year lagged dummies for outright homeownership, mortgage holding, whether the individual moved in the past year, real housing expenditures, whether the worker was unemployed in the past year, whether the worker made a job-to-job transition in the past year, the number of employment spells, whether the spouse or partner was employed last year, a government job dummy, union status, mode of commute, and 1-digit industry and occupation dummies for the job in $t - 1$ and for the job in year t . All regressions include region, month, year, 1-digit industry and occupation and individual fixed effects. Robust standard errors are reported in parentheses. * denotes $p < .1$, ** $p < .05$, and *** $p < .01$.

Table 16: Marginal Effects: Commuting and Transition Probability, Regional Subsamples

	Excluding London J2J _t	England only J2J _t
Commute _{t-1} × 30	0.014*** (0.002)	0.014*** (0.002)
Real log Wage _{t-1}	-0.028** (0.009)	-0.034*** (0.008)
Individual Characteristics	✓	✓
Region, Time, Commute Method Size, Industry & Occ FE	✓	✓
Pseudo R ²	.123	.129
N obs	9,643	12,021

Table 17: Log Present Value of Earnings, Individual Fixed Effects

	<u>2 Years</u>	<u>3 Years</u>	<u>4 Years</u>	<u>5 Years</u>
Initial Commute $\times 30$	0.066*** (0.016)	0.052*** (0.015)	0.047*** (0.013)	0.053*** (0.013)
Initial log Income	0.014 (0.017)	-6.00e-05 (0.016)	-2.74e-04 (0.015)	-0.006 (0.014)
Region, Time,				
Commute Method,	✓	✓	✓	✓
Industry, Occ FE				
Individual FE	✓	✓	✓	✓
R^2	.436	.488	.530	.545
N obs	1,496	1,284	1,092	923
N ind	589	511	439	375

Notes: BHPS Sample 1992-2009, annual. Universe: respondents aged 24-55 reporting a nonemployment spell ending in full-time employment and appearing in the sample for the next T years. The present value of earnings over T years following a nonemployment spell as $\sum_{t=2}^{T+1} \frac{inc_t}{(1.05)^{t-1}}$. Controls for observables include the commute and log of annual labor income in the year in which the nonemployment spell ended, gender, age, a quadratic term in experience, education, marital status, number of children, dummies for whether homeownership and job has changed, and dummies in the year in which the nonemployment spell ended for: whether the spouse was employed, 1-digit industry and occupation, homeownership, housing expenditures and the annual regional house price index. Robust standard errors are reported in parentheses. * denotes $p < .1$, ** $p < .05$, and *** $p < .01$.

Table 18: Log Present Value of Earnings, Individual Fixed Effects, 2.65% Interest Rate

	<u>2 Years</u>	<u>3 Years</u>	<u>4 Years</u>	<u>5 Years</u>
Initial Commute $\times 30$	0.066*** (0.016)	0.051*** (0.015)	0.047*** (0.014)	0.053*** (0.013)
Initial log Income	0.020 (0.017)	0.006 (0.016)	0.007 (0.015)	0.003 (0.015)
Region, Time,				
Commute Method,	✓	✓	✓	✓
Industry, Occ FE				
Individual FE	✓	✓	✓	✓
R^2	.440	.493	.537	.558
N obs	1,496	1,284	1,092	923
N ind	589	511	439	375

Notes: BHPS Sample 1992-2009, annual. Universe: respondents aged 24-55 reporting a nonemployment spell ending in full-time employment and appearing in the sample for the next T years. The present value of earnings over T years following a nonemployment spell as $\sum_{t=2}^{T+1} \frac{inc_t}{(1.0265)^{t-1}}$. Controls for observables include the commute and log of annual labor income in the year in which the nonemployment spell ended, gender, age, a quadratic term in experience, education, marital status, number of children, dummies for whether homeownership and job has changed, and dummies in the year in which the nonemployment spell ended for: whether the spouse was employed, 1-digit industry and occupation, homeownership, housing expenditures and the annual regional house price index. Robust standard errors are reported in parentheses. * denotes $p < .1$, ** $p < .05$, and *** $p < .01$.

Table 19: Log Present Value of Earnings, Individual Fixed Effects, Excluding London

	<u>2 Years</u>	<u>3 Years</u>	<u>4 Years</u>	<u>5 Years</u>
Initial Commute $\times 30$	0.066*** (0.017)	0.055*** (0.016)	0.047*** (0.014)	0.058*** (0.014)
Initial log Income	0.020 (0.019)	0.004 (0.017)	0.003 (0.016)	-0.001 (0.015)
Region, Time,				
Commute Method,	✓	✓	✓	✓
Industry, Occ FE				
Individual FE	✓	✓	✓	✓
R^2	.433	.482	.539	.567
N obs	1,353	1,162	1,002	848
N ind	530	460	402	343

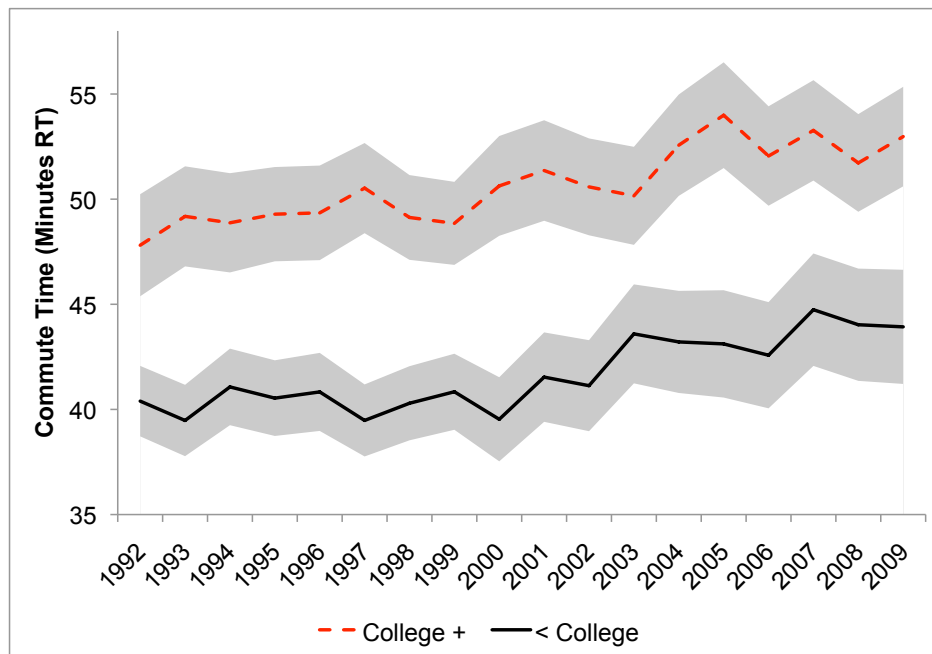
Notes: BHPS Sample 1992-2009, annual. Universe: respondents aged 24-55 who do not reside in London, reporting a nonemployment spell ending in full-time employment and appearing in the sample for the next T years. The present value of earnings over T years following a nonemployment spell as $\sum_{t=2}^{T+1} \frac{inc_t}{(1.05)^{t-1}}$. Controls for observables include the commute and log of annual labor income in the year in which the nonemployment spell ended, gender, age, a quadratic term in experience, education, marital status, number of children, dummies for whether homeownership and job has changed, and dummies in the year in which the nonemployment spell ended for: whether the spouse was employed, 1-digit industry and occupation, homeownership, housing expenditures and the annual regional house price index. Robust standard errors are reported in parentheses. * denotes $p < .1$, ** $p < .05$, and *** $p < .01$.

Table 20: Log Present Value of Earnings, Individual Fixed Effects, England Only

	<u>2 Years</u>	<u>3 Years</u>	<u>4 Years</u>	<u>5 Years</u>
Initial Commute $\times 30$	0.064*** (0.017)	0.049*** (0.016)	0.044*** (0.015)	0.050*** (0.015)
Initial log Income	0.019 (0.019)	0.010 (0.018)	0.012 (0.017)	-1.22e-05 (0.016)
Region, Time,				
Commute Method,	✓	✓	✓	✓
Industry, Occ FE				
Individual FE	✓	✓	✓	✓
R^2	.453	.507	.556	.578
N obs	1,267	1,082	921	781
N ind	502	431	370	317

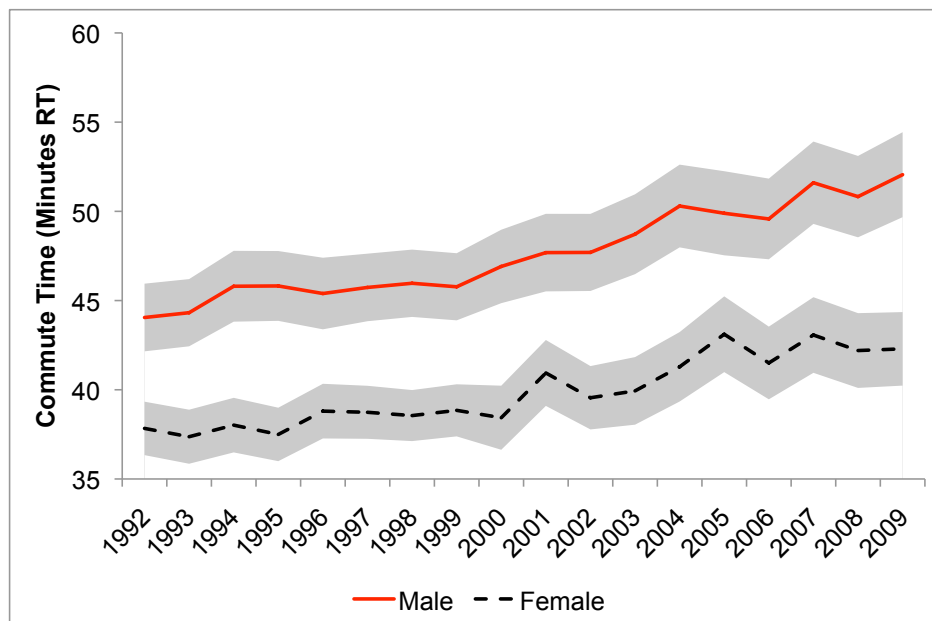
Notes: BHPS Sample 1992-2009, annual. Universe: respondents aged 24-55 who reside in England, reporting a nonemployment spell ending in full-time employment and appearing in the sample for the next T years. The present value of earnings over T years following a nonemployment spell as $\sum_{t=2}^{T+1} \frac{inc_t}{(1.05)^{t-1}}$. Controls for observables include the commute and log of annual labor income in the year in which the nonemployment spell ended, gender, age, a quadratic term in experience, education, marital status, number of children, dummies for whether homeownership and job has changed, and dummies in the year in which the nonemployment spell ended for: whether the spouse was employed, 1-digit industry and occupation, homeownership, housing expenditures and the annual regional house price index. Robust standard errors are reported in parentheses. * denotes $p < .1$, ** $p < .05$, and *** $p < .01$.

Figure 7: Average Commute Time, By Education Level



Notes: Average commute time for full-time employed respondents aged 24-55 in the BHPS, with daily commute less than 180 minutes. Shaded areas denote the 5th and 95th percentiles.

Figure 8: Average Commute Time, By Gender



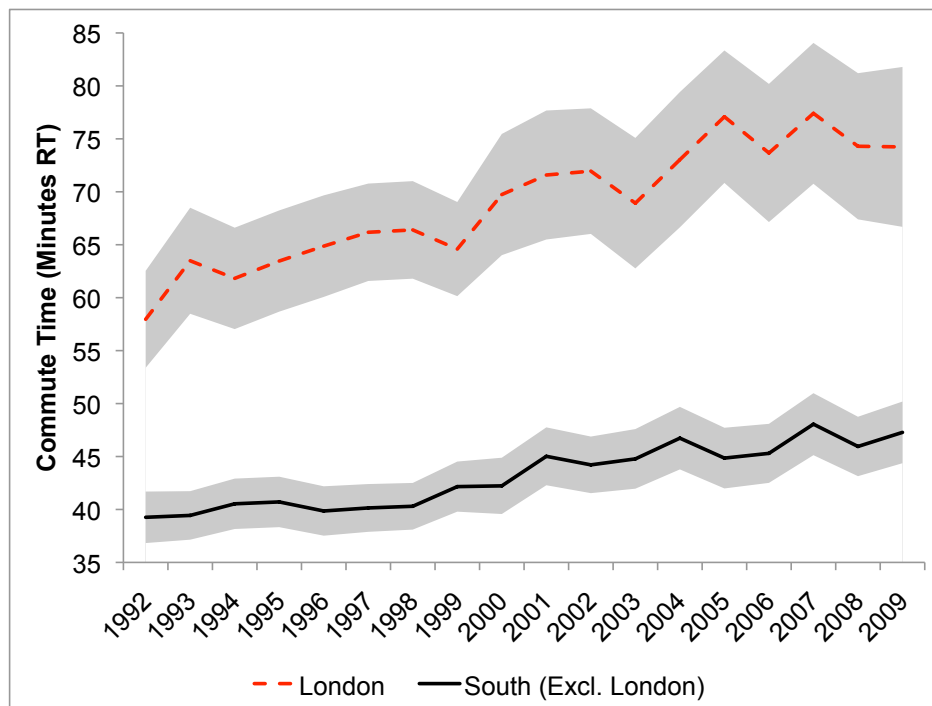
Notes: Average commute time for full-time employed respondents aged 24-55 in the BHPS, with daily commute less than 180 minutes. Shaded areas denote the 5th and 95th percentiles.

Figure 9: Average Commute Time, By Region



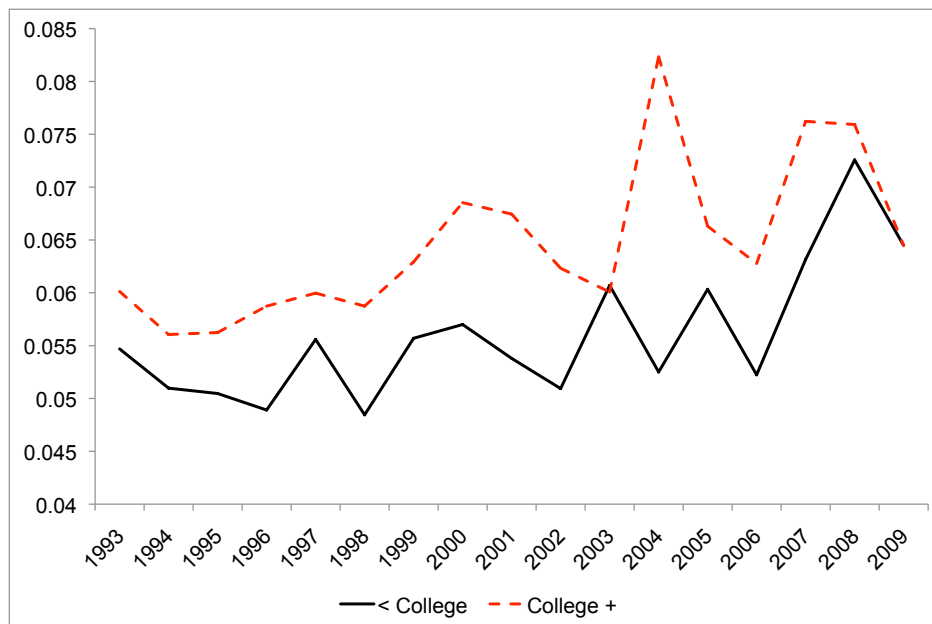
Notes: Average commute time for full-time employed respondents aged 24-55 in the BHPS, with daily commute less than 180 minutes. Shaded areas denote the 5th and 95th percentiles.

Figure 10: Average Commute Time, Southern England



Notes: Average commute time for full-time employed respondents aged 24-55 in the BHPS, with daily commute less than 180 minutes. Shaded areas denote the 5th and 95th percentiles.

Figure 11: Opportunity Cost of Commuting



Notes: Opportunity cost of commuting time for full-time employed respondents aged 24-55 in the BHPS, with daily commute less than 180 minutes. Computed as the product of the annual time spent commuting (hours) and the hourly wage, scaled by annual labor income. Shaded areas denote the 5th and 95th percentiles.