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# Modeling the impact of transportation on urban segregation

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## Abstract

In this paper, we seek to determine the effect that a change in transportation supply can have on the poverty level of a neighborhood. In particular, the evolution of the unemployment rate by developing a model that takes into account differences in the dispersion of skilled and unskilled jobs as well as the location strategies of the employed and the unemployed. We begin by presenting some stylized facts representing the distribution of jobs, employed and unemployed in some French urban units. The location of these different agents seems to follow a constant pattern. Skilled jobs and skilled inhabitants are more concentrated near the city center, while the unskilled are more dispersed. Within the same category, the unemployed are the least dispersed agents. For jobs and employed workers, it depends on the urban units. Jobs may be more concentrated than the employed, or vice versa. We propose two models to account for these distributions. The first one is based on the idea that the worse the accessibility to jobs, the higher the level of unemployment. The location of unemployment then depends entirely on the distribution of jobs and inhabitants. The second approach integrates a search-matching mechanism. Unemployment is no longer a consequence of the distribution of jobs and inhabitants, but the result of location and job search strategies on the part of the unemployed. It turns out that this second model provides the closest results to those observed empirically, because it explains both the greater concentration of jobs and qualified inhabitants, and the greater concentration of unemployed.

## 1 Introduction

In Europe, as in the United States, the existence of neighborhoods in our cities that concentrate social difficulties is the subject of particular attention from the public authorities. Post-war social housing areas, American black ghettos, formerly dynamic city centers that have lost their jobs, these neighborhoods take many forms and are the subject of specific programs aimed at addressing the real or supposed problems they generate. In France, the action of the State and local authorities in these neighborhoods is known as the “Politique de la Ville”. The programs set up within the framework of this policy have in common that they consider that the spatial concentration of poverty is the source of the disorders observed. Guided by this premise, the public authorities have constantly sought to increase their social mix by diversifying the housing stock and through settlement policies (Epstein, 2013; Béhar, 1995). Little attention has been paid to the impact of transportation organization on the situation of these neighborhood’s. To date, there has been no

precise reflection on the forms that a policy to improve the mobility of the inhabitants of poor neighborhoods should take, in the absence of a clear definition of the objectives that it should pursue and the effects that can be expected.

An improvement in mobility conditions, which may involve the creation of a new service or a reduction in costs, can have both positive and negative effects. Such an improvement may provide easier access to employment areas and may thus be able to reduce the number of unemployed people living in the area. Several empirical studies have attempted to establish a link between job accessibility and unemployment rates, with results that are, however, not very clear or even counter intuitive. Gobillon et al. (2007) show that the density of jobs accessible within 45 minutes by public transport has a significant but negative effect on unemployment in Paris, which they interpret as possibly resulting from unobserved variables that bias the result. Dujardin et al. (2008) make the same finding for Brussels, where good job accessibility does not seem to be accompanied by low unemployment. In Paris again, Duguet et al. (2009) obtain more contrasting results. While good physical accessibility to jobs seems to favor lower unemployment on a broader scale, they observe the opposite effect in the immediate vicinity of job-dense areas, which they interpret as an indicator of the poor performance of certain job-rich cities in their policy of reducing unemployment.

Furthermore, such a change is not neutral in the medium term on the location choices of households and firms. The organization of the transportation system has a direct influence on land use and city formation. Crozet et al. (2006) write that while the pedestrian city had to be compact so that every point was accessible on foot, the car city extends the urban fabric until it is torn apart. Farber et al. (2011) show that the democratization of the automobile has not improved accessibility to places of activity but has contributed to their dispersion. In France's main urban areas and over the last few decades, unskilled jobs have tended to disperse further and further away from city centers, often outside the urban transport perimeter (Wenglenski, 2004; Hubert et al., 2010; Fol, 2010). The same phenomenon of concentration of skilled jobs and deconcentration of unskilled jobs is observed in the United States (Kasarda, 1988; Kasarda, 1989).

In the worst-case scenario, improved mobility conditions can lead to increased urban segregation by pushing precarious populations further to the margins of cities, increasing the dispersion of jobs and, finally, rendering null and void any beneficial effect for precarious households, whose improved situation was the initial objective. Modeling the effect of a change in transportation conditions must therefore be able to account for both the positive and negative effects of such a change. Such a model must be able to account for three components:

- The link between transportation and the location of households with differentiated incomes ;
- The link between transportation and the location of skilled and unskilled jobs;
- The existence of unemployment and its location.

## 2 Existing models are not adapted

Separately, there are models that can address any of these three issues. None of them is able to address them simultaneously and account for the predictable evolution of a neighborhood's social mix and unemployment levels because of two major assumptions underlying them. Employment is concentrated in one location in the center (monocentric hypothesis) and everyone works (full employment).

## 2.1 The basic model of urban economics

The classical urban economics model, or AMM (Alonso, 1964; Mills, 1967; Muth, 1969), predicts the general shape of cities and the location choices of households from the rent of agricultural land (also known as the opportunity cost of land), the total population, the average income level of the population, and transportation costs. From these parameters, the amount of land consumed per household, the price of land, the city boundaries and, subsequently, the distribution of the population within the city are derived. Intuitively, the farther away households live from the city center, the higher the transportation costs of getting to work. Since all individuals must achieve the same level of utility, the price of land offsets the transportation costs so that the price declines with distance from the city center. There is a trade-off between the costs of housing and travel.

Introducing households with differentiated incomes is a common extension. The assumption generally used is that all social mix is impossible. Each point in the city is occupied by the population willing to pay the highest rent to live there. Determining the location of each population then amounts to examining the way in which the bid-rent of each category evolves. If we realistically consider that land is a normal good, i.e. that its consumption increases with income, then the poorest households should live near the city center and the wealthiest on the suburbs (Fujita, 1989). This formulation is too simplistic to capture the complexity of different real-world city configurations. But it does highlight an important point. The trade-off between transportation costs and land consumption are major determinants of urban segregation phenomena, as the «best choice» of location depends directly on disposable income (Fujita, 1989; Brueckner, 2011).

Another extension to account for the location choices of individuals with different incomes is to introduce multiple modes of transportation. Glaeser et al. (2008) and before them Leroy et al. (1983) emphasize the role of transportation supply in the location choices of households. Poor households would tend to seek proximity to public transport. Wealthy households would prefer the speed of the automobile, even at a higher financial cost. Introducing several modes of transport and a value of time in this way provides a more complete account of the location choices of individuals according to their income and leads to organizational patterns closer to those observed in European cities.

## 2.2 Relaxing the monocentric city assumption

The monocentric city hypothesis does not apply well to the problems of poor neighborhoods. This hypothesis of job concentration may hold for skilled workers. For unskilled workers, who are in the majority in these neighborhoods, it is much less certain (cf. Tableau 1). Low-skilled workers cannot claim to hold just any job. However, existing models do not include a mechanism to account for the segmentation of the labor market and the greater dispersion of low-skilled jobs, which is at the heart of the difficulties encountered by the inhabitants of these neighborhoods.

According to several authors (Fujita; Thisse, 1996; Ciccone, 2002; Rosenthal et al., 2004; Brülhart et al., 2008; Glaeser, 2010), the mechanism that leads jobs to be concentrated in the same place and that would explain the very existence of cities comes from agglomeration economies. These agglomeration economies increase the productivity of firms the closer they are to the city center (Fujita; Thisse, 1996). A trade-off is sought between their level of productivity and the price they must pay to occupy their premises.

These agglomeration effects can be incorporated into models in several ways. In the model of Fujita; Ogawa (1982), their magnitude depends on the proximity of other jobs. In the model of Wheaton (2004), which is very simple in its formulation, their magnitude decreases linearly with

distance from the city center. While the way in which agglomeration effects are introduced seems more realistic in Ogawa and Fujita's model, Wheaton's model has the advantage of relaxing the assumption of non-mixed land use, which is closer to the real organization of cities.

These models have the advantage of proposing a mechanism to account for firms' location choices. However, they have several weaknesses that make them inapplicable to our problem. They assume that there is no cross-commuting, i.e. that no individual crosses paths during his or her travels. Thus, employment is necessarily more concentrated than individuals and there is no such thing as outward commuting. Second, wages adjust to compensate exactly for any additional transportation costs, leaving individuals indifferent to their choice of employment location and making unemployment impossible.

Table 1: Density of executive and worker jobs in some French urban units (source: INSEE - RGP 2015)

City	Spatial density	Executive jobs	Worker jobs
Lille	Emplois cadres	110k	89k
	Emplois ouvriers		
Lyon	Emplois cadres	285k	155k
	Emplois ouvriers		
Paris	Emplois cadres	2 266k	831k
	Emplois ouvriers		

### 2.3 Existence and location of unemployment

Most urban models consider that companies freely set the wage they pay to their employees so that everyone has a job. Yet in France, there is a legal minimum wage that 13.4% of the working

population earns as of January 1, 2019, and the unemployment rate reached 9.4% in 2017<sup>1</sup>. Unemployment and the location choices of those affected by it are blind spots in these theories. However, the location of unemployment seems to be somewhat constant within French urban units. Whatever the level of qualification and whatever the urban unit, unemployed individuals tend to be more concentrated near the city center than individuals with a job (cf. figure 1). The unemployment rate is 2.7 times higher in French priority neighborhoods than in other neighborhoods (ONPV, 2018). It is necessary to extend these models to include a friction mechanism in the labor market that can explain how unemployment and the location choices of unemployed individuals are formed.

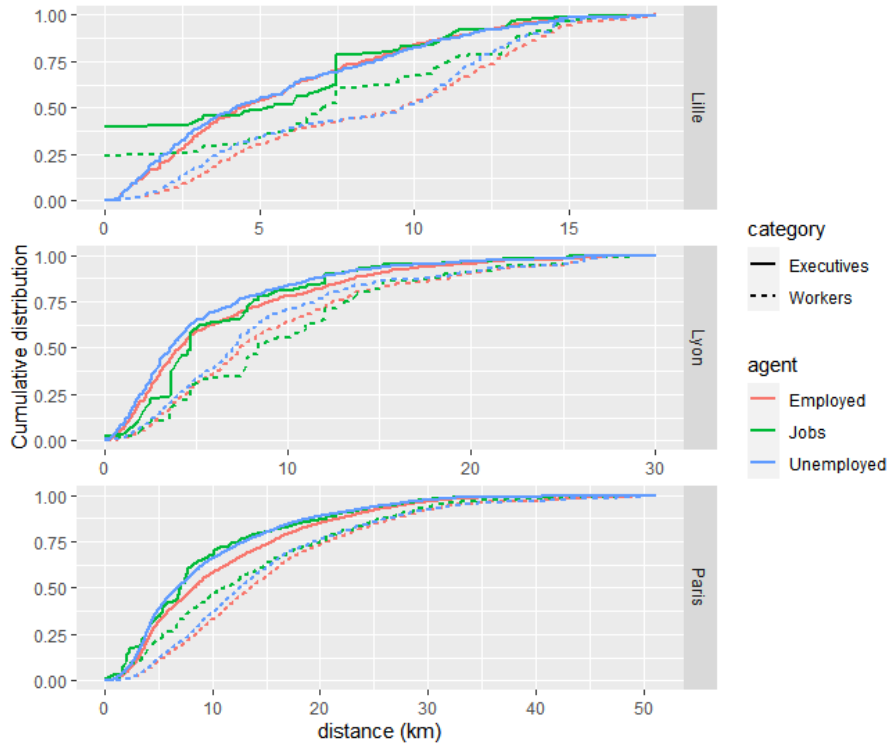
Very few studies have addressed the question of the location of unemployment within an urban model. In this field, the works of Yves Zenou are references (Zenou, 2009b; Brueckner; Zenou, 2003). These models use theories derived from labor economics (“search-matching”, “efficiency wage”) by inserting them into an urban model making it possible to account for the formation of unemployment. However, these models have the same limitations as those previously mentioned: the city is monocentric, all jobs are concentrated in one point and no social mix exists.

In terms of empirical studies, the common approach to linking transportation and unemployment rates is to use a measure of gravitational accessibility (Bonnafous et al., 1983; Geurs et al., 2004; Koenig, 1974; Hansen, 1959) based on the assumption that the better the accessibility to jobs, the lower the unemployment rate. However, many of these studies struggle to establish a clear link between the two (Gobillon et al., 2007; Gobillon et al., 2004; Dujardin et al., 2008; Duguet et al., 2009).

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<sup>1</sup>Source : DARES

Figure 1: Empirical cumulative distribution of agents\* in some French urban units (source: INSEE - RGP 2017)



\* The distribution of the employed and unemployed are represented at the IRIS level. The distribution of jobs is represented at the municipality level, which results in a less smooth curve

### 3 Introduction of the two sectors with mixed land use

In this section, we leave aside the question of unemployment to focus on the introduction of several types of agents. To do this, we rely on a hybrid model between that of Fujita; Ogawa (1982) and that of Wheaton (2004). We take the more complete expression of agglomeration effects proposed in the former and incorporate mixed land use in the manner of the latter. For the moment, we retain the assumptions of no cross-commuting and no outward trips as well as perfect wage adjustment. We obtain a model capable of explaining the greater dispersion of unskilled jobs but not that of unskilled workers and without unemployment.

#### 3.1 Household side

The two categories of individuals, caricaturally referred to as «rich» and «poor», are distinguished by a different level of wage ( $w_r > w_p$ ). Land is considered a normal good. The differences in income are reflected in a difference in the quantity of land consumed ( $l_r^h > l_p^h$ ).



Individuals choose their location so as to maximize their utility. For simplicity,  $l_r^h$  and  $l_p^h$  are exogenous and constant, reducing the utility maximization problem to that of consumption of the basket of goods  $z$  :

$$z_{\{r,p\}} = \max_{x,x_w} \{w_{\{r,p\}}(x_w) - R(x)l_{\{r,p\}}^h - td(x, x_w)\} \quad (1)$$

Where  $x$  and  $x_w$  are the individual's place of residence and work, respectively,  $w_{\{r,p\}}(x_w)$  is the wage offered in  $x_w$ ,  $t$  is the cost per unit distance of a trip, and  $d(x, x_w)$  is the distance between  $x$  and  $x_w$ .

Under the assumptions made, and since we exclude any outward trips, jobs are more concentrated than household and wages adjust to transportation costs, which simplifies their writing, since  $w_{\{r,p\}}$  decreases linearly with distance from a value at the origin  $w_{\{r,p\}}^0$  (Fujita; Ogawa, 1982).

$$\begin{aligned} w_{\{r,p\}}(x_w) - td(x - x_w) &= w_{\{r,p\}}^0 - tx_w - td(x - x_w) = w_{\{r,p\}}^0 - tx = w_{\{r,p\}}(x) \\ \Rightarrow z_{\{r,p\}} &= \max_x \{w_{\{r,p\}}^0 - R(x)l_{\{r,p\}}^h - tx\} \end{aligned}$$

### 3.2 Firm side

Firms are divided into two sectors, each offering jobs for one type of resident. Skilled jobs, or «jobs for the rich», are occupied by «rich» individuals, and unskilled jobs, or «jobs for the poor», are occupied by «poor» individuals. A warehouse or a factory does not use the same amount of land per employee as a research laboratory, a bank or a school. We can assume that, on average, a low-skilled job consumes more land than a high-skilled job ( $l_r^e \leq l_p^e$ ). The other distinction concerns their level of output per job, which in turn depends on the extent of agglomeration effects. The few empirical studies of agglomeration effects that decompose the labor market show that they differ in intensity across sectors. Sectors with high-skilled jobs tend to have strong agglomeration effects, whereas agglomeration effects are weak for sectors with lower-skilled jobs (Brülhart et al., 2008).

A job is more productive the closer it is to other jobs. This productivity gain is expressed through a «location potential function»  $F_{\{r,p\}}(x)$ , which depends on  $b_{\{r,p\}}(y)$  the number of jobs in  $y$ ,  $\beta_{\{r,p\}\{r,p\}}$  a parameter representing the speed of decrease of the contribution of the proximity of jobs in one sector to the productivity of another,  $t$  the transportation cost per unit of distance, and  $d(x, y)$  a distance between  $x$  and  $y$ . Agglomeration effects can thus be solely intra/extra sectoral or depend on the proximity of all jobs regardless of the sector. Note that  $\beta$  takes the form of a 2x2 matrix and has enough flexibility to integrate various effects. If  $\beta$  is a diagonal matrix, the agglomeration effects are intra-sectoral and only the proximity of jobs in a sector influences the productivity of this same sector. On the contrary, if  $\beta$  has an empty diagonal, the agglomeration effects are purely extra-sectoral and the proximity of jobs in one sector only influences the other sector.

$$F_{\{r,p\}}(x) = \sum_{i=\{r,p\}} \int b_i(y) e^{-\beta_{\{r,p\}i} td(x,y)} dy \quad (2)$$

The two sectors differ in terms of higher output for rich jobs ( $k_r \geq k_p$ ), or a faster decay of agglomeration effects for poor jobs ( $\beta_r \leq \beta_p$ ). Each job locates so as to maximize its profit, which depends on its output  $k_{\{r,p\}}$ , the location potential  $F_{\{r,p\}}(x)$ , the rent  $R(x)$  paid per unit of area consumed  $l_{\{r,p\}}^e$  and the wage  $w_{\{r,p\}}(x)$  paid.

$$\pi = \max_x \{k_{\{r,p\}} F_{\{r,p\}}(x) - R(x) l_{\{r,p\}}^e - w_{\{r,p\}}(x)\} \quad (3)$$

For simplicity,  $l_{\{r,p\}}^e$  is taken as exogenous and constant. Firms are considered to be in perfect competition so that in equilibrium,  $\pi = 0$ .

### 3.3 Resolution

From the writings of the maximization problems for jobs and individuals in the two sectors, we obtain the writing of the bid-rent functions of rich households  $\psi_r$ , poor households  $\psi_p$ , rich jobs  $\phi_r$  and poor jobs  $\phi_p$ .

$$\psi_r(x) = \left\{ \frac{w_r^0 - z_r - tx}{l_r^h} \mid z_r = z_r^* \right\} \quad (4)$$

$$\psi_p(x) = \left\{ \frac{w_p^0 - z_p - tx}{l_p^h} \mid z_p = z_p^* \right\} \quad (5)$$

$$\phi_r(x) = \left\{ \frac{k_r F_r(x) - (w_r^0 - tx)}{l_r^e} \mid \pi_r = 0 \right\} \quad (6)$$

$$\phi_p(x) = \left\{ \frac{k_p F_p(x) - (w_p^0 - tx)}{l_p^e} \mid \pi_p = 0 \right\} \quad (7)$$

Since we seek to highlight the degree of dispersion of these agents, we use the same mixed land use mechanism as in the Wheaton's model. For example, the fraction of land occupied by the jobs of the rich is :

$$f_r^e(x) = \frac{\phi_r(x)}{\psi_r(x) + \psi_p(x) + \phi_r(x) + \phi_p(x)} \quad (8)$$

The resolution of the model consists in finding the values of  $\{z_r, z_p, w_r^0, w_p^0, x_r^e, x_p^e, x_r^h, x_p^h\}$ , with  $x_{\{r,p\}}^{\{e,h\}}$  the limit where the bid rent of the agent category reaches the opportunity cost of land  $R_a$ , so that all jobs and households of each category fit in the city. The equilibrium obtained depends on the parameters  $\{N_r, N_p, l_r^h, l_p^h, l_r^e, l_p^e, k_1, k_2, \beta_{rr}, \beta_{rp}, \beta_{pr}, \beta_{pp}, R_a\}$ , where  $N_{\{r,p\}}$  is the number of inhabitants and jobs of a category.

To achieve this, we use a 6-step algorithm with a loop between step 2 and 5:

1. We define an arbitrary initial distribution of available land among all agents,  $f_r^e(x) = f_p^e(x) = f_r^h(x) = f_p^h(x) = 1/4 \forall x$ , four functions (equation 9 and 10) to calculate their new distribution when  $w_{\{r,p\}}$  and  $z_{\{r,p\}}$  change and arbitrary initial values for  $w_{\{r,p\}}$  and  $z_{\{r,p\}}$  ;

$$f.new_{\{r,p\}}^e(x, w) = \frac{\phi_{\{r,p\}}(x, w)}{\psi_r(x) + \psi_p(x) + \phi_{\{r,p\}}(x, w) + \phi_{\{p,r\}}(x)} \quad (9)$$

$$f.new_{\{r,p\}}^h(x, z) = \frac{\psi_{\{r,p\}}(x, z)}{\psi_{\{r,p\}}(x, z) + \psi_{\{p,r\}}(x) + \phi_r(x) + \phi_p(x)} \quad (10)$$

- then we define four optimization functions  $o.w_{\{r,p\}}(w_{\{r,p\}})$  and  $o.z_{\{r,p\}}(z_{\{r,p\}})$  (equations 11 and 12) and find their roots  $w.new_{\{r,p\}}$  and  $z.new_{\{r,p\}}$ ;

$$o.w_{\{r,p\}}(w) = N_{\{r,p\}} - \frac{1}{l_{\{r,p\}}^e} \int_x f.new_{\{r,p\}}^e(x, w) \quad (11)$$

$$o.z_{\{r,p\}}(z) = N_{\{r,p\}} - \frac{1}{l_{\{r,p\}}^h} \int_x f.new_{\{r,p\}}^h(x, z) \quad (12)$$

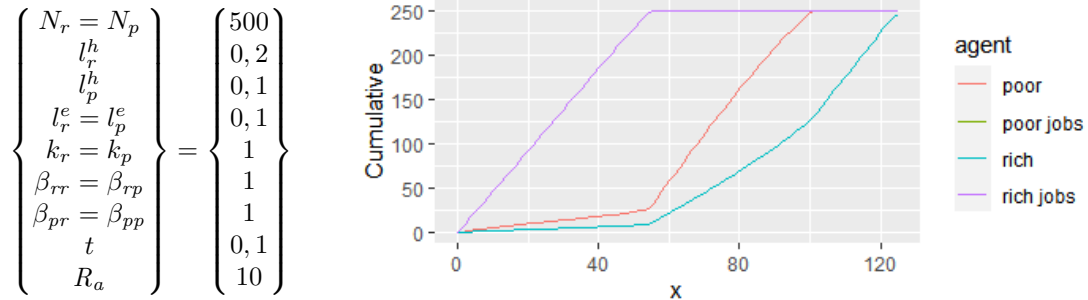
- we calculate the new values of  $w_{\{r,p\}} = w_{\{r,p\}} + \delta_1 * (w.new_{\{r,p\}} - w_{\{r,p\}})$  and  $z_{\{r,p\}} = z_{\{r,p\}} + \delta_1 * (z.new_{\{r,p\}} - z_{\{r,p\}})$ , with  $\delta_1$  a step between 0 and 1;
- then we calculate the new values of  $f_{\{r,p\}}^e(x) = f_{\{r,p\}}^e(x) + \delta_2 * (f.new_{\{r,p\}}^e(x, w_{\{r,p\}}) - f_{\{r,p\}}^e(x))$  and  $f_{\{r,p\}}^h(x) = f_{\{r,p\}}^h(x) + \delta_2 * (f.new_{\{r,p\}}^h(x, z_{\{r,p\}}) - f_{\{r,p\}}^h(x))$  with  $\delta_2$  a step between 0 and  $\delta_1$ ;
- if the new values of  $w_{\{r,p\}}$ ,  $z_{\{r,p\}}$  or  $f_{\{r,p\}}^{\{e,h\}}(x) \forall x$  are different from their previous values by more than  $\varepsilon\%$ , we return to step 2;
- finally, we calculate  $x_{\{r,p\}}^{\{e,h\}}$  as the roots of  $\phi_{\{r,p\}}(x) - R_a$  and  $\psi_{\{r,p\}}(x) - R_a$ .

### 3.4 Numerical applications

#### 3.4.1 Household land consumption differs (figure 2)

For this first numerical application, the two employment sectors are identical and only household land consumption differs. Since jobs are identical, they are distributed in the same way. For households, we find the classic result of a poor population located closer to the city center because of its lower consumption of land.

Figure 2: Cumulative distribution of jobs and households, different household land consumption

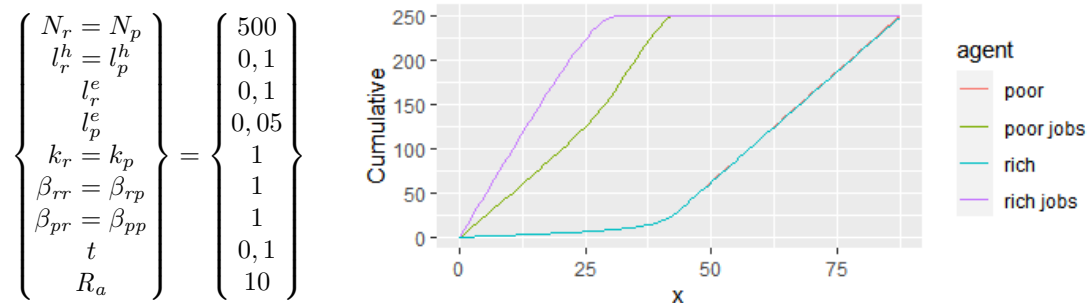


#### 3.4.2 Only the land consumption of jobs differs (figure 3)

Household land consumption is now the same, but poor jobs consume more land than rich jobs. As a result, poor jobs are more dispersed than rich jobs. At the household level, rich and poor are

distributed in exactly the same way. This result may be surprising, since the greater dispersion of poor jobs should intuitively translate into a greater dispersion of those who hold them. However, there is no mechanism in the model to link the two, because wages exactly compensate for transport costs, so that individuals are indifferent to where they work, which has no impact on their choice of location. This is an important limitation of this model that we will address later.

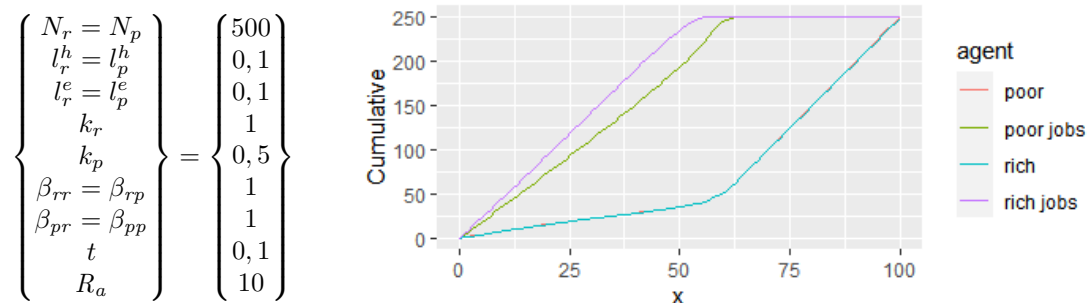
Figure 3: Cumulative distribution of jobs and households, different job land consumption



### 3.4.3 Only the production of jobs differs (figure 4)

The jobs of the rich are here twice as productive as the jobs of the poor ( $k_r = 2 * k_p$ ). The agglomeration effects are identical (same value of  $\beta$ ). Jobs in the least productive sector are more dispersed than those in the most productive sector. This result is logical, since the bid-rent increases with output ( $\frac{\partial \Phi_i(x)}{\partial k_i} = \frac{F_i(x)}{l_i^e} > 0$ ).

Figure 4: Cumulative distribution of jobs and households, different production



### 3.4.4 Only the rate of decay of the agglomeration effects differs (figure 5)

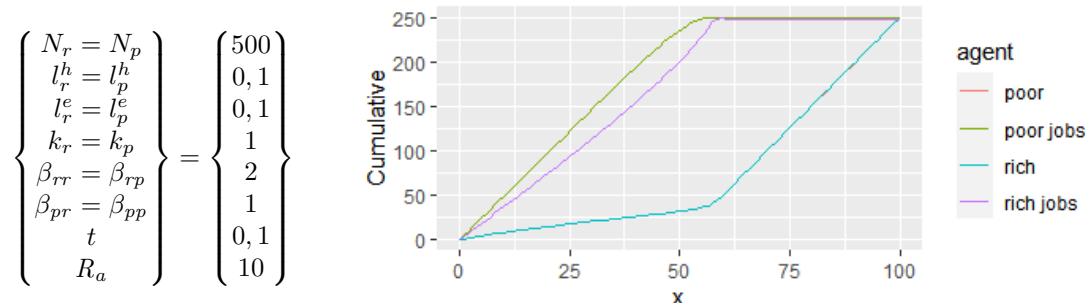
The intensity of agglomeration effects decreases in this application more rapidly for the jobs sector of the rich ( $\beta_{r\{r,p\}} > \beta_{p\{r,p\}}$ ).

The sector with the slowest decreasing agglomeration effects is more concentrated. Since proximity to other jobs influences the level of output, the sector with the slowest decreasing effects gains

more productivity through agglomeration effects. However, as we saw earlier, the more productive sector will be more concentrated, which is what we observe here.

In other words, changes in agglomeration effects are only important because they change the level of production, which is what really influences the location of jobs. The sector that will ultimately prove to be the most productive will be the most concentrated. This result is important because it allows us to reduce the number of parameters in the model and to focus on the level of production.

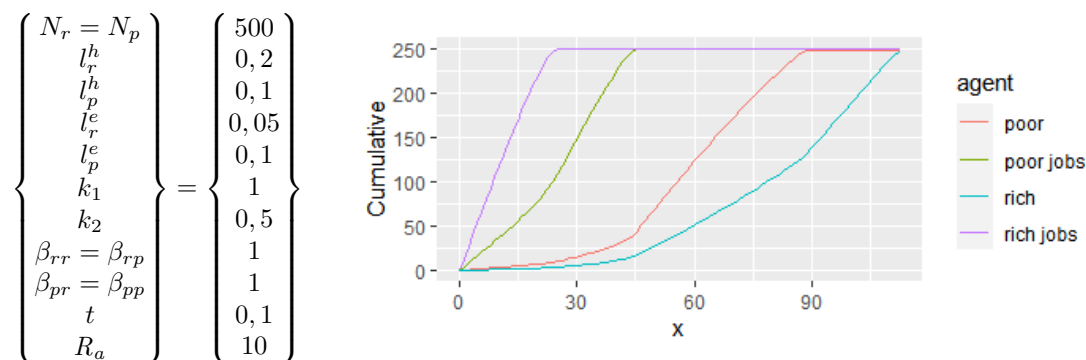
Figure 5: Cumulative distribution of jobs and households, different agglomeration effects



### 3.4.5 Everything is different (figure 6)

We finally vary all of these parameters simultaneously for each type of agent except for the parameter  $\beta$  since it is primarily the level of production that matters. The rich consume more land than the poor, rich jobs consume less land than poor jobs and rich jobs produce more than poor jobs. The result is a segregated organization of the city. Rich jobs are more concentrated, because they are more productive. Then come the poor jobs, the poor households and the rich households.

Figure 6: Cumulative distribution of jobs and households, different agglomeration effects



Other organizations are possible, always with a concentration of jobs that is necessarily higher than that of households of the same type because of the assumption of no cross-commuting. At this stage, however, it is less interesting to explore the different possible configurations than to note

that the forces introduced make it possible to obtain a segregated city, with poor neighborhoods, rich neighborhoods, and areas of skilled and unskilled employment.

The second finding is that, although the existence of agglomeration effects is at the root of job concentration, their evolution is ultimately of little importance compared to the overall level of production in determining the location of one sector of employment relative to another. This is important, because the work that has attempted to establish differences between sectors in these effects is few and far between, and often yields weakly significant results, including Brühlhart et al. (2008) previously cited, and does not address the question of their rate of decay with distance. On the other hand, that output is lower for a low-skilled job than for a skilled job is a much less hazardous hypothesis.

## 4 Location of unemployment

In this section, we will develop two different approaches to introduce the existence of a friction on the labor market leading to the existence of unemployment in the model and to explain its location. The first approach introduces unemployment caused by low job accessibility. The second approach introduces a "search-matching" mechanism from labor economics. We then end up with two models that simultaneously reproduces the dispersion of households and jobs, the existence of spatial segregation and the presence of unemployment that tends to be concentrated in certain places.

### 4.1 Accessibility and allocation of jobs

The first method consists in relaxing the assumptions that wages are adjusted to transport costs and that there is no cross-commuting. Without these assumptions, individuals are no longer indifferent to their place of employment, as it is in their interest to live as close as possible to their place of employment in order to minimize transportation costs. However, it is necessary to obtain an equilibrium where all individuals in the same category achieve the same level of utility. We obtain this condition by considering that individuals do not know at first sight where their job will be located. Indeed, occupational mobility is more frequent than residential mobility. It is therefore conceivable that individuals choose their place of residence according to the location of all available jobs and not the one they occupy at the time of their choice of place of residence. This hypothesis also has the advantage of being compatible with the existence of observed wasteful commuting (Hamilton; Röell, 1982; Hamilton, 1989; Small et al., 1992; Brueckner, 2011), i.e. individuals locating close to a major employment center while working elsewhere. If there are fewer jobs than individuals, the latter integrate this risk of unemployment into their choice of place to live. In equilibrium, the result is an organization of the city where, at each point, a share of individuals have chosen to live but find themselves unable to have a job.

#### 4.1.1 Presentation of the model

In concrete terms, individuals evaluate the chance that they have of occupying a job located in  $y$  if they live in  $x$ , according to the number of jobs in  $y$  allocated to individuals living in  $x$ , noted  $a(x, y)$ . This function checks the conditions of equation 13, with  $n_l(x)$  the potential number of employed persons located in  $x$ .

$$\begin{cases} \int^x a(x, y) = b(y) & \forall y \\ \int^y a(x, y) = n_l(x) & \forall x \end{cases} \quad (13)$$

The first condition means that all jobs located in  $y$  are allocated somewhere. The second condition is more complex. If  $n_l(x) \leq n(x)$ , it means the number of jobs allocated in  $x$  equals the potential number of employed workers living there. Note that  $n_l(x) < n(x)$ , a share equal to  $1 - \frac{n_l(x)}{n(x)}$  of the individuals residing in  $x$  are unemployed and unemployment rate, noted  $u(x)$ , is given by equation 14. If  $n_l(x) > n(x)$ , there are not enough inhabitants in  $x$  to fill all the jobs there. A share equal to  $1 - \frac{n(x)}{n_l(x)}$  of the allocated jobs are vacant. We choose to distribute these vacancies proportionally among all those assigned in  $x$ , so that the share of vacancies in  $y$ , denoted  $v(y)$  is given by equation 15.

$$u(x) = \begin{cases} 1 - \frac{n_l(x)}{n(x)} & \text{if } n_l(x) \leq n(x) \\ 0 & \text{if } n_l(x) > n(x) \end{cases} \quad (14)$$

$$v(y) = \frac{1}{b(y)} \int^{x \setminus n_l(x) > n(x)} \left[1 - \frac{n(x)}{n_l(x)}\right] a(x, y) dx \quad (15)$$

All the equations relating to the problem of household utility and firm profit maximization are modified, because individuals do not know where they will work or whether they will be unemployed, and firms incorporate the risk of vacancy. The distance to travel to work is now an expectation:

$$D(x) = \int^y \frac{b(y) * a(x, y) * d(x, y)}{\int^z b(z) * a(x, z) dz} dy \quad (16)$$

By denoting  $w^l$  the wage of a working person,  $w^u$  the unconditional income of an unemployed person, and  $\tau < 1$  the number of trips that a unemployed person makes each day to places of employment for reasons other than work (shopping, services), the agents' maximization problem becomes:

$$\begin{cases} z_{\{r,p\}} = \max_x \{ [w_{\{r,p\}}^l - tD(x)] * [1 - u(x)] + [w_{\{r,p\}}^u - \tau tD(x)] * u(x) - R(x) l_{\{r,p\}}^h \} \\ \pi_{\{r,p\}} = \max_x \{ [k_{\{r,p\}} F_{\{r,p\}}(x) - w_{\{r,p\}}^l(x)] * [1 - v(x)] - R(x) l_{\{r,p\}}^e \} \end{cases} \quad (17)$$

By inverting equation 17, we finally obtain the expression for the bid-rent functions:

$$\begin{cases} \psi_{\{r,p\}}(x) = \left\{ \frac{[w_{\{r,p\}}^l - tD_{\{r,p\}}(x)] * [1 - u_{\{r,p\}}(x)] + [w_{\{r,p\}}^u - \tau tD_{\{r,p\}}(x)] * u_{\{r,p\}}(x) - z_{\{r,p\}}}{l_{\{r,p\}}^h} \mid z_{\{r,p\}} = z_{\{r,p\}}^* \right\} \\ \phi_{\{r,p\}}(x) = \left\{ \frac{[k_{\{r,p\}} F_{\{r,p\}}(x) - w_{\{r,p\}}^l(x)] * v_{\{r,p\}}(x) - \pi_{\{r,p\}}}{l_{\{r,p\}}^e} \mid \pi_{\{r,p\}} = \pi_{\{r,p\}}^* \right\} \end{cases} \quad (18)$$

#### 4.1.2 Examples of allocation functions

The function chosen to express the allocation of jobs in  $y$  to inhabitants in  $x$  is decisive. We illustrate this with two examples.

First, we consider that a job has the same probability of being occupied by each inhabitant, whatever his location (equation 19). In this case, the unemployment rate is the same at all points of the city (equation 20), which is of little interest except as an extreme case in which distance to jobs has no influence on the unemployment rate.

$$a(x, y) = \frac{n(x)b(y)}{N} \quad (19)$$

$$u(x) = 1 - \int^y \frac{b(y)}{N} dy = 1 - \frac{B}{N} \quad (20)$$

With  $N_{\{r,p\}}$  and  $B_{\{r,p\}}$  the total number of inhabitants and jobs in the sector  $\{r, p\}$ .

Second, we consider that the number of jobs in  $y$  allocated to inhabitants in  $x$  decreases exponentially with the cost of transportation between  $x$  and  $y$  (equation 21). In this case, the unemployment rate is no longer uniform and is given by equation 22. Note that when the transportation costs  $t$  are zero, we find the expression of equation 19, because the distance no longer matters. This expression is particularly relevant because it takes the form of a measure of gravitational accessibility to employment, which is commonly used in transportation engineering for demand modeling (Bonafous et al., 1983; Geurs et al., 2004; Koenig, 1974; Hansen, 1959) and has already been used in several empirical studies that seek to determine the relationship between transportation supply and neighborhood unemployment rates (Gobillon et al., 2007; Gobillon et al., 2004; Dujardin et al., 2008; Duguet et al., 2009). The numerator of equation 21 is the canonical form of a gravitational accessibility indicator. The denominator allows for competition between workers who all want to occupy the available jobs. To use the denomination of Barlet et al.<sup>2</sup> (Barlet et al., 2012), it is a "gravitational indicator of localized potential accessibility" which has the advantage of taking into account the relative scarcity of the number of jobs available per inhabitant.

$$a(x, y) = n(x)b(y) \frac{e^{-\alpha*t*d(x,y)}}{\int^z n(z)e^{-\alpha*t*d(z,y)} dz} \quad (21)$$

$$u(x) = 1 - \int^y b(y) \frac{e^{-\alpha*t*d(x,y)}}{\int^z n(z)e^{-\alpha*t*d(z,y)} dz} dy \quad (22)$$

### 4.1.3 Resolution

The resolution of the model is identical to the previous section, except that we do not optimize over  $w$  but  $\pi$  for the distribution of jobs and we now have a mechanism for locating unemployed people and job vacancies.  $u(x)$  and  $v(y)$  are calculated at the beginning of step 2 of the algorithm in section 3.3.

## 4.2 "Search-matching" based model

The other method is based on the urban model of unemployment developed by Yves Zenou (2009b). In this model, individuals can lose or find a job according to the "search-matching" theory, widely used in labor economics. It introduces in an urban model a job search model to explain the location and the level of unemployment in a city. However, this model has the same limitation

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<sup>2</sup>Barlet et al. use a similar form of this indicator in a different register. Their article aims at characterizing the accessibility to general practitioners of the French population



as those previously mentioned: the city is monocentric and all jobs are concentrated in one point. We propose to extend this model by making it compatible with a dispersion of jobs linked to the existence of agglomeration effects.

#### 4.2.1 Labor market

In this model, it is necessary to obtain both an urban equilibrium and a labor market equilibrium, the two being linked. We use a formulation of the labor market directly inspired by that developed by Yves Zenou (2009b), itself inspired by previous work on search-matching theory (Mortensen et al., 1999; Pissarides, 2000). According to this theory, unemployment results from frictions linked to the lack of coordination among job seekers. Many job seekers may apply for the same offers and not consider other offers at all. It therefore takes time to match a job offer with a job seeker. A job seeker will find a suitable offer following a random Poisson process, so that at each unit of time, the rate of job vacancies finding an employee and the rate of unemployed finding a job are given by equations 23 and 24 respectively, with  $s(e)$  the intensity of an individual's job search as a function of the effort  $e$  put into this search (cf. section 4.2.2),  $\bar{s}$  its average value,  $u$  the unemployment rate,  $v$  the share of job vacancies,  $\theta = \frac{vB}{\bar{s}uN}$  a measure of the tightness of the labor market,  $m_0$  a parameter and  $\zeta$  another parameter between 0 and 1 (cf. Zenou, 2009b).

$$q(\theta) = m_0\theta^{-\zeta} \quad (23)$$

$$s(e)\theta q(\theta) = s(e)m_0\theta^{1-\zeta} \quad (24)$$

Individuals can therefore find a job, but they can also lose it, because at each unit of time, an exogenous part of the jobs are destroyed at a rate  $\delta$ . To solve the model, it is necessary to determine the values of  $s(e)$ ,  $\bar{s}$ ,  $u$ ,  $v$  and  $\theta$ , because the total number of inhabitants  $N$  and jobs  $B$  are assumed to be given. The values of  $s$  and  $\bar{s}$  are determined by the urban model and will be treated later. This is how the link between the two parts of the model is established. The values of  $u$ ,  $v$  and  $\theta$  are obtained by solving the following system of equations:

$$\begin{cases} \delta(1-v)B = \bar{s}\theta q(\theta)uN \\ (1-v)B = (1-u)N \\ \theta = \frac{vB}{\bar{s}uN} \end{cases} \quad (25)$$

The first line of this system of equations means that in equilibrium, there are as many jobs destroyed as there are unemployed finding jobs in each period, so that the unemployment rate no longer varies. The second line means that the number of occupied jobs equals the number of employed workers. The third line is simply the definition of  $\theta$  (Zenou, 2009a).

#### 4.2.2 Land market

Unlike previous models, the problem of maximizing the utility and profit of residents and firms now has a temporal component. In each period, a job can be destroyed or created and an individual can lose or find a job. Agents thus maximize an intertemporal utility or profit described by the following Bellmann equations (equation 26), with  $\rho$  the discounted rate of time,  $I^l$ ,  $I^u$ ,  $I^v$  the intertemporal utilities of the employed, the unemployed and the jobs. We do not write the expression for the intertemporal profit of vacant jobs, because like Zenou we assume that firms create jobs until  $I^v = 0$ .

$$\begin{aligned}
\rho I_{\{r,p\}}^l &= w_{\{r,p\}}^l - l_{\{r,p\}}^h R(x) - t D(x) - \delta(I_{\{r,p\}}^l - I_{\{r,p\}}^u) \\
\rho I_{\{r,p\}}^u &= w_{\{r,p\}}^u - l_{\{r,p\}}^h R(x) - (e + \tau) t D(x) + s(e)\theta q(\theta)(I_{\{r,p\}}^l - I_{\{r,p\}}^u) \\
\rho I_{\{r,p\}}^e &= k_{\{r,p\}} F_{\{r,p\}}(x) - w_{\{r,p\}}^l - l_{\{r,p\}}^e R(x) - \delta I_{\{r,p\}}^e
\end{aligned} \tag{26}$$

As in the previous model, we do not retain the assumptions of no cross-commuting and wage adjustment, so that the distance to jobs is again an expectation of the same form as in equation 16, because without it individuals are not indifferent to their place of employment. These equations show the nature of the effort  $e$  made by individuals to find a job. This effort is actually represented by the amount of travel they make to get to the jobs. The greater this effort, the greater their chance of finding a job. The value of this effort is determined endogenously, as individuals choose the optimal value of  $e$  to maximize their intertemporal utility. It is thus necessary to have  $s'(e) > 0$  and  $s''(e) \leq 0$ . It is also preferable to have  $s(0) > 0$ , so that even without moving, individuals have a non-zero chance of finding a job by looking for a job from home. Equation 27 gives an example of a function that checks these conditions when  $s_1 > 1$  and that we will use for numerical applications.

$$s(e) = \log(s_0 e + s_1) \tag{27}$$

The optimal value of  $e$  is obtained thanks to the 1st degree condition applied to the expression of  $I^u$ :

$$r \frac{\partial I^u}{\partial e} = -t D(x) + s'(e)\theta q(\theta)(I^l - I^u) = 0$$

Using the form of  $s(e)$  retained in equation 27, we obtain:

$$e^*(x) = \frac{\theta q(\theta)(I^l - I^u)}{t D(x)} - \frac{s_1}{s_0}$$

In other words, the higher the transportation costs, the lower the effort made by individuals to find a job. Conversely, the higher the chance of finding a job and the higher the potential benefit, the greater the effort.

Finally, we obtain the expression of the bid-rent of the different agents from equation 26 :

$$\begin{aligned}
\psi_{\{r,p\}}^l &= \frac{1}{l_{\{r,p\}}^h} \left[ w_{\{r,p\}}^l - t D(x) - \delta(I_{\{r,p\}}^l - I_{\{r,p\}}^u) - \rho I_{\{r,p\}}^l \right] \\
\psi_{\{r,p\}}^u &= \frac{1}{l_{\{r,p\}}^h} \left[ w_{\{r,p\}}^u - (e + \tau) t D(x) + s(e)\theta q(\theta)(I_{\{r,p\}}^l - I_{\{r,p\}}^u) - \rho I_{\{r,p\}}^u \right] \\
\phi_{\{r,p\}}^e &= \frac{1}{l_{\{r,p\}}^e} \left[ k_{\{r,p\}} F_{\{r,p\}}(x) - w_{\{r,p\}}^l - (\delta + \rho) I_{\{r,p\}}^e \right]
\end{aligned} \tag{28}$$

### 4.2.3 Resolution

As before, land use is mixed and depends directly on the ratio between the auction rents of the different agents. Obtaining an equilibrium comes down to finding the values of  $\{I_r^l, I_p^l, I_r^u, I_p^u, I_r^e, I_p^e, \theta_r, \theta_p, u_r, u_p, v_r, v_p, x_r^e, x_p^e, x_r^h, x_p^h\}$  as well as functions  $e_{\{r,p\}}^*(x)$  with  $x_{\{r,p\}}^{\{e,h\}}$  the limit where the bid rent of the agent category reaches the opportunity cost of land  $R_a$ , so that all jobs and households of each category fit in the city.

We optimize the distribution of agents over  $I_{\{r,p\}}^{\{l,u,e\}}$  instead of  $w_{\{r,p\}}$  and  $z_{\{r,p\}}$ . The values of  $e$ ,  $u$  and  $v$  are calculated at the beginning of step 2 of the algorithm presented in 3.3.

### 4.3 Numerical applications

The purpose of these examples is both to compare the results obtained with the two models presented above and to examine the impact of a change in transportation costs on the level and location of unemployment within the city. For simplicity, land consumption and the rate of decay of agglomeration effects are identical for all agents. Rich and poor inhabitants are distinguished by their income ( $w_r^l > w_p^l > w_r^u > w_p^u$ ). Rich and poor jobs are distinguished by their level of production ( $k_r > k_p$ ). The "rich" sector has as many jobs as inhabitants, while the "poor" sector has 20% fewer jobs than inhabitants for exogenous reasons (global shortage of unskilled jobs). For each unit of distance, one unit of land is available. The table 3 shows the value of the exogenous parameters except for the unit transportation costs, which we vary.

Table 3: Models parameters

(a) Common parameters		(b) Search-Matching model parameters	
Parameter	Value	Parameter	Value
$N_{\{r,p\}}$	500	$m_0$	2
$B_r$	500	$\zeta$	0.5
$B_p$	400	$\delta$	0.1
$l_{\{r,p\}}^{\{e,h\}}$	0.1	$\rho$	0.2
$w_r^l$	150	$s_0$	2
$w_p^l$	90	$s_1$	1.1
$w_r^u$	50		
$w_p^u$	30		
$R_a$	10		
$\alpha$	0.01		
$\beta_{\{r,p\}\{r,p\}}$	0.04		
$k_r$	0.3		
$k_p$	0.1		

Figure 7 shows the bid-rent curves of all agents and figure 8 their cumulative distribution from the city center for different values of unit transportation costs and for both models.

Overall, the location of jobs and employed workers is very similar in the two models. When transportation costs are very low ( $t \sim 0.2$ ), jobs in both sectors tend to be more concentrated than the employed, because agglomeration effects, and hence the bid-rent of jobs, are very high. As transportation costs increase, the bid-rent curve for the employed in both sectors becomes steeper and steeper until they are as concentrated as jobs, as it becomes more and more expensive to live at a distance from jobs. Jobs and employed workers then share the available land equally, but the two sectors occupy a different place in the city that is more consistent with empirical observations (cf. figure 1). Rich employed and jobs are concentrated near the center, while poor employed and jobs are dispersed. Beyond a certain value of transportation costs ( $t \sim 0.8$  for the accessibility model,  $t \sim 1.1$  for the search-matching model), the employed are more concentrated than jobs. Their bid-rent curve flattens out in the center, because the dispersion of jobs leads transportation costs to vary very little with distance. Then it collapses very quickly as we approach  $x_{\{r,p\}}^r$ , the

limit at which there are no more jobs. At this point, the city is completely segregated, with each sector occupying a different place in the city.

The two models differ strongly, however, in the location of the unemployed. In the model with job allocation according to accessibility, the unemployed are always relegated to the outskirts of the city, whatever the transportation costs. This finding is not surprising, since in this model unemployment is the result of poor job accessibility. The variation of transportation costs seems, in this framework, to have only a very limited effect on the location of unemployment. In the case of the search-matching model, the opposite is true. When transportation costs are low ( $t < 0.5$ ), the unemployed tend to be more concentrated than the employed, which is once again consistent with empirical observations, because the effort to find a job is not very costly in terms of transport, which leads them to adopt an active search ( $e$  is high) and to prefer the most favorable locations for this search. As transportation costs increase, job search becomes more and more expensive and the effort of the unemployed decreases, leading them to make fewer trips to job sites, to have a less steeper bid-rent curve and thus, finally, to be more and more dispersed.

Figure 7: Bid rent curves

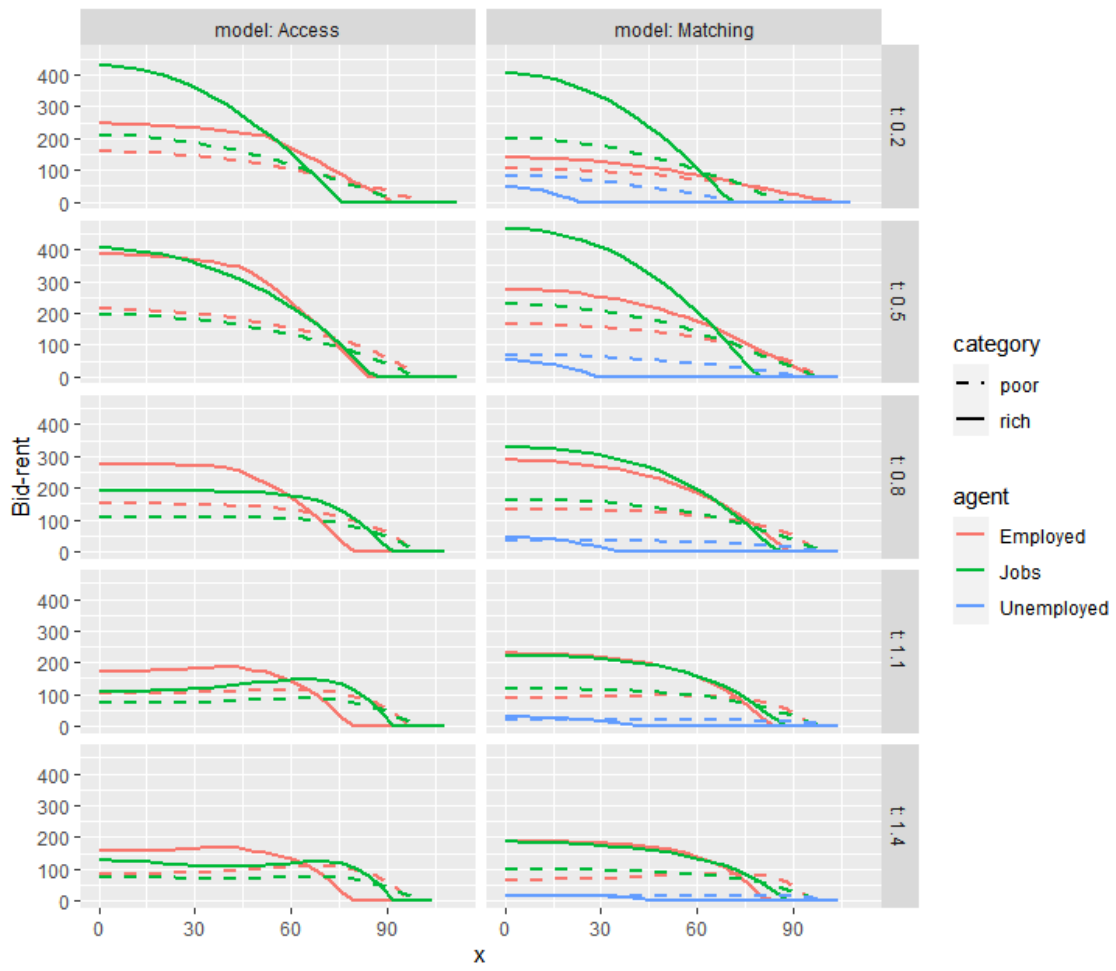
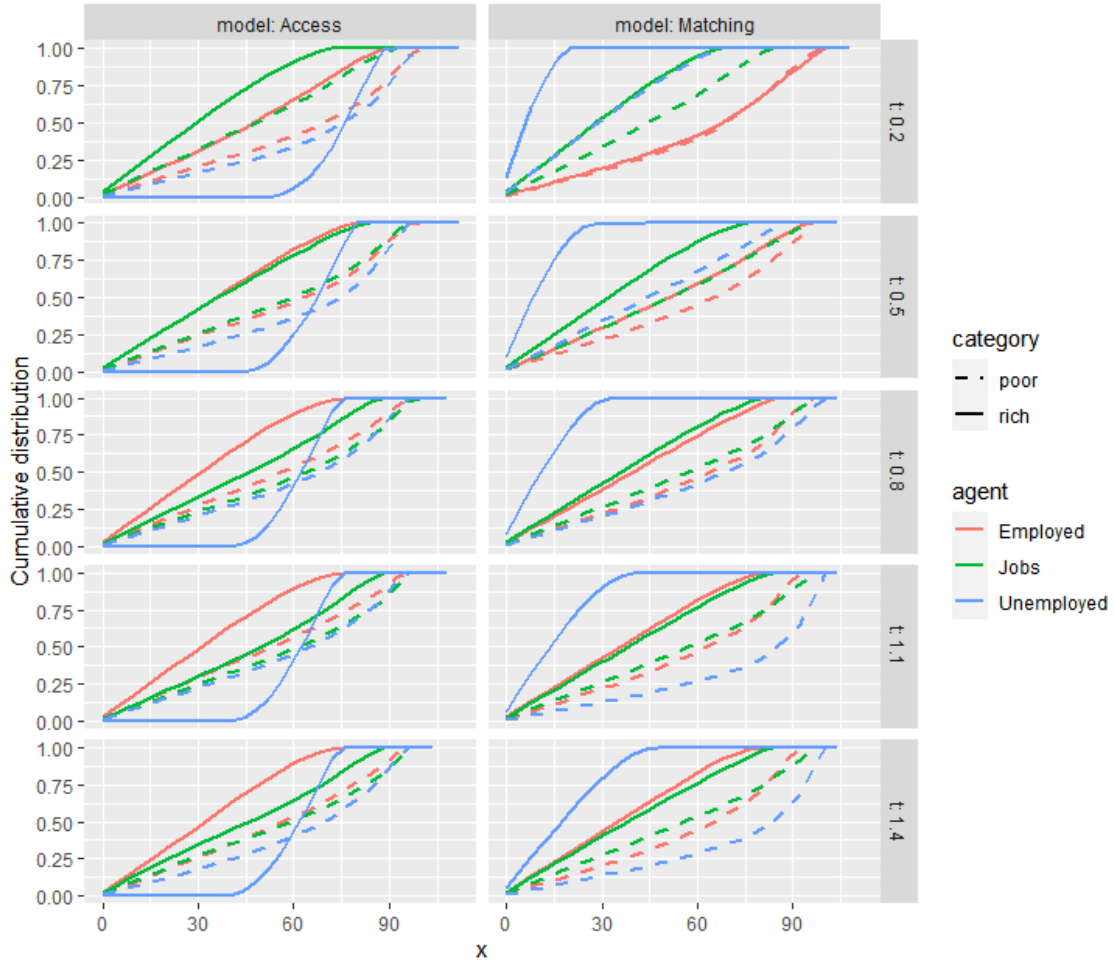


Figure 8: Cumulative distribution of Agents



Let us now take a closer look at the evolution of the unemployment rate. In the case of the model with job allocation according to accessibility, the level of transportation costs does not seem to have an effect on the overall city-wide unemployment rate (figure 9). Jobs are allocated in one way or another and the overall unemployment rate depends primarily on the ratio of jobs to population. Transportation costs, however, influence the unemployment rate by neighborhood (figure 10). The higher the transportation costs, the lower the unemployment rate in the center, because it becomes difficult for inhabitants in the periphery to occupy them, and the higher the unemployment rate in the periphery, where the number of jobs is low.

In the case of the search-matching model, the effect of transportation costs is much more significant. As transport costs increase, the unemployed become less active in searching for jobs, so that the global unemployment rate increases (figure 9). This rate increases sharply around  $t \sim 1.1$ , because at this point, a large share of the “poor” unemployed stop moving to find a job altogether ( $e^* = 0$ ), entering a logic of long-term unemployment and exclusion from the labor market. This

is illustrated by the representation of the unemployment rate of the "poor" according to distance from the center (figure 10). When transport costs are below 0.8, the unemployment rate of the "poor" is high in the city center and zero in the periphery. From  $t = 0.8$ , the unemployment rate jumps to 100% at the edge of the city, populated by unemployed people who have given up looking for work.

Figure 9: Global unemployment rate

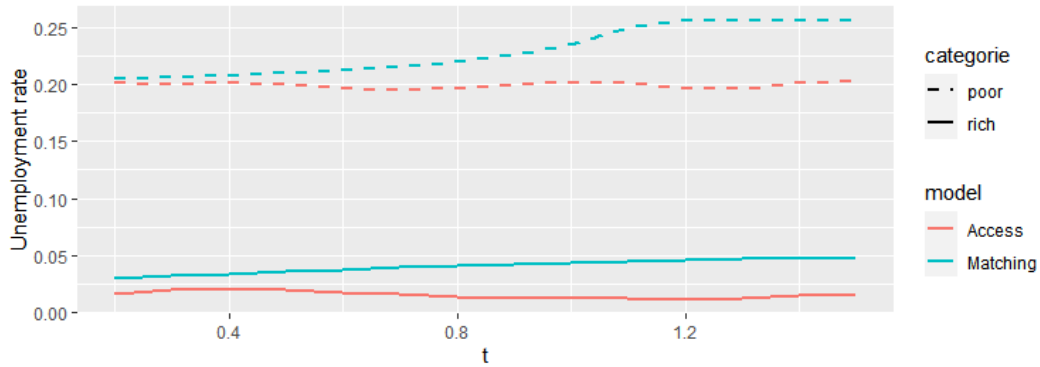
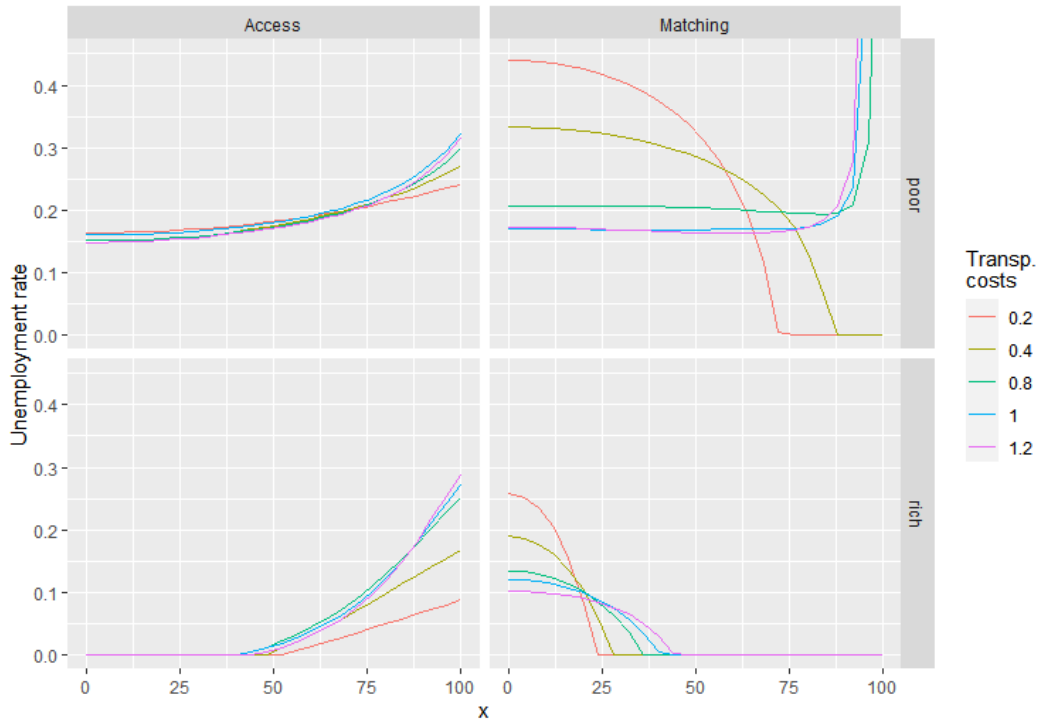


Figure 10: Localized unemployment rate



## 5 Discussion

In this paper, we propose two urban models integrating the location strategies of jobs, employed and unemployed inhabitants belonging to two sectors representing different qualification levels. These models make it possible to reproduce an organization of the city that is globally quite similar to that of French urban units, as we can see from the few stylized facts presented. While both models produce a segregated city, where skilled jobs and inhabitants live close to the city center and unskilled jobs and inhabitants are more dispersed, only the model using the "search-matching" theory, derived from labor economics, seems able to reproduce the higher concentration of the unemployed observed empirically.

The most striking result of our work, because it is counter-intuitive, is that improving a neighborhood's transportation conditions, or rather improving its accessibility to jobs, can have the opposite effect from that desired and lead to an increase in the unemployment rate. In both models, unemployment increases near the city center as transportation costs decrease. In the case of the accessibility-based job allocation model, it is because there is greater competition for jobs in the city center that were previously inaccessible to the unemployed in the outskirts. This occurs because transportation conditions improve for all residents of the city, not just those in the neighborhood. Does this mean that a targeted improvement, such as a new public transportation line or financial support for commuting, would prevent this increase in unemployment? If we give credence to the results of the search-matching model, this is not so certain. In this model, unemployment rate increases near the city center when transportation costs decrease because the intensity of job search increases. In this way, the city center, with its good accessibility to jobs, becomes more attractive to unemployed people who make multiple trips in search of a job.

These findings have two strong implications. First, it puts into perspective the explanatory power of physical accessibility to jobs on the unemployment rate of a neighborhood. Since Kain (1968), living in locations far from jobs is considered to be accompanied by a higher unemployment rate than elsewhere, and vice versa. However, in Europe, the empirical studies that have sought to establish such a link have not been able to verify this hypothesis, which seems self-evident (Gobillon et al., 2007; Duguet et al., 2009; Dujardin et al., 2008). Our results lead us to propose an alternative explanation for these observations. Contrary to the commonly accepted hypothesis, it may well be that good physical accessibility to jobs is accompanied by a high level of unemployment, due to the location strategies of job seekers who take advantage of this good accessibility for their search, which then turns out to be less costly.

Second, our results lead us to question the relevance of neighborhood unemployment as an indicator of the success of a policy to reduce poverty through transportation. Using the example of the search-matching model, although unemployment increases near the city center, it nevertheless decreases overall for the city as a whole, demonstrating the effectiveness of the measure. Let us turn the analysis around. If the concentration of unemployment in the city center is a sign of good access to jobs, leading to active job search by the unemployed, it is paradoxically the increase in the unemployment rate in the central neighborhoods that attests to the success of a transportation policy. This is, of course, a difficult discourse for any public policymaker to defend. In France, "urban policy" has been built on the idea that the spatial concentration of poverty is inherently bad (Simon, 1995; Simon, 2005; Fitoussi et al., 2004; Vallet, 2005), based on North American work on the neighborhoods effects (Wilson, 1987; Wilson, 1996; Marpsat, 1999; Sampson et al., 2002). Guided by this preconception, the public authorities have continued to set up programs targeting their perimeter in order to increase their social mix and reduce their poverty



level (Béhar, 1995; Epstein, 2013). However, the thesis of the existence of neighborhood effects has been criticized by many authors, both for the ideology that underlies it (Bacqué et al., 2007) and for the methodological and identification bias (Hauser, 1970; Duncan et al., 1997; Dietz, 2002; Breen et al., 2005). Without claiming to provide elements for this debate, our results tend to confirm that the neighborhood perimeter is not the right scale for the implementation of a transportation policy capable of reducing the level of unemployment, since this is more a symptom of dysfunctions on the scale of the agglomeration (dispersion of unskilled jobs), and even on the national scale (lack of unskilled jobs). Is increasing the unemployment rate in a few neighborhoods so deleterious, if these neighborhoods are precisely those offering the best conditions for their unemployed to seek to improve their lot?

Finally, we must insist on the limitations of these models. The greater concentration of the unemployed may have other causes. First, our models incorporate only one mode of transportation and no congestion. However, several authors show that longer commuting times and proximity to public transportation tend to attract a low-income population (Leroy et al., 1983; Glaeser et al., 2008). However, public transportation is generally much better near the city center. Second, the supply of social rental housing is historically much higher near city centers and may also explain this concentration of unemployment. But again, this dimension is excluded from our analysis.

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