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# Urban Costs and the Spatial Structure of Cities: A Laboratory Experiment<sup>1</sup>

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Michiel Bliemer<sup>2</sup>, Laurent Denant-Boemont<sup>3</sup>, Sabrina Hammiche<sup>3</sup>, David Hensher<sup>2</sup> and Corinne Mulley<sup>2</sup>

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## Abstract

This paper presents a laboratory experiment to investigate how urban costs might determine the internal structure of urban areas (monocentric or polycentric) by influencing location choices of firms and households. The experimental design is in part guided by a theoretical model that shows how the trade-off between communication costs faced by firms and commuting costs borne by workers determine the degree of cities' polycentricism by influencing the distribution of the workplaces within it. In the laboratory experiment, groups of 16 subjects participated in a two-step auction game, where firms and workers first negotiated to find a job contract and second where workers bid for land in order to find a home. The game is repeated for four rounds and different experimental treatments are implemented, each defining a given scenario for communication costs and commuting costs. The chosen benchmark is a polycentric city treatment, where no communication cost exists for firms, giving them no incentive to locate in the CBD. In two other treatments, the communication cost is positive. In the Monocentric City treatment, commuting cost for workers is low, giving a clear incentive for firms to locate in the CBD, as workers do not suffer from potential high commuting costs, giving an outcome where all firms should locate in the CBD. In the Hierarchical City treatment, the commuting cost is very high for workers, giving workers a strong incentive to live close to their workplace and accepting lower wages as a result. Experimental results are in line with theoretical predictions: firms tend to locate in the CBD under the monocentric treatment, whereas more distant locations are accepted leading to a hierarchical outcome as workers propose lower wages for not working in the CBD so as to escape high commuting costs.

Keywords: Polycentric City, commuting costs, location choices, job contracts.

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# 1. Introduction

In many developing countries, urban housing and commuting costs represent a significant share of household income. For European countries for instance, Winqvist (1999) estimates this amount to be more than 40% of income, and estimates are even larger for the USA. Haas et al. (2006) estimate that 48% of household income for 28 US metropolitan areas is spent on housing and commuting, and even more (around 58%) for working families with income between \$20,000 and \$50,000. Most important, the share of such costs in income is increasing each year. In the case of Australia, Burns (2008) indicates that borrowers now require 38% of their family income to cover mortgage repayments with those in the rental market surrendering 24.7% of their incomes to rent. Focusing on the Australian case, commuting costs<sup>4</sup> could represent around 6,000 AU\$ for Sydneysiders per year and more than 5,000\$ for Melbourne citizens (Flood and Barbato, 2005), and therefore urban cost for inhabitants of urban areas could weigh more than 50% of their income.

These urban costs play an important role in the determination of location choices by households, as early demonstrated by Alonso (1964)'s seminal article with households trading commuting costs to land costs in order to determine their location place. This framework was used to describe the monocentric city, i.e. a city where all jobs and firms are exogenously located in the CBD. Nevertheless, as shown by Anas et al. (1998), urban structure has over many decades exhibited major qualitative changes in growth patterns. Cities continue to spread out, this being perfectly in line with Alonso's theory if (intra-urban) commuting cost decreases. But it is intrinsically not possible with Alonso's model to explain why in some cities this spreading out in urban structure is taking a more polycentric form, with a number of concentrated employment centres making their mark on the spatial distribution of both employment and population. More generally, as demonstrated theoretically in Fujita and Ogawa (1982), the urban spatial structure of a city is the outcome of the economic interactions between firms and households, which favours spatial concentration because of agglomeration economies. This conclusion also holds in the case of the theoretical model developed by Lucas and Rossi-Hansberg (2002), where the intensity of production externality and the level of commuting costs for workers explain the zoning structure of the city. Depending on the degree of concentration or dispersion of firms, these agglomeration economies vary among intra-metropolitan locations. Some of these locations might become main employment centres, whereas others remain as non-central.

High urban costs create incentives for firms to leave the main urban employment centres (Lucas and Rossi-Hansberg, 2002), despite the numerous advantages arising from

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<sup>4</sup> It is nothing to say that these commuting costs are measured as monetary costs, and do not include time costs that could be significantly above it.

agglomeration (Duranton & Puga, 2005; Hensher et al., 2012). In so doing, firms are able to pay lower wages and land rents while remaining within a metropolitan area. That is, the formation of subcenters within a city seems to be a natural response for alleviating the burden of urban costs. Nevertheless, as pointed by Anas et al. (1998), these growing subcenters do not eliminate the importance of the main CBD, since higher-order metropolitan functions (executives, engineers, research, banking and insurance, etc.) tend to remain in the main employment centre. This concentration of facilities, that remains essential for firms in order to produce, implies communication costs for firms that are to locate outside the main employment centre, even if there is a clear empirical evidence about the decrease of these costs (Glaeser and Ponzetto, 2010).

The aim of this paper is to study how the observed urban spatial structure could be produced by the interaction between firms and households facing different urban costs. More specifically, we focus on the effect of transport costs on the evolution of city structure through a laboratory experiment. The relationship between transport/trade costs and location choices is one of the key questions that exist in two economic related literatures, the first being Urban Economics - starting with the seminal work of Alonso (1964) - and second, more recently, the New Economic Geography (NEG), following the paper of Krugman (1995) (see also Krugman, 1998). Most papers in the urban economics literature have focused on the Monocentric City, assuming that all jobs are located in the Central Business District (CBD), building theoretical models to 'explain' location choices for households given the relationship to transport costs (for a review, see Fujita, 1989). Very few papers are about location choices both for firms and households, workplaces being possibly everywhere in the urban area, which is the main characteristic of a Polycentric Urban Spatial Structure<sup>5</sup>.

Empirical relevance regarding New Economic Geography Model or Urban Economics models is wide, but restricted essentially to field data studies (see Combes et al, 2008).

While empirical evidence cannot be viewed as a clear test of any of these theoretical models, economic experiments that relate to location choices are rare. The main part of the experimental literature has focused on firm's location choice in a Hotelling-like environment: Firms compete for a location slot, consumers already being located and uniformly distributed among space, supporting transport costs in order to consume, with price being exogenously fixed by the experimenter (See Brown-Kruse et al., 1993; Brown-Kruse & Shenk, 2000; Collins & Sherstyuk, 2000; Huck et al., 2004; Anderson et al., 2007). On the other hand, the only experimental work, which considers households' location choice in a monocentric model, where all firms are exogenously located in the CBD, is the one by Bergman et al (2009). Their classroom game aims at testing Alonso's bid rent theory, in particular that land rent should decrease with distance to the CBD where all

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<sup>5</sup> At the theoretical level, and to our knowledge, the only articles that investigate how transport costs could influence location choices by firms and households as workers are Fujita & Ogawa (1982) and Cavailhes et al. (2007).

jobs (firms) are located and the resulting experimental bid rent functions matched quite well the theoretical predictions.

Ostbye and Heen (2010) have implemented an experimental test of the Dixit-Stiglitz-Krugman competition theory, a key element of New Economic Geography (NEG) models, where both firms and consumers are able to locate. They aim at testing the empirical relevancy of NEG models. But in fact, their experimental study focuses on the location choices of workers between two regions, assuming that the distribution of firms will follow workers' distribution (which is a usual assumption of NEG models, as pointed out by Combes et al., 2008).

The laboratory experiment presented in this paper is novel in two ways. To our knowledge, it is the first experiment to investigate the question of other possible spatial structures than the usual monocentric one, in particular polycentric and hierarchical structures for cities by enabling firms and workers to determine a locational equilibrium that is observed within the laboratory.

As suggested by Cavailhes et al. (2004), the emergence of polycentric urban structures is due at least to three reasons. The first is the increase in city population that leads to suburbanization and to the decentralisation of jobs. The second relates to the increase in commuting costs<sup>6</sup>, and the third reason is a fall in firm's communication costs. The experiment aims to show how the balance between communication costs and commuting costs matters in the location choice of all agents that live within the city, and how changing the relative values of these different costs produces different urban structures.

Focusing on the urban equilibrium issued from a trade-off between communication costs and commuting costs, our experimental design inspires upon the theoretical model of Cavailhes et al. (2007). In this model, the internal structure of a city depends on the relative value of communication costs borne by firms compared to commuting costs faced by workers, workers and firms having to choose a location place. In their model, when communication costs are above commuting costs, a city should be monocentric (that is, all jobs being placed in the CBD) In contrast, when communication costs are below commuting costs, there is a polycentric city outcome (that is, jobs to be distributed among one CBD and several secondary business districts (SBDs)). As commuting cost as well as communication cost can be influenced by exogenous public policies, hence the outcome of the experiments will have implications for public policy design.

More specifically, the experiment consists in conducting a Market experiment with two successive steps, the first one being a double-auction market for the labour market where workers and firms interact, and the second a sealed-bid second-price auction where only workers compete for land. Three experimental treatments are defined, depending on the value of communication costs and commuting costs. In the first treatment, defined as the

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<sup>6</sup> For instance, Cavailhes et al. (2004) estimate that commuting costs (direct monetary cost) in the Ile-de-France region increased by 38% between 1976 and 1991.

benchmark in this paper and called “polycentric city”, there is no communication costs and only commuting costs. In this case, the equilibrium corresponds to a Pure Polycentric City, CBD surrounded by two Secondary Business Districts (SBDs), each workplace being of equal size.

Two other treatments introduce positive communication costs for firms in respect of the essential facilities located in the CBD, which in the experiment are specified as a necessity to produce output. In the “Monocentric City” treatment, communication costs are higher than commuting costs, and consequently, the locational equilibrium converges to a single CBD where all jobs (firms) are located and where no SBD can longer exist. The last treatment, called “Hierarchical City” is characterized by a communication cost that is lower than commuting cost, giving incentives for firms and households to locate outside of the CBD. The equilibrium structure corresponds to a situation where a main CBD is surrounded by smaller SBDs of the same size.

The main results are as follows. In the polycentric treatment, the distribution of firms tends to be uniform among possible locations places, as predicted by the theoretical model. Most important, comparing a monocentric treatment to a hierarchical one, a clear convergence towards the monocentric city in the former case is observed, whereas in the latter, dispersion forces tend to reduce the size of CBD with smaller workplaces being created in its environs.

The paper is organized as follows. Section 2 outlines the theoretical model of Cavailhes et al. (2007), as it informs the experimental design. Section 3 is devoted to the experimental design, while section 4 presents experimental results. Section 5 presents a set of conclusions.

## **2. Theoretical model: Transport costs and The Urban structure of cities**

The theoretical model for building the experiment is inspired by Cavailhes, Gaigné, Tabuchi and Thisse (2007). In this model, they derive location and price equilibriums for an economy with two regions, endowed with mobile firms and workers. There are four goods, primary goods as labour and land, and consumption goods, one being homogenous as a numéraire and the other being a differentiated good produced under monopolistic competition and increasing returns, using labour as the only input. Workers/consumers display a preference for variety.

The case study is restricted to proposition 1 of this theoretical model, which defines single city equilibrium and locations within it. Proposition 1 states that, depending on communication costs supported by firms for accessing essential facilities compared to commuting costs supported by workers for accessing their workplace, the structure of the city can be either monocentric or polycentric. More precisely, if communication costs are

high compared to commuting costs, the city structure will be monocentric (that is a city where all jobs are in the CBD) and otherwise it will be polycentric (that is, jobs will be split over one CBD and several SBDs). Before presenting the design of the experiment, the main elements of the theoretical model are summarised.

## 2.1. Preferences of Agents and City Limit Points

Workers and firms are free to locate within the city, but essential facilities are located in the city centre, at  $x=0$ . These facilities are necessary for firms to produce and, if a firm decides to locate in a different place from  $x=0$ , the communication cost assumed for a given firm is

$$\kappa(x^S) = K + kx^S \quad (1)$$

Where  $x^S$  is the place chosen by a firm to locate, i.e. defining a workplace.

Since there are  $l$  workers and  $\theta$  being the share of workers (or firms) located in the CBD, the limit points for the city are the following (recall that will be described here only the right side of the city, and that left side is symmetrical).

As each individual consumes 1 unit of land, and as the city is symmetrical, the right end of the CBD area is defined by

$$y = z_1 = \frac{\theta l}{2} \quad (2a)$$

As there is a positive communication cost, which increases with distance to the CBD, SBDs are necessarily adjacent to the CBD, and then the left side frontier of SBD 1,  $z_1$ , is confounded with  $y$ .

Furthermore, the centre of SBD 1,  $x^S$  - having in mind that  $(1 - \theta)l$  individuals should be distributed over the 2 SBDs - is defined by the following equation.

$$x^S = \frac{\theta l}{2} + \frac{(1 - \theta)l}{4} = \frac{(1 + \theta)l}{4} \quad (2b)$$

The limit of the city corresponds to the left frontier of each SBD, given as equation 2c.

$$z_2 = \frac{l}{2} \quad (2c)$$

At equilibrium, as in the usual monocentric models (see Fujita, 1989), utility level should be the same for each individual, and also the consumption for non-spatial goods  $E$ , which defines as:

$$E = \int_0^n p(i)q(i)di + q_0 \quad (3)$$

The budget constraint for an individual residing at  $x$  and working in the CBD, or for an individual residing at  $x$  and working in a SBD, implies that

$$w^C + \bar{q}_0 - tx - R(x) = E = w^S + \bar{q}_0 - t|x - x^S| - R(x) \quad (4)$$

At equilibrium, a worker residing in  $y=z_1$  is indifferent between working in the CBD or in the SBD, which implies that

$$w^C - ty - R(y) = w^S - t(x^S - z_1) - R(z_1) \quad (5)$$

Since  $y=z_1$  and  $R(y)=R(z_1)=0$ , by using the expressions of eqns (2) we obtain equation (6).

$$w^C - w^S = t(2y - x^S) = tl \left( \frac{3\theta - 1}{4} \right) \quad (6)$$

This wage gap is positive as long as  $\theta > \frac{1}{3}$ .

The comparative statics suggest that if  $l$  or commuting cost  $t$  increases, the wage gap must also increase.

## 2.2. Equilibrium Wages and the City Structure

Equilibrium wages are determined by assuming zero profit condition, i.e., the wage bill absorbs firms' profit. Assuming that  $\phi = 1$ , equilibrium wages are

$$w^{C*} = I \quad w^{S*} = I - \kappa(x^S) \quad (7)$$

Then, by using eqn (6), the expression of communication costs (eqn (1)), and finally equilibrium wages (eqn (7)), it is possible to solve with respect to  $\theta$ , the share of workers to be located in the CBD, which yields equation (8).

$$\theta = \frac{4K + (t + k)l}{3(t + k)l} \quad (8)$$

Such a value is positive and more than 1/3 IFF  $k/3 < t$ .

Assuming that this condition holds (in the contrary case, city is always monocentric), the optimal value for  $\theta$  is

$$\theta^* = \min \left\{ 1, \frac{4K + (t\phi + k)l}{3(t\phi + k)l} \right\} \quad (9)$$

**Proposition 1 states that the city will be monocentric iif**

$$t \leq \frac{2K + kl}{\phi l} \quad (10)$$

**Otherwise it will be polycentric.**

Land rents have the following form

$$\Psi^C(x) = R(x) = t \left( \frac{\theta^* l}{2} - x \right) \quad \text{for } x < y \quad (11)$$

and

$$\Psi^S(x) = R(x) = t \left( \frac{(1 - \theta^*)l}{4} + x^S - x \right) \quad \text{for } x > x^S \quad (12)$$

### 3. Experimental design

This section describes the situation game that was played by participants and sets the theoretical predictions<sup>7</sup>.

The experimental game consists of two parts, the first being a double-auction procedure where both firms and workers negotiate in order to determine wage salary and workplace, and the second one consisting in an auction procedure between workers that compete for land (homes)<sup>8</sup>. Finding work will give a worker a salary and enable him to

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<sup>7</sup> The experimental calibration of payoffs is explained in appendix B. In a nutshell, payoffs are based on assumptions regarding preferences for firms and workers that are the closest as possible to Cavailhes et al. (2007).

<sup>8</sup> Of course, it is an important difference regarding Cavailhes et al. (2007) model where the equilibrium process is purely static.

consume a composite good, i.e., obtaining a certain amount of income. The second step is only for workers (ie players who have found work) who then compete for land through a sealed-bid second price auction procedure.

### 3.1. The Situation Game

The game consists of two steps, the first one where 8 firms interact with 8 workers in order to define a wage contract and a workplace, the second one where only workers that found a job contract are bidding for a living place.

A line represents Land, with slots numbered from 1 to 11. A particular slot, located in the middle of this line is the CBD (Central Business District, located at slot 6). This CBD is pre-specified since essential facilities required by firms for production are located there.

In each step of the game, possible locations slots are proposed to participants, from slot 1 to slot 11, and including the CBD slot. Each worker must locate in a living place and there consumes exactly one slot and so it is not possible to have more than one worker for a given slot. In contrast, firms are free to locate at each slot since it is assumed, to be consistent with Cavailhes et al. (2007), that working places are dimensionless so multiple firms can use the same slot as a working place. If a firm chooses a slot as a working place that is not the CBD, this defines a Secondary Business District (SBD). The only constraint for firms is that they are not able to create more than two SBDs, the rule “first-in, first served” being applied. The consequence of that is, as in the initial model of Cavailhes et al., there cannot be more than 2 SBDs next to the existant CBD.

#### - **First step: Defining the workplaces for firms and workers**

The first step consists of a double-auction market that aims at solving the labour market and to define the workplaces. Firms need a single worker to produce output and face two kinds of costs for producing revenue, that is wage and communication costs to the CBD. If firms are not able to find a worker, they get 0 points at the end of this stage of the game.

Workers need to have a job (that is to define a contract with a given firm) in order to obtain revenue that corresponds to their net utility, and additionally a wage, even if this wage is zero. If workers are not able to find a job, they get 20 points at the end of the first stage of the game but are unable to participate in the second step of the stage game.

In stage 1, both firms and workers participate to a double-auction market when each of them proposes or accepts a wage and workplace contracts. In the game, this labour market is opens for 10 minutes during which each worker can propose for each slot as a working place a wage ask, or a certain amount of points he intends to get as a wage. The player provides and finds this information through the computer screen by looking at the best wage asks that have already been made for each slot by all workers (that is, the lowest wage requested by workers for each slot), as well as the best wage bids that have been already made by all firms (that is, the highest wage offered by firms for each slot). Figure 1 shows a screen capture of the computer interface for workers, and figure 2

captures the screen available for firms. The interface was computerized using ZTREE (Fischbacher, 2007).

Figure 1. Double Auction computer interface for participants as workers (Hierarchical treatment)

Period: 1 of 4 Remaining time [sec]: 38

Click on the wage level you want and then click "Accept"

FIRM : WAGE BID

Slot 1 as working place	Slot 2 as working place	Slot 3 as working place	Slot 4 as working place	Slot 5 as working place	Slot 6 as working place	Slot 7 as working place	Slot 8 as working place	Slot 9 as working place	Slot 10 as working place	Slot 11 as working place
<input type="button" value="Accept"/>	<input type="button" value="Accept"/>	<input type="button" value="Accept"/>	<input type="button" value="Accept"/>	<input type="button" value="Accept"/>	<input type="button" value="Accept"/>	<input type="button" value="Accept"/>	<input type="button" value="Accept"/>	<input type="button" value="Accept"/>	<input type="button" value="Accept"/>	<input type="button" value="Accept"/>

WORKER : WAGE ASK

Slot 1 as your working place	Slot 2 as your working place	Slot 3 as your working place	Slot 4 as your working place	Slot 5 as your working place	Slot 6 as your working place	Slot 7 as your working place	Slot 8 as your working place	Slot 9 as your working place	Slot 10 as your working place	Slot 11 as your working place
------------------------------	------------------------------	------------------------------	------------------------------	------------------------------	------------------------------	------------------------------	------------------------------	------------------------------	-------------------------------	-------------------------------

Please remember that you will have to pay a transport cost of 9 points per unit of distance from your home place to your working place

Your type : WORKER 1

Wage

Slot as your working place :

Contract	Wage	Slot as working place

Figure 2. Double Auction computer interface for participants as firms (Polycentric treatment)

The double auction rule applies as follows: When a worker wants to make a wage ask, he chooses a lower amount than those already publicly displayed and offered by workers as a whole. In contrast, a firm wishing to make a wage bid should propose higher amounts than those already displayed for a given slot. Market clearing is achieved as usual when workers or firms accept contracts that are publicly displayed. The market is closed after 10 mn duration or when no worker/firm remains available for a job contract. The important feature is that accepting a contract either for a firm or for a worker defines firms' location as workplaces.

At the end of this first step, firms are located either in the CBD or in SBDs. They face communication and wage costs depending on the wage contract. As a consequence, participants as firms already know their final payoff for the round at the end of this first step.

On the other side, after completing the first step, workers are aware about their workplace location and personal wage level. The next step is to find a living place with this decision incurring commuting costs.

- **Second step: Finding a living place for workers**

In this step, only workers participate in a land market that opens for 5 minutes. The supply consists in slots that are sold under a sealed-bid second price auction, for which

each worker enters multiple bids for each slot available (from 1 to 11). For each slot, the winning bidder pay the second-highest bid. We constrain each winner to have a single slot. In case of multiple wins for a given worker, she finally gets the slot that defines the lowest distance to their workplace. In case of multiple winners for a given slot (due to equal maximum bids), we allocate the slot to the winning bidder for whom the distance between this particular slot and his working place is the smallest. When distances to working place are identical, the winning bidder is randomly picked by the computer.

Figure 3 captures the screen available for workers during the second step of the stage regarding land market auction procedure.

*Figure 3. Computer interface for workers in the land auction procedure*

Period

Trial 1 of 1

Remaining time [sec]: 291

Your type : WORKER 8  
 Your firm : FIRM 2  
 Your wage : 10  
 Slot as your working place : 1  
 Your income : 82

Please remember that you will have to pay a transport cost of 9 points per unit of distance from your home place to your working place

Slot as your home	Slot 1	Slot 2	Slot 3	Slot 4	Slot 5	Slot 6	Slot 7	Slot 8	Slot 9	Slot 10	Slot 11
Your home place bid	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

OK

### 3.2. Experimental treatments

The definition of experimental treatments is based on proposition 1 by Cavailhes et al. (2007), that implies that an increase in commuting cost, all things being equal should break the monocentric city (all firms located in the CBD) and change the location equilibrium towards a hierarchical city with at least one SBD. A benchmark treatment is provided by assuming that communication costs do not exist ( $K=k=0$ ), that is - following proposition 1 - in this particular case, city should be polycentric (i.e., structured in 3 workplaces having the same size and where population of workers is evenly distributed, land rents and wages being equal in each workplace).

For all the treatments described below, we assume that  $\phi$  is 1 and  $l$  is 8. Moreover, land rents values described in the graph or text are only related to relative levels, not to absolute values since these depend on utilities and consumption about non-spatial goods for the workers (see above).

In order to have a hierarchical treatment with  $L=n=8$ , this implies from the theoretical prediction that 4 persons locate in the CBD (i.e.,  $\theta^*=0.5$ ), and the calibration function between  $t$ ,  $K$  and  $k$  is:

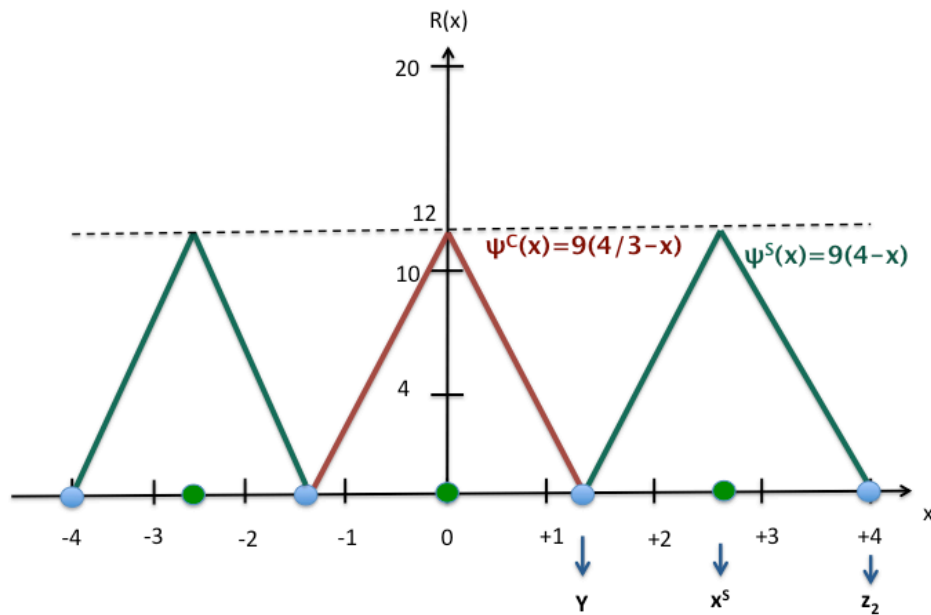
$$t = K + 3k$$

Values of  $t$ ,  $K$  and  $k$  will also give the bid rent function for land (see equations for that in section 1).

### 321. Treatment 1 (benchmark): Polycentric City

In this case, as there is no communication cost to the CBD for firms, firms and workers have no reason to locate in the CBD, and workers-firms split between 3 workplaces. The value of  $\theta^*$  is  $1/3$  and the limit points (see eqn 1) for the city are  $x=4/3$ ,  $8/3$  and 4. The following graph illustrates theoretical predictions for bid levels.

Figure 4. Rents and Limit points in Polycentric City Treatment ( $K=0$ ,  $k=0$ ,  $t=9$ )



Of course, as the number of workers/firms is an even number and not divisible by 3, there is no possibility to have all possible workplaces with an equal number of firms. This pitfall is justified by the fact that the most important issue for this experiment is to obtain limit points that correspond to discrete locations or actual slots that exist in the experiment.  $L=n=8$  has been chosen following a series of numerical simulations in which it was found that it is almost impossible to have integer values for workplaces location if  $L < 8$ .

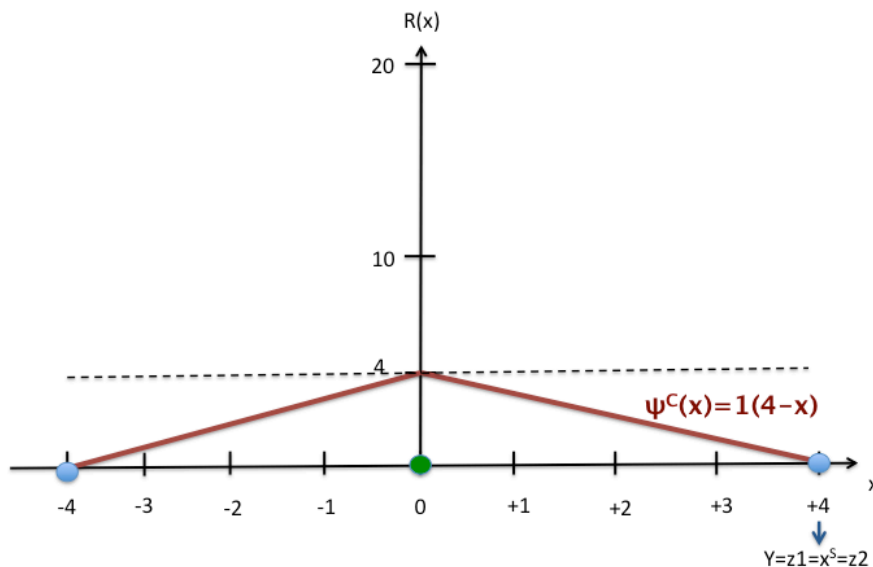
In this benchmark treatment, there is no particular incentive to locate in the CBD for firms, since no communication cost exists. The only concern for workers is being able to maximize wages as well as minimizing commuting costs between a workplace and a home place, there should be bidding functions for land that depends on first step location choice for firms. As firms are indifferent to any given slot as a particular location there should be no relationship between bids levels for home and distance to the CBD.

The comparative statics of the model described in the previous section define the two following treatments, i.e., the monocentric and the hierarchical ones. In the case of positive communication costs ( $K > 0, k > 0$ ), if  $K=3$  and  $k=2$ , the threshold value for  $t$  is 2.75. As a consequence, if  $t$  is less than this value, the locational urban equilibrium, should be consistent with a monocentric city, whereas if it is above this threshold, the city structure should be hierarchical.

### 322. Monocentric City Treatment

In the monocentric city treatment, commuting cost is low compared to communication cost, so there is no incentive for firms/workers to locate far from the CBD. The following graph illustrates this point and describes equilibrium bid rent values.

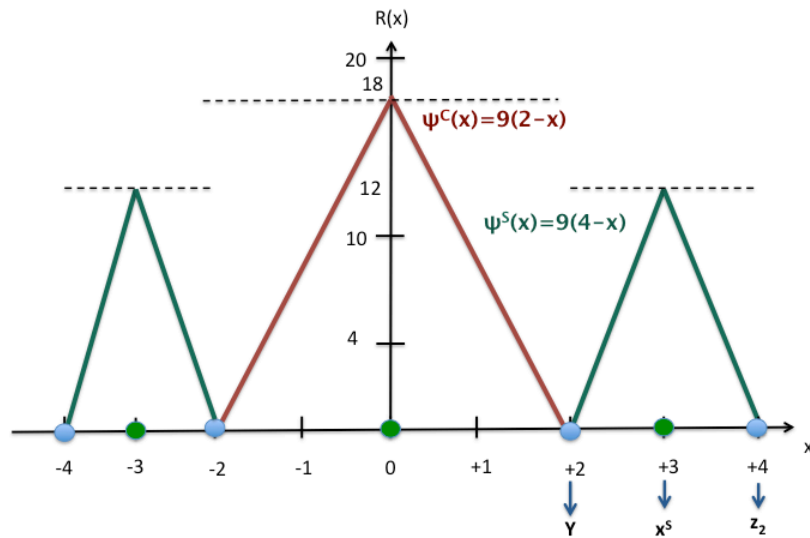
Figure 5. Rents and Limit Points in Monocentric City Treatment ( $K=3, k=2, t=1$ )



### 323. Hierarchical City Treatment

By contrast, if communication cost is low compared to commuting cost, then workers have a strong incentive to locate outside the CBD. The graph below shows the emergence of polycentric hierarchical structure where bid-rent functions do not have the same slope, as in the polycentric treatment, and where the total amount of bids that will be paid for a CBD location is higher than the sum of bids for each SBD.

Figure 6. Land Rents and Limit Points in Hierarchical City Treatment (K=3, k=2, t=9)



### 3.3. Theoretical predictions (one-shot stage game)

Communication costs are the support for defining optimal wage bids for homogenous firms. Indeed, the greater is the communication cost, the fewer wages bids should be distant from the slot where essential facilities are located. As the payoff for firms if they do not succeed to have a worker is zero, then each firm should be willing to pay for slots from 1 to 11:

$$w_i^s = \pi - (K + k|s - 6|)$$

The consequence is that firms play a coordination game where each firm gets epsilon at the Nash equilibrium<sup>9</sup> and is located at each slot indifferently.

For any worker, the optimal distribution of bids among available slots, as Vickrey's auction rule ensures full revelation, should be the value of income plus his wage, minus potential commuting cost, the latter depending on workplace determined in step 1.

Assuming that wages that could be proposed by firms decrease necessarily with the distance to CBD as a result of increasing communication costs, some behavioural conjectures regarding competition for land between workers can be established.

#### 331. Conjectures relative to the intensity of competition between workers for living places

The first and easiest behavioural conjecture concerns bidding behaviour on land market. Assuming the highest wages are to be found in the CBD, workers having a workplace in

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<sup>9</sup> That corresponds precisely to Cavailhes et al. (2007) where operating profits are completely absorbed by the wage bill, equilibrium wage wedge being proportional to the level of communication cost.

the CBD should bid higher for living places lying in the CBD or being close compared to the farthest ones. For those workers, bids should decrease linearly with distance to the CBD both for hierarchical and monocentric treatments. For the polycentric treatment, as there is no incentive for firms to locate in the CBD, bids should not depend on the distance with it, unless workplace being there.

But under a hierarchical treatment, workers that do not work within the CBD but instead in a SBD should bid higher for land not in the CBD as compared to workers that work in the CBD. Moreover, under a monocentric treatment, workers in the CBD should always bid higher than workers not working in the CBD.

### **332. Conjectures relative to locational equilibrium in the City**

When communication costs exist (that is, for Monocentric and Hierarchical treatments), firms should choose to locate in the CBD by proposing wages that are around their revenue (since operating profits should be completely absorbed by the wage bill). Following that, if commuting costs are sufficiently small, workers should prefer to accept contracts with maximum wages associated to workplaces lying in the CBD even if they have to face commuting costs. Therefore, in the Monocentric treatment where commuting cost is small compared to communication costs faced by firms, Nash equilibrium consists in having all firms in the CBD, and workers choosing to live nearby the CBD, with the bid rent function declining slowly with the distance to it.

In contrast, when commuting cost is sufficiently high relatively to communication cost, such equilibrium is not a stable equilibrium, since workers have an incentive to accept contracts with lower wages as the firm locates further from the CBD as such contracts enable workers to decrease commuting costs. Consequently, in the Hierarchical treatment, workers are incentivised to propose lower wages to the firm for a workplace that does not correspond to the CBD. In this treatment, having all firms in the CBD is not a locational equilibrium.

## **4. Experimental results**

### **4.1. Procedure and experimental sessions**

As far as possible, each session uses 32 subjects. Each participant is randomly attached to a group of 16 players. Types (firms or workers) are also randomly drawn at the beginning of the session. Each participant is required to participate under one experimental treatment (either Monocentric or Hierarchical) in a between-subject design, this information being identified after the instructions are read<sup>10</sup> and some comprehension

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<sup>10</sup> Instructions were framed using words like « city », « firms », « workers », « wage », « land rent », « transport costs » etc. It is more usual in an experiment to avoid context specific words but with this complex experiment the use of abstract concepts for this problem of location choice could give rise to confusion in participants' mind. This would have undermined the participant's understanding of the

questions being completed. After that, participants make a first practice round followed by 4 rounds for real. Each participant remains either a worker or a firm for the entire session. The payoff was determined by drawing one particular round for each subject, in order to avoid any income effect.

Each session lasted between 2 hours and 2 hours 15mins, with an average payoff of approximately AU\$40.

Experimental sessions were undertaken at the Experimental Computer Laboratory of the School of Economics, The University of Sydney with 272 participants from various fields and levels (42% from the Economics and Business field, 58% from Engineering, Law and others). A detailed breakdown of the experimental sessions is given in table 1.

*Table 1. Experimental Procedure and Data description*

Experimental treatment	Parameters	Number of participants	Number of groups
Polycentric City	$K=k=0 ; t=9$	80	5
Monocentric City	$K=3 ; k=2 ; t=1$	96	6
Hierarchical City	$K=3 ; k=2 ; t=9$	96	6
Total		272	17

## 4.2. Location of the workplaces

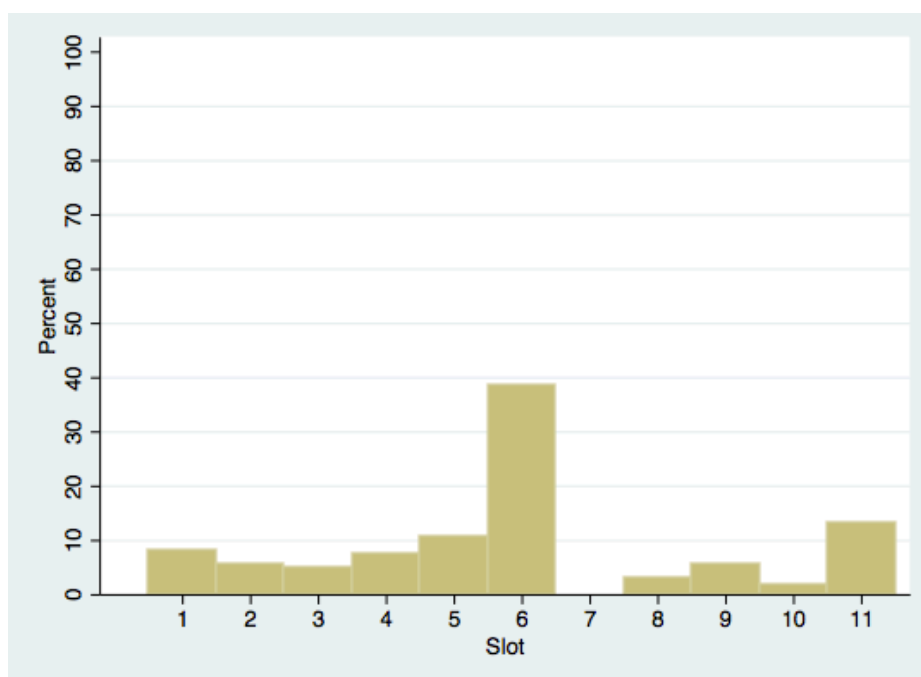
One important consequence of behavioural conjectures presented above is that locational equilibrium within the city should be different between experimental treatments, as the relative weight between communication costs and commuting cost is changing. The next subsection is to describe experimental results for firms regarding locational choice defined by the job contract. The last subsection focuses on worker's competitive bidding behaviour regarding his living place.

The first evidence is dedicated to job contracts that are to define a wage for the worker and a location place for the firm that is also a workplace for the workers. The following figures present the distribution of chosen workplaces throughout the different experimental treatments.

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economic situation they are placed in (See Bohm, 2002). More important, avoiding this framing would have increased the length of instructions, which were already quite long given the complexity of our game (30 minutes on average were used from the beginning of the session to the computerized game in giving the participants instructions).

Figure 7. Distribution of workplaces, polycentric treatment (periods 1 to 4)

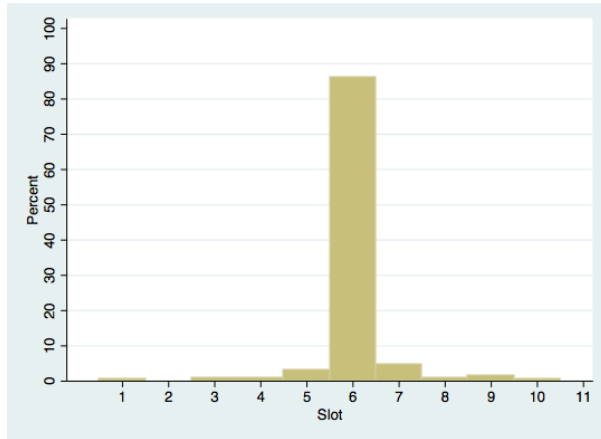


Recall that the theoretical prediction is that there should not be any particular concentration of firms in slot 6 that represents the CBD where essential facilities are exogenously located, since no communication costs exist for firms.

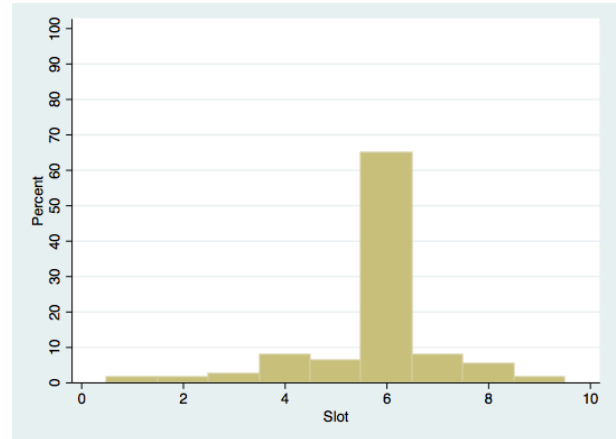
Indeed, around 40% of job contracts firms finally locate in this particular slot, which is significantly above any particular frequency that was observed for other slots, as figure 7 suggests. This result, which does not correspond to theoretical predictions, is probably due to a framing effect of the experimental design. In the experimental instruction, “Firms” are told that they can choose to locate either at slot 6 or at two other slots depending on the actual choices for firms on a first in first served basis. That is, if firm 1 chooses to locate at slot 1, being the first to make a contract with a given worker, and if firm 2 chooses then to locate at slot 2, being the second to make a contract with another worker, then remaining firms must choose a location slot that is either slot 1, slot 2 or slot 6. The reason for proceeding with this rule is to give consistency with the theoretical model of Cavailhes et al. (2007), where firms do not consume space, but where only two Secondary Business Districts are possible, giving a total number of workplaces of no more than three. By just saying that firms should choose either slot 6, or 2 other slots, as our game is a coordination game with multiple locational equilibriums, we probably produce a focal effect (Schelling, 1960) on slot 6. Of course, as the formulation given to participants was the same in all treatments, this focus could partly explain the experimental results. But recall that we are mainly interested in the differences between treatments, and to that respect, if our behavioural conjectures may be confirmed, we should have significant differences about firm concentration depending on experimental treatments. In particular, as communication costs are positive, concentration of firms in CBD should

increase sharply. Figures 8a and 8b display the distribution of workplaces in treatments where communication costs become positive.

*Figure 8a. Distribution of workplaces, monocentric treatment*



*Figure 8b. Distribution of workplaces, hierarchical treatment*



Figures 8a and 8b summarize the distribution of the workplaces defined by job contracts between workers and firms located either in the monocentric treatment (left side) or in the hierarchical treatment (right side). There is a clear difference between each treatment, including the polycentric one (figure 7 above), regarding the density of firms to be located in the CBD (slot 6). This frequency is around 86% for the monocentric treatment, 65% for the hierarchical treatment, and only 38.6% for the polycentric treatment.

Moreover, the experimental data indicate a pattern of learning for participants, as the following figures about the distribution of workplaces in the last period show below.

Figure 10. Distribution of slots as workplaces, Polycentric treatment, last period

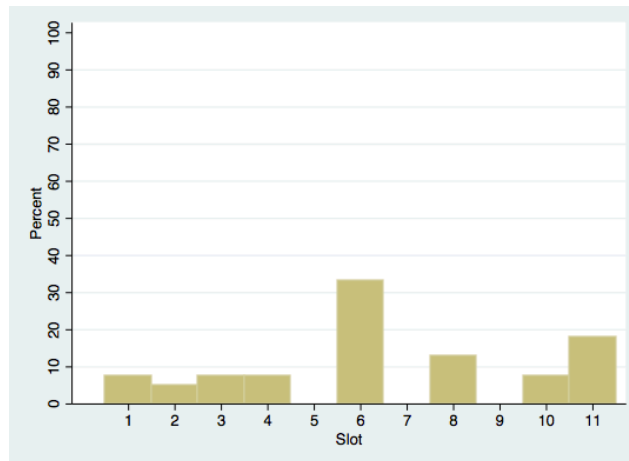


Figure 11. Distribution of slots as workplaces, Monocentric treatment, last period

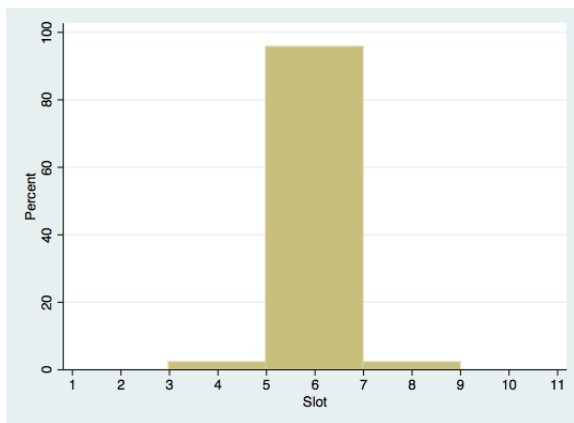
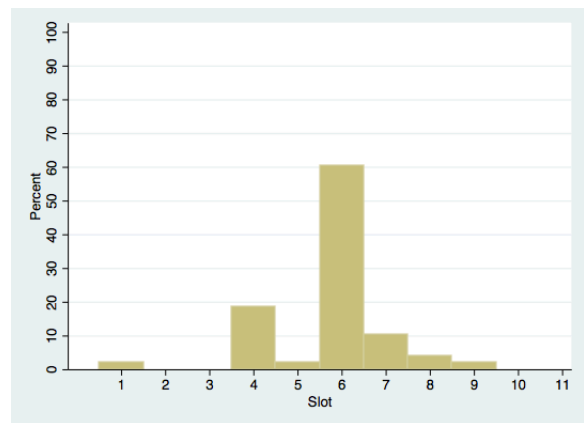


Figure 12. Distribution of slots as workplaces, Hierarchical treatment, last period

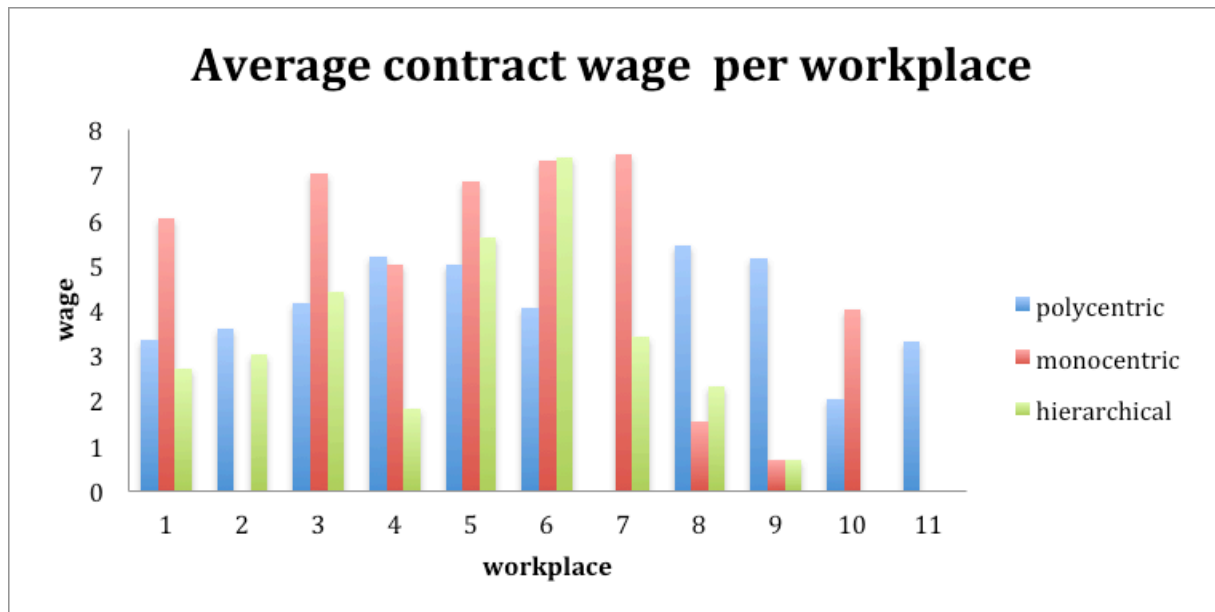


For the last period, the frequency of slot 6 as a workplace is around 95% in the monocentric treatment, close to 60% in the hierarchical one, but drops to 32% in the polycentric treatment.

Contract wages must also reflect the trade-off individuals are to make within the job market between commuting costs borne by workers and communication costs borne by firms. When commuting cost is low compared to communication costs, workers have some market power in order to negotiate higher wages, wherever their workplace is, since commuting cost does not matter so much. In contrast, when commuting cost is high compared to communication costs (hierarchical treatment), workers might be willing to accept lower wages if a firm proposes a contract that implies a workplace outside the CBD. In the same way, workers may negotiate higher wages for having a workplace in the CBD, since it is likely that in the second step, they may not obtain the CBD slot as a possible home (there is just one living place and all firms should be there). The following figure

displays the average contract wage depending on workplace, such for each experimental treatment.

Figure 13. Average contract wage per slot (trial period was excluded)



Even if the average wage is not significantly different for all three treatments for workplaces that lie in the CBD, there is a sharp decrease of contract wage as distance from CBD increases under Hierarchical treatment, when the contract wage remains almost constant as this distance grows under the monocentric treatment. For the polycentric treatment, as expected, no clear trend emerges. A strange asymmetry is also to be noticed: The average wage contract at the left of CBD is higher than average wage contract to the right of the CBD, without any possible clear interpretation of this behavioural pattern.

Another interesting observation is that average wage is lower in the polycentric treatment compared to the other treatments that implement a positive communication cost for firms (respectively 4.11 vs. 7 for the monocentric treatment and 5.9 for the hierarchical one). This could be partly due to the fact that, in polycentric treatment, as firms do not incur any communication cost for accessing essential facilities, their bargaining power for choosing job contract (workplace and wage) is higher than in the other treatments. The consequence is therefore that workers obtain lower wages in this particular situation.

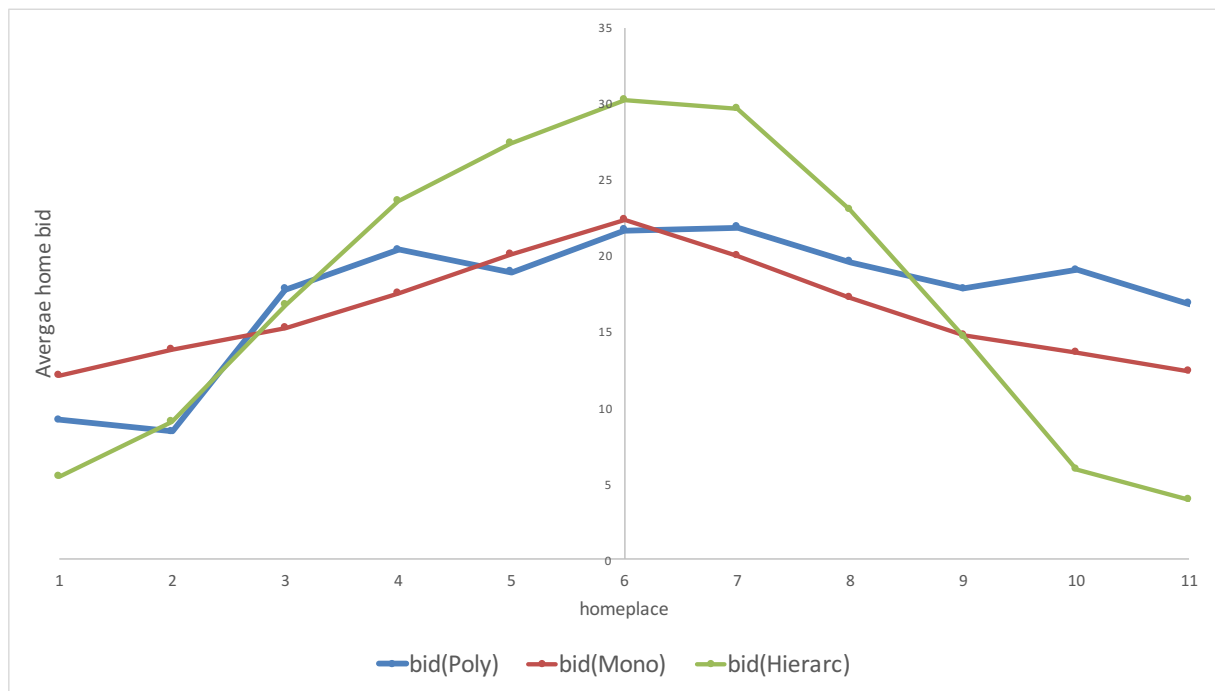
### 4.3. Worker's bidding behaviour for land

In the case when a given worker obtains a job contract in step 1, defining her workplace and her wage, she gets a maximum total income of 91 points in order to make simultaneous bids on each possible slot to choose it as a living place. She might obtain at most one single living place. Depending on the experimental treatment, and the incentives

firms have to locate in the CBD, balanced by potential commuting costs for workers, bids are to differ. In the polycentric treatment, as there is no particular reason to have a higher density for workplaces (communication costs are null), firms decisions represent a coordination game where each firm could be located in each workplace. Then, as commuting costs are quite high in this treatment, the nearer living place from workplace, the better for workers.

The following graph displays average bids for each slot as a possible living place for the last period, and thus for each experimental treatment.

Figure 14. Average bid per slot as a home

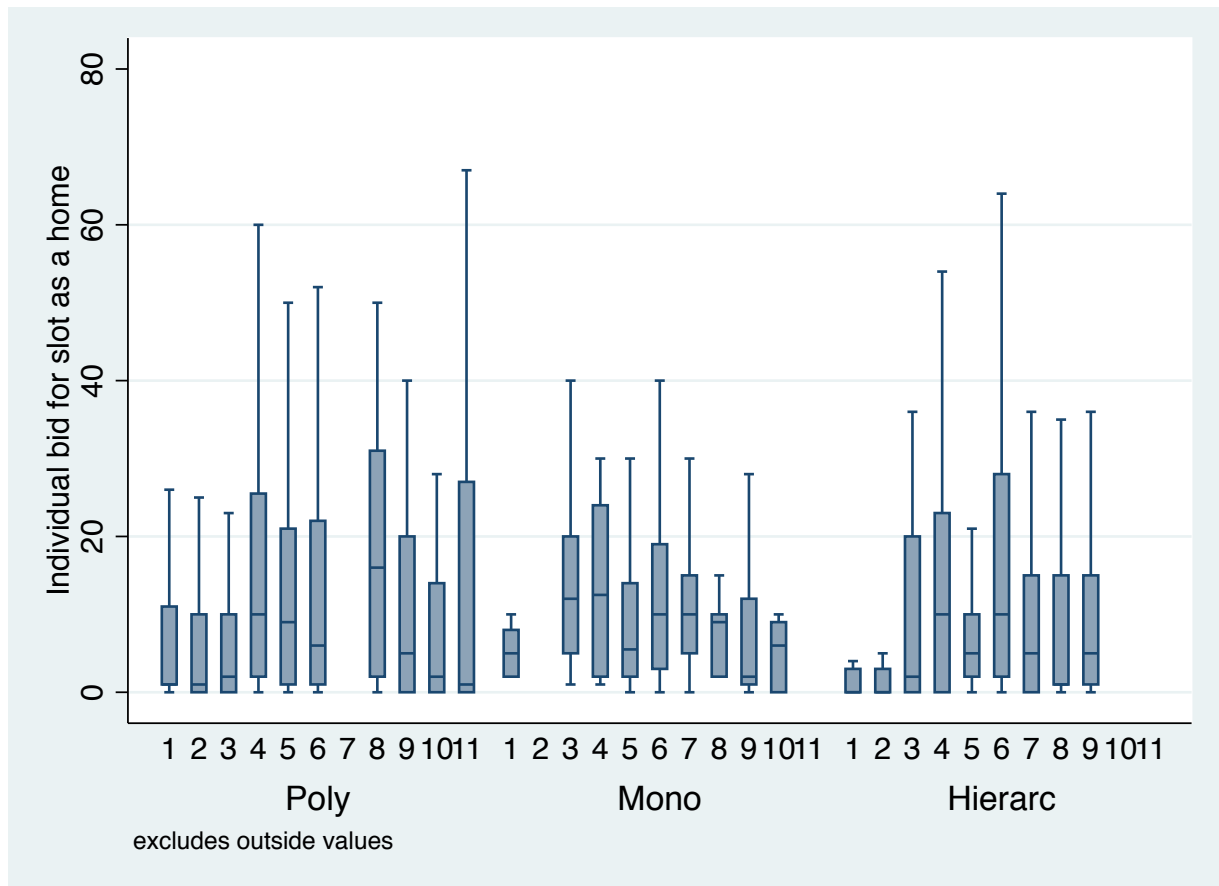


As expected, there is no particular trend for workers' home bids in the polycentric treatment, the bidding curve exhibiting either sharp increases or sharp decreases as distance from CBD rises.

For the monocentric treatment, a peak should be observed for a location place in the CBD, which is clearly the case: A clear and steady decrease for living places nearer the CBD could be seen in the graph, which is quite consistent with the bid-rent curve predicted at equilibrium for these particular values of commuting cost and communication cost.

For the hierarchical treatment, it is important to notice that, consistently with theoretical model, there is a slight decrease in bid-rents for living places near CBD (for a distance not less than 3 units), and then a sharp decrease in rents proposed by workers for the farthest locations.

Figure 15. Box Plots of Individual Bids by workers for workplace as a home place



Lecture note: Slots are numbered from 1 to 11, missing values corresponding to slots that were not chosen as a workplace during step 1. 'Poly' is for polycentric treatment, 'Mono' and 'Hierarc' are respectively for monocentric and hierarchical ones.

The average value of bids for a particular workplace did not exhibit any clear trend for the polycentric treatment, as expected given the theoretical model. On the contrary, for the monocentric treatment, it is possible to observe that the maximum average bid is for slot 6, which is the CBD, this fact being a clear prediction of the theoretical model. For the hierarchical treatment, things are less clear-cut. If slot 1 is excluded (the extreme left frontier for the city), the trend is also to have a decrease in bids as workplace is farther from CBD. It is also interesting to observe that high bids could be made for workplaces that are not located in CBD, like slot 1 or slot 4.

In order to disentangle all the effects that might drive bidding decisions for workers, we conduct a parametric analysis based upon a Tobit Analysis at the individual level<sup>11</sup>. The dependent variable is the level of bid for each slot by each participant, for all periods with excluding trial period. Explanatory variables are socioeconomic and demographic characteristics, and more important, wage level for the worker, and the potential

<sup>11</sup> Tobit model is used since we restrict possible bid prices from 0 to a maximum of 140 in order to avoid potential losses that could arise in a Vickrey's auction process (Cooper and Fang, 2008).

commuting cost associated to a particular location for home. The results of this Tobit analysis are given in the table below.

*Table 2: Tobit analysis of individual bids for home*

Treatment	Polycentric	Monocentric	Hierarchical
Explanatory variables			
Potential commuting cost	-0.620*** (0.0265)	-2.266*** (0.169)	-0.762*** (0.0240)
Period	2.685*** (0.513)	0.865*** (0.130)	2.385*** (0.351)
Age	-0.477*** (0.132)	-0.676*** (0.112)	-0.224** (0.109)
Gender (=1 if male)	0.782 (1.285)	2.917*** (0.582)	-2.068** (0.882)
Activity (=1 if any activity)	9.456*** (1.322)	2.531*** (0.609)	1.140 (0.756)
Level	-0.548 (0.531)	1.994*** (0.350)	1.569*** (0.489)
Field (=1 if economics & management)	7.613*** (1.163)	4.181*** (0.627)	0.727 (0.829)
Wage	0.855*** (0.263)	0.791*** (0.119)	1.088*** (0.118)
Constant	23.22*** (3.189)	16.11*** (2.364)	20.28*** (2.750)
Observations	1738	2057	2079
Log. Likelihood	-6396.39	-7854.04	-7303.69

NB: \*\*\* means significant at the 1% level, \*\* at the 5% level, \* at the 10% level.

Some socio-demographic variables are highly significant, as 'field' and 'activity': Economists and salaries tend to bid higher than other participants. Older participants tend to bid less than younger ones. We do not observe any gender or level effect. More important, we observe that, as commuting cost potentially rises when distance to working place increases, participants tend to bid lower, which is quite reasonable. But if coefficients have expected signs, the value for this particular coefficient tend to be very different when experimental treatments are compared. The highest coefficient is

observed in the monocentric treatment and the lowest in the polycentric one. The last effect to notice is about learning ('Period' variable), participants bidding higher as the game is repeated.

## 5. Concluding comments

The aim of our experiment was to investigate how firms and households choose a location place when confronted to communication costs or to travel costs. To this end, our experimental design inspires upon the theoretical model of Cavailhes et al. (2007) where firms are to incur communication costs with the CBD where essential facilities are exogenously located and households could face commuting costs related to the distance between home and workplace. Our experiment consists in implementing a two-step game where firms and workers are to interact. In a first step, a double auction market where workers and firms negotiate in order to define a contract characterized by a wage and a working place is settled. In a second step, workers compete for land in order to find a living place.

Urban equilibrium results from the bargaining between firms and workers that are confronted to different costs. In our experiment, high commuting costs for workers and no communication costs for firms define our benchmark treatment, which should produce the polycentric structure as the outcome. In this benchmark case, no firm as a particular incentive to locate in the CBD, and as a consequence, competition between workers should not imply higher bids for homes located in the CBD or adjacent to it.

Other experimental treatments are characterized by positive communication costs for firms and therefore, the urban structure for the city at equilibrium depend to commuting costs faced by workers. If it is low, then workers could accept to live far from the CBD, as firms will try to avoid communication costs by locating there, being able therefore to offer higher wages. This situation defines our monocentric treatment.

On the contrary, when commuting costs are high, workers should be willing to accept lower wages in order to convince firms to locate far from the CBD. Indeed, anticipating that positive communication costs will give some incentive for firms to locate in the CBD and that bidding competition for home could be high between them, they should prefer to have lower wages that compensate higher communication costs for firms. Therefore, secondary business districts could exist along the CBD, where wages should be lower. This last situation defines our hierarchical treatment.

Our experimental results confirm partially these conjectures about theoretical equilibriums. In the polycentric treatment, density of firms tends to be uniform as the game is repeated, whereas in the monocentric treatment, almost all firms choose to locate

in the CBD. As expected, the hierarchical treatment exhibits intermediate results. These empirical results are in line with the main conclusions by Cavailhes et al. (2007).

Concerning bidding behaviour by workers about living places, evidence is more mixed. Average bids for living places are approximately the same whatever the distance to CBD in the polycentric treatment, which is to be expected. On the contrary, peak values are observed for bids made on living places that belong to CBD for the other treatments, different shapes for bid-rent function being observed between hierarchical and monocentric treatments.

One important lesson that could be taken from our experiment is that not only the magnitude but also the relative balance between transport costs and communication costs might produce different urban structures, by affecting deeply locational equilibrium within the city. In particular, if public decision-makers are willing to avoid urban sprawl in order to decrease negative externalities related to daily commuting costs, increasing travel costs by raising taxes on oil for instance for households is not necessarily the good answer, as such policy might disrupt locational equilibrium from a monocentric structure to a more polycentric one.

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## 7. Appendix A: Experimental Instructions (hierarchical treatment)

### Instructions

*Please do not read this material until instructed to.*

*Please do not touch your computer until we have completed the instructions.*

#### Welcome

Thank you for coming to today's experiment. Please do not talk with anyone. If you have any question, please raise your hand- an experimenter will come over and answer your question privately.

This is a decision-making experiment. You will be asked to make many decisions, which the object is to score as many points as possible. All of your decisions will be kept completely anonymous. Your decisions and the decisions of others will determine how many points you will earn. These points will be changed in Australian Dollars at the end of the session, defining your final payoff. Moreover, you will get a participation fee of 10\$. We will pay you in cash at the end of the experiment. However, you will not receive anything if you leave before the end of the experiment.

#### The players

In this experiment, there are 32 participants. These 32 participants will be split randomly into 2 groups of 16 participants. You will be allocated to one of these groups randomly by the central computer.

In this experiment, you will form a group of 16 participants. You and the other 15 participants will remain partners during the entire experiment.

In each group, there will be two types of players, *firms* and *workers*. Your type will be chosen randomly at the beginning of the experiment, and your computer will recall your type during the experiment. Your type will not change over the entire experiment, and other participants will not know which type had been attributed to you personally. In the same way, you will not know what will be the type of your partners during the experiment. There will be 8 participants as firms and 8 participants as workers.

You will interact with the other participants during 5 rounds. The first round will be a trial one's, and no point can be gained or lost during this trial. The last four rounds are for

real and will give you some points. At the end of the experiment, one of these four rounds will be randomly chosen by the computer and the points you gained in this round will be exchanged in Australian dollars according the following rate:

$$1 \text{ point} = \$\text{AU } 0.5$$

## The principle of the game

In this game, workers have to find a job and also to locate in a certain place within the city. Firms have to find one worker in order to produce goods and should also locate in a certain place within the city. In the city, some essential facilities that are a necessity for firms to be able to produce goods are located on a certain slot. If firms do not locate on this given slot, they will have to pay a cost in order to reach these essential facilities. This cost depends on the distance between firm's location and the place where facilities are located.

Workers have also to choose a location place as home. As workers will have a workplace depending on their job, if a worker's home place differs from his workplace, he will have to pay a transport cost depending on the distance between his workplace and his home.

Each round in this experiment consists in 2 steps.

**The first step** will consist in a job market where both all firms and all workers interact in order to find a job contract. Indeed, firms need workers to produce goods and have to find one worker for each round, no more no less. If firms do not succeed to have a worker, they get 0 point for the entire round. If workers do not succeed to be employed by any firm, they get 20 points for the entire round.

Moreover, firms will have to choose a certain slot for location. This location will be defined by the job contract they get with a given worker. This location will also be the workplace for the worker that had been hired by the firm.

**The second step** is only with workers who are to compete for available slots in order to find a home. There will be a certain number of slots as homes that are available, but for each slot there can be only at most one worker. That is, it is not possible to have 2 workers or more on a given slot. But it is possible to have more than one firm on a given slot. Workers will have to make some **bids over each home slot**, and the highest bidder will win the corresponding slot as a home. Then, the distance between a worker work place and his home will imply transport costs for him. If a worker succeeds to have a home at his work place, there is no transport cost. But the longer the distance to his work place, the higher transport costs. All these steps will be explained more deeply now.

## Specific instructions for firms' type

As a firm, you will need 2 inputs to produce revenue from your sales. This revenue you will get if you are able to produce will be 18 points. **To produce you will need to recruit one employee that will get a wage that you paid as a firm.** The wage value will be subtracted from your revenue at the end of the round. **The other output you need is essential facilities that are located in slot 6.** Depending on your location choice (that is the final slot you choose to locate), you will have to bear a *communication cost* in order to access these essential facilities. The cost will be the following:

*Communication cost for accessing facilities = 3 points + 2 points (times) distance to slot 6*

For instance, if you locate in slot 4, the distance to Essential Facilities is 2 (that is, 6-2), and you will pay as a firm a communication cost of  $3 + 2 \times 2 = 7$  points. If you locate in slot 8 for instance, the distance is also of 2 slots (8-6), and then the cost will be also 7 points. This communication cost will be subtracted from your revenue, as wage will be. Note that if you are not able to recruit an employee, there is no revenue for the firm, but there will also be no cost, and consequently, you will win 0 point for the round.

Firms only participate to the first step (the labour market), since the second step is only a concern for workers (the land market). Workers will also participate in the first step since they will be able to make proposals regarding the wages they ask for.

In this first step, labour market will open for 10'. During this time, workers and firms can make bids and ask over wages as much they want to, but will be constrained to make a better bid or ask than the best ask or bid that will be currently available at the time they make it.

As a firm, you will be asked to indicate the wage level you are willing to bid at a given time **for each possible slot**, from 1 to 11, in points. You can validate these bids (let call it "**wage bids**") by clicking on OK. You can also change your offers and validate it by clicking on OK at any time during these 10'.

The pieces of information that you will have on your computer screen are the following

- A table where you can bid for wage for each possible location slot,
- A table where you see the best bids and asks that have been made for the moment by all workers and all firms, such for each possible slot,
- A table that indicates which agreements have been reached between a given firm and a given worker, that is the wage level and the location slot for firm (workplace).

Your computer screen will also give you the opportunity to make offers by using a table that resembles to the following:



proposals that have not been already accepted. In this case, the computer will tell you that the first step ended.

- you can make a proposal by bidding on wage for each slot, with the following rule: Your offer should be higher than the current best offer by other firms, displayed in the table. If one of your offers is to be accepted by a given worker (he should click on it), the computer will tell you that the first step is finished since you have found a worker.

In all of these 2 cases, the computer will tell you which employee you get and at what wage. **Note that this wage contract will also define your location place as a firm that is the workplace for your employee.** That is, if one worker accepts a bid you made for a wage of 7 points for slot 4, you will be located in slot 4 (work place), and the distance for essential facilities will be of 2 slots ( $6-4 = 2$ ).

As a firm, you can choose to locate on any slot, but recall that if a worker accepts one of your wage bids on a given slot, it will define your location place. **Moreover, there will be only 2 slots different from slot 6 that will be available as a possible location for firms (first-in, first served). But several firms can choose the same slot that already had been chosen by another firm. For instance, if firm 1 has already a contract with a worker for slot 2 at a given wage, and that firm 2 has already a contract with a worker for slot 3 at a given wage, firms that do not have a contract will be constrained to choose either slot 2, slot 3 or slot 6 for having a contract that defines their location.**

As a firm, if you get a contract with a worker, you will not be able to make other proposals in order to have an employee, since you have already one. Moreover, your worker will no longer be available for other firms until the current round ends.

Then, after this first step, as a firm, you will have to wait until the second step ends, this step being only for workers, in order to be informed about your payoff.

### Your payoff for the round as a firm

**Your payoff in points for the round =**

**18 - wage paid – cost for accessing facilities**

### Your final payoff as a firm

At the end of the 4 rounds you made for real, central computer will pick randomly for each participant 1 round among the 4 and will pay it to you for real by transforming the points you gained in Australian dollars. Your total payoff will be this sum plus a participation fee of 10 AU\$.

## Specific instructions for workers' type

As a worker, **you will have to find a job and a living place** (home). To find a job, you will participate to a job market where 8 firms interact with 8 workers, including you. Then, finding a job will give you revenue and also a wage that you will use to find a home. If you do not find a job, you will get an amount of 20 points for the entire round. If you find a job and a home, your final revenue in points will depend on the wage you have and on the price you paid for having your home.

The round will consist in 2 steps, and for each you will interact with other participants. In the first step, you will interact with the other workers and also with the firms (that is 15 other participants in your group) in order to find a job. In the second step, you will interact only with other workers (that is 7 participants) in order to find a home.

Firms only participate to the first step (**the job market**), since the second step is only a concern for workers (**the land market**). Workers will also participate in the first step since they will be able to make proposals regarding the wages they ask for.

### The first step: Finding a Job

The first step will be organized in the following way.

As a worker, the fact to get a job will give you revenue, this revenue being not the wage. This revenue that you will get if you have a job is of 72 points (20 if you have not). Moreover, if you get a job, you will have a wage that is paid by a firm. That is, your total income for the round will be the sum of your revenue (72 points) *plus* your wage.

In this first step, labour market will open for 10'. During this time, workers and firms can make bids and ask over wages as much they want to, but will be constrained to make a better bid or ask than the best ask or bid that will be currently available at the time they make it.

As a worker, you will be asked to indicate the wage level you are willing to ask at a given time **for each possible slot**, from 1 to 11, in points. You can validate these offers by clicking on OK. You can also change your asks (let call it "**wage asks**") and validate it by clicking on OK at any time during these 10'.

The pieces of information that you will have on your computer screen are the following:

- A table where you can bid for wage for each possible location slot,
- A table where you see the best bids and asks that have been made for the moment by all workers and all firms, for each possible slot,
- A table that indicates which agreements have been reached, that is the wage level and the location slot for firm for each contract (see screen capture 1).



proposals that have not been already accepted. In this case, the computer will tell you that the first step ended, and will indicate your payoff for the current round.

- you can make a proposal by bidding on wage for each slot, with the following rule: Your ask(s) should be lower than the current lowest wage ask by all workers for each slot, that are displayed in the table. If one of your asks is accepted by a given firm (she should click on it), the computer will tell you that the first step ended, and will indicate your total income for this first step.

**When you will make these wage asks in order to find a job, please consider that, depending on your final workplace, you will be charged for transport costs that depends on the distance between your workplace and your home (please read carefully the second step below).**

In all of these 2 cases, the computer will tell you which firm you get as an employer and the corresponding wage. This wage contract will also define location place for this firm that is your workplace as an employee.

In this case, as an employee, you will not be able to make other proposals in order to have another job, since you have already one. Moreover, your employer will no longer be able to recruit another employee, since he has already one, until the current round ends.

Then, after this first step, as a worker, your income will have 2 possible values.

- If you get a job, your income is 72 points (plus) your wage, and you will be allowed to participate to the second step.
- If you do not get a job, your income is 20 points, and you are not allowed to participate to the second step,

### The second step: Finding a Home

As a worker, you will have also expenses that are related first to the distance you will have between your home location and your workplace (**transport cost**), and second, to the **land rent** you will have to give to obtain a given slot as a home. This second step will last at most 5'.

*The transport cost between your home and your workplace*

There are 11 possible slots that could be chosen as your home, and each worker consumes one slot and no more. That is, if a worker buys slot 3, it belongs unavailable for all other workers as a home (see the graph below).

1	2	3	4	5	6	7	8	9	10	11
---	---	---	---	---	---	---	---	---	----	----

As an employee, you will have to commute to your workplace that is the slot that had been chosen by firm as a location in step 1. If your home location is the same as your workplace, there will not be any transport cost for you.

Otherwise, the transport cost will be computed in the following way:

***Transport Cost = (distance from workplace to home) times 9 points***

For instance, if your home location is slot 4, and your workplace is on slot 6, the transport distance is 2 (that is, 6-4), and you will pay as a worker a transport cost of  $2 \times 9 = 18$  points. If you locate in slot 4 for instance, and workplace is on slot 2, the distance is also of 2 slots (4-2), and then the cost will be also 18 points (that is  $2 \times 9$  points). This cost will be subtracted from your total income.

*How will you find a home?*

There are 11 possible homes or slots, from slot 1 to slot 11. As you are 8 workers, there are enough slots for each of you. The computer screen will always recall the following pieces of information:

- what is your identity as a worker,
- which firm is your employer and at which slot is your workplace, what is your income (that is 72 points + your wage).

The slots or homes will be auctioned by using the following procedure. Each worker will have to put **bids for every slot**, from 1 to 11 that is a certain number of points he will have to pay in case he obtains a given slot. Each worker through his computer will submit these bids (from 0 to a max of 140), in a table that resembles to the following:

Period

Trial 1 of 1

Remaining time (sec): 291

Your type : WORKER 8  
 Your firm : FIRM 2  
 Your wage : 10  
 Slot as your working place : 1  
 Your income : 82

Please remember that you will have to pay a transport cost of 9 points per unit of distance from your home place to your working place

Slot as your home	Slot 1	Slot 2	Slot 3	Slot 4	Slot 5	Slot 6	Slot 7	Slot 8	Slot 9	Slot 10	Slot 11
Your home place bid	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

OK

When you will click on “OK” to validate these choices, your bids are transmitted to the central computer and will not be known by the other workers, that will similarly have to transmit bids to central computer. You will not know the bids that other workers are to make.

When all workers have transmitted their bids, or as the 5' period ends, slots will be given to workers by applying the following rule:

***The highest bidder on a given slot will win the slot for which he is the highest bidder, but will pay the second highest bid.***

For instance, assume that you are the highest bidder on slot 3, your bid being 10 points as the highest bid, as the second highest bid for this slot being 7 points by another worker. Then, you will win the home located at slot 3 and pay 7 points for his home. The other workers won't win slot 3 since you won it.

In case of equal bids among workers for a given slot, the following rule will be applied in order to determine the winner for each slot:

- if bids are equal, computer will attribute slots by giving priority to workers for which workplace are close to. Winner will have also to pay the second highest bid for the slot he wins,
- if bids are equal, and distance between workplaces are the same for the winning bidders, computer will randomly pick one of the winning bidders, and the winning bidder will pay the second highest bid,

Of course, the price you paid for slot will be subtracted from your income. Last but not least, computer will make the difference between your home location and your workplace (distance), and will subtract your transport cost from your total income.

When slots will be allocated among the workers, you will get your payoff for the round, displayed on your computer screen. Then the round ends, and another round begins. There will be 4 rounds, after one first round as a trial.

### **Your payoff for the round as a worker**

$$\begin{aligned} &\textbf{Your payoff in points for the round =} \\ &\quad \textbf{(72 + your wage)} \\ &\quad \textbf{- (Home price you paid) - (your Transport Cost)} \end{aligned}$$

### **Your final payoff as a worker**

At the end of the 4 rounds you made for real, central computer will pick randomly for each participant 1 round among the 4 and will pay it to you for real by exchanging the points you gained in Australian dollars. Your total payoff will be this sum plus a participation fee of 10 AU\$.

## 8. Appendix B: Experimental calibration of preferences for workers and firms

In this appendix, we describe how we induce particular preferences for participants as workers or participants as firms within the laboratory by assuming specific production technologies a

In order to focus on land rents and city structure, the experimental design excludes the equilibrium process for production of the homogenous good. This means that firms do not have to choose a quantity or a price and consumers-workers do not have to propose price. It is assumed that when firms and consumers have reached equilibrium both for the labour market and the land market, they obtain a payoff that corresponds respectively to the Nash equilibrium profit or to a net income that corresponds to the optimal level of utility.

Competition between firms is a Cournot-Nash one (see Thisse, 2010 for justification of this), which ensures positive profit at equilibrium<sup>12</sup>. But as revenue comes from using both facilities and one worker (no more no less), firms are incentivised to offer wages that are close to the revenue level, since in the experiment, a firm that does not succeed to hire a worker gains 0 points. Moreover, to ensure that competition among firms for workers is sufficiently strong, we give to workers a positive endowment (which corresponds to the initial quantity of the numéraire in the theoretical model) if not recruited by any firm.

The utility for workers is a quadratic sub-utility. Workers' payoff is the difference between the utility they get, given a predetermined level of consumption for non-spatial goods less urban costs (i.e., *commuting cost* and *land rent*) if they succeed to locate. If they do not succeed in gaining a job, an initial level of a numéraire is their payoff.

### 8.1. Preference for Firms

To avoid the assumption that goods are differentiated, which is usual in NEG models, but not essential to obtain its results, firms are assumed compete à la Cournot (oligopolistic competition on quantities). In the subsequent paragraphs,  $L$  describes the number of consumers and  $n$  the number of firms.

Therefore, each firm  $i$  choose  $q_i$  such as to maximize profit, which is

$$\pi_i = pq_i - w = \left( a - \frac{1}{L} \sum_i q_i \right) q_i - w \quad (15)$$

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<sup>12</sup> As Thisse (2010) explains “Standard models of economic geography assume that the  $M$ -good is differentiated. Contrary to general beliefs, this assumption is not necessary. What we need is the existence of a positive difference between the market price and the social marginal cost”.

This is equivalent to

$$\pi_i = \left( a - \frac{1}{L} \sum_{j \neq i} q_j - \frac{1}{L} q_i \right) q_i - w = a q_i - \frac{1}{L} \sum_{j \neq i} q_j q_i - \frac{1}{L} q_i^2 - w \quad (16)$$

F.O.C. implies that  $\frac{\partial \pi_i}{\partial q_i} = 0$ , which can be rewritten as equation (17).

$$\frac{\partial \pi_i}{\partial q_i} = a - \frac{1}{L} \sum_{j \neq i} q_j - \frac{1}{L} 2q_i = 0 \quad (17)$$

As at Cournot-Nash equilibrium  $q_i = q$  for all firm  $i$ , we can write that  $\sum_{j \neq i} q_j = (n - 1)q$

Then F.O.C. becomes:

$$\begin{aligned} \frac{\partial \pi_i}{\partial q_i} &= a - \frac{1}{L} (n - 1)q - \frac{1}{L} 2q = 0 \\ &\leftrightarrow (nq + q) = L \end{aligned}$$

Nash-Cournot quantity is therefore

$$q^* = \frac{aL}{n + 1} \quad (18)$$

$$Q^* = \frac{naL}{n + 1} \quad (19)$$

$$p^* = \frac{a}{n + 1} \quad (20)$$

Total revenue  $I$  for each firm at market equilibrium is

$$I^* = \left( \frac{a}{n + 1} \right)^2 L = \frac{a^2 L}{(n + 1)^2} \quad (21)$$

As in the experiment,  $n=8$  (see below), firms each get a revenue of 18 points, the equilibrium price is  $p^*=1.5$  for  $q^*=12$ , this revenue being used for wage expense and communication costs between  $x=0$  and their current location.

## 8.2. Preferences for workers

The quadratic sub-utility function is used as a starting point (used for instance by Thisse (2010) or Gagné et al. (2012)) as shown in equation (12).

$$U = \left(a - \frac{q}{2}\right)q + q_0 \quad (12)$$

$a$  is a positive parameter,  $q$  is the consumption for a homogenous good and  $q_0$  the quantity of the numéraire to be consumed, assumed to be positive at equilibrium, i.e., implying that the initial endowment of numéraire is large enough<sup>13</sup>.

The Budget Constraint is

$$qp + q_0 + R(x) + tx = w + \bar{q}_0 \quad (13)$$

If workers maximize utility under that constraint, then the (total) inverse demand for the manufactured good is given as equation (14)

$$p = \text{Max} \left\{ a - \frac{Q}{L}, 0 \right\} \quad (14)$$

Where  $Q=Lq$ ,  $L$  being the total number of workers that live and consume in the city.

Therefore, at equilibrium, given the price level, each worker consumes  $q = \frac{an}{n+1}$ .

For experiment calibration, it is assumed that  $a=13.5$ , that is consumption for a good will be of 12 units, and as we fix the ex-post consumption of the numéraire to 1, such a consumption pattern gives to each worker a utility of 91 (points). Moreover, the exchange rate for experimental point could be (at least) 1 euro for 10 points, or 1.5 AU\$ for 10 points.

As a consequence, each worker that consumes receives 91 points plus their salary, and then the consumption value for  $q$  and  $q_0$  is deducted. As, at equilibrium, the number of units to be consumed for  $q$  is 12 and the equilibrium price is  $p^*=1.5$  (see below), the consumption value for the homogenous good is 18. As the ex-post quantity of the numéraire to 1 is fixed, the net utility is 72 points ( $91 - (18+1)$ ). A worker has to add his wage, and his budget is consequently net utility plus wage for urban expenses, i.e., land rent plus commuting cost which is  $R(x) + tx = Un + w$ .

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<sup>13</sup> This characterization of individual utility corresponds to Ottaviano, Tabuchi and Thisse (2002) equation (2) with the following calibration: alpha = 1; Beta = 1; gamma = 0 and  $x = 1$  ( $x$  is here not the distance from CBD, but the number of varieties for good).