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History versus expectations in economic geography: An experimental analysis

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Abstract

This paper adapts the canonical NEG model (with an infinite number of agents) for experimental testing (with a finite number of subjects) by developing a game-theoretic framework. The model gives clearly distinctive predictions when migration is consistent with history-driven behavior (HDB) and when it is consistent with expectation-driven behavior (EDB). The two alternatives are tested in an economic laboratory experiment with increasing number of agents in different treatments. Results show that EDB looses ground against HDB as the number of agents and periods increases, and this number may be surprisingly small.

JEL codes: R1; C91; C73.

Keywords: New Economic Geography; Migration; Experiments.

1 Introduction

Endogenous demand is a distinctive feature of New Economic Geography (NEG) compared to economic geography and trade theory. In the core-periphery (CP) model that launched NEG as a separate field (Krugman, 1991b), demand was made endogenous by allowing people to move between different locations in order to maximize utility. From the very beginning, the migration dynamics came under attack and was seen by some of the the critics as the weakest part of the model (see, e.g. Baldwin et al., 2003).

When first introducing migration in the NEG framework, there was no explicit migration model. Parallel reading of contemporary work by Krugman suggests that dynamics used in trade theory to model capital mobility were reinterpreted and added without much further ado (see, in particular, Dymski, 1996). The migration model was elaborated in Krugman (1992) and later presented essentially unchanged in Fujita et al. (1999).[1]

Attempts have been made to rationalize the dynamics as rational household migration behavior and the model has been analyzed under different assumptions concerning expectations (Baldwin, 2001). This discussion could be phrased in terms of what determines migration choices: history or expectations. As such, the discussion can be traced back to the early 1990s when Krugman discussed the importance of history and expectations in shaping equilibrium in a trade model with external economies and adjustment costs (Fukao and Benabou, 1993; Krugman, 1991a).

In this paper we follow the early history versus expectations literature, but we build on the elaboration of the original CP model by Forslid and Ottaviano (2003) allowing a closed form solution for the inter-regional real wage differential. In order to adapt the model to experimental testing, we develop a finite horizon dynamic game of migration and solve for the Markov-perfect equilibria. Our theoretical findings show that the equilibrium outcome of the migration game can be different depending on whether agents' behavior are driven by history or expectation. This makes our framework suitable for testing history-driven behavior (HDB) against expectation-driven behavior (EDB).

In the baseline treatment of the experiment, we give EDB the best of all possible chances by considering an experimental laboratory framework that places minimal cognitive burdens on the potential mover in a very simple environment (only 2 potential migrants moving sequentially) closely related to the theoretical model much more than the field. If behavior is not consistent with EDB in this environment, then, to paraphrase one of the pioneers of experimental economics Charles Plott, how can one be convinced that it will nonetheless emerge in inevitably more complex field settings (see Plott, 1991).

It is also worth mentioning that several of the shortcomings in terms of internal validity, when confronting the CP model with field data (see Combes et al., 2008), do not apply with

[1]The CP model has been elaborated further in other aspects, through the study of existence and stability of equilibria in the long run (Fujita et al., 1999; Robert-Nicoud, 2005) and the short run (Mossay, 2006). Tractability has been improved (Forslid and Ottaviano, 2003; Ottaviano, 2001), and (Oyama, 2009) has analysed the robustness of multiple equilibria.

our experimental data: 1) Homogeneous migrants - real migrants care about more than wage differences and price levels. True, but this is all that distinguishes different locations in the experimental setting; 2) Two regions - there are multiple regions real migrants can choose from. Yes, but in the experiment there are only two by design; 3) History-driven migration behavior - outcomes may also be shaped by expectations and in the experiment the role of history versus expectations is determined by humans and not *homines oeconomici* in a theoretical model or robots in a simulation model.

We run two additional treatments to the baseline treatment, where complexity is marginally increased by first adding one potential migrant and period, and then adding one more. We find that behavior is consistent with EDB in the baseline treatment as expected. This is also true when adding one potential migrant, but, surprisingly, adding two is all it takes in terms of complexity to make a majority of subjects behave consistently with HDB. Importantly, this suggests that HDB may be a better model than EDB from a behavioral perspective in a world with an even much larger number of decision makers.

We are not the first to use controlled laboratory experiments for studying migration decisions. Experimental techniques were suggested by a distinguished group of migration researchers more than 25 years ago (Greenwood et al., 1991). For some reason the suggestion never caught on. The few exceptions include Greenwood et al. (1997) and Edwards and Huskey (2008, 2014).[2]

There are also some relevant experimental work indirectly related to the game theoretic approach we are using. Although we have not been able to find any work directly related to finite horizon dynamic games, there are some experimental studies on backward induction failure in finite horizon repeated games. See, e.g., Binmore et al. (2002) and the more recent paper by Dufwenberg and van Essen (2018).

The paper is organized in four more sections: The core-periphery model is based on the simplifying assumption of an infinite number of agents and does not in its original (Krugman, 1991b) or more recent and more analytically tractable forms (Forslid and Ottaviano, 2003; Ottaviano, 2001), allow for a meaningful analysis based on the finite number of agents that necessarily has to be the basis for an experimental laboratory design with a limited number of experimental subjects. In Section 2 (proofs in Appendix A), we therefore develop a theoretical framework that can bridge the gap between existing theoretical models and one that can be implemented in the laboratory.

Based on the theoretical model, in Section 3 we present an experimental design that makes it possible to discriminate between the competing hypothesis: History-driven behavior (HDB) and expectation-driven behavior (EDB) (Instructions for the experiment in Appendix B). Experimental results are presented in Section 4 and concluding remarks in Section 5.

[2]Experimental methodology, now widespread in economics, has in general not been much used in economic geography, with a few exceptions like land use research (for a recent example and a review, see Winn and McCarter (2018)).

2 Theoretical analysis

We consider the analytically solvable CP model developed in Ottaviano (2001) and Forslid and Ottaviano (2003). We extend the model to allow inter-regional asymmetry in the production technology, the trading cost and the size of the unskilled labor force.[3] We then introduce a group-based migration process to address the mobility of skilled workers between regions.

2.1 Preliminaries: An analytically solvable CP model

Basic ingredients

There are two regions, 0 and 1. A continuum of mass 1 of skilled workers is distributed over the two regions and we let $s \in [0,1]$ denote the fraction of skilled workers in region 1. There are mass L of (immobile) unskilled workers, of which L_i are in region $i = 0, 1$, and $L_0 + L_1 = L$. Everyone gets utility from consumption of two goods, a differentiated modern good D and a homogeneous traditional good A. Preferences of the representative consumer involve CES preferences over the differentiated varieties of the modern good nested in a Cobb–Douglas upper-tier utility function

$$U_i\left(D_i, A_i\right) = \alpha \ln D_i + (1-\alpha) \ln A_i, \ i \in \{0,1\} \tag{1}$$

with

$$D_i = \left[\int_{q \in n_i} d_{ii}\left(q\right)^{\frac{\sigma-1}{\sigma}} dq + \int_{q \in n_j} d_{ji}\left(q\right)^{\frac{\sigma-1}{\sigma}} dq \right]^{\frac{\sigma}{\sigma-1}}, \ \sigma > 1, \tag{2}$$

where D_i and A_i are consumptions in region i of the CES composite of modern varieties and the traditional good, respectively. $d_{ji}\left(q\right)$ is consumption in region i of a certain variety q that is produced in j, and n_i and n_j are the ranges of varieties produced in regions i and j and $i, j \in \{0,1\}$. And, $\sigma > 1$ is the elasticity of substitution between any two varieties. Let r_i and w_i denote the wages of skilled and unskilled workers in region i. Production of the modern good takes place in a Dixit-Stiglitz monopolistic competition sector subject to increasing return. Production of a modern good variety in region i requires a fixed input of one skilled worker and a marginal input of β_i units of unskilled worker. With a fixed distribution of skilled workers, the ranges of varieties of modern goods are thus fixed at $n_0 = 1 - s$ and $n_1 = s$. A firm incurs a cost of $r_i + \beta_i w_i m$ to produce m units of a specific variety of the modern good. The traditional good is produced using a constant returns to scale technology in a perfectly competitive sector, and production requires a marginal input of 1 unit of unskilled worker.

Both goods are traded across regions. The traditional good is freely traded and so the wage of

[3] Forslid and Ottaviano (2003) also provides an extension of the basic model allowing for the trading cost and the size of the unskilled labor force to vary between the two regions. The model, however, does not incorporate asymmetric production technology, which is necessary in order to create a real wage difference for skilled labor in one region compared to the other under full agglomeration.

an unskilled worker is the same between the two regions.[4] Trading of a modern good is affected by frictional (iceberg) trading cost. Specifically, $\tau_{ji} > 1$ units must be shipped from region j to sell one unit in region i. Let $\rho_i = \tau_{ji}^{1-\sigma} \in (0, 1)$ measure the degree of trade openness in region i.

Equilibrium of the CP model

The following proposition describes the indirect utility of a skilled worker in region i in equilibrium. A formal proof is given in Appendix A.

Proposition 1. *For a given s, the indirect utility of a skilled worker in region i is*

$$v_i(s) = \alpha \ln\left(\alpha \frac{r_i}{P_i}\right) + (1-\alpha)\ln\left((1-\alpha) r_i\right), \tag{3}$$

where P_i is the CES-price index and r_i is the nominal wage of a skilled worker in region i, and they are given by

$$P_i = \frac{\sigma}{\sigma - 1}\left[x_i \beta_i^{1-\sigma} + \rho_i x_j \beta_j^{1-\sigma}\right]^{\frac{1}{1-\sigma}}, \tag{4}$$

$$r_i = \frac{1}{\psi}\left[a_i L_i + b_i L_j - L_i x_j (a_i a_j - b_i b_j)\right], j \neq i, \tag{5}$$

where

$$\begin{aligned} x_1 &= s, \\ x_0 &= 1 - s, \\ a_i &= \frac{\alpha \beta_i^{1-\sigma}}{\sigma\left[x_i \beta_i^{1-\sigma} + \rho_i x_j \beta_j^{1-\sigma}\right]}, \\ b_i &= \frac{\alpha \rho_j \beta_i^{1-\sigma}}{\sigma\left[x_j \beta_j^{1-\sigma} + \rho_j x_i \beta_i^{1-\sigma}\right]}, \\ \psi &= 1 - a_0 x_0 - a_1 x_1 + x_0 x_1 (a_0 a_1 - b_0 b_1). \end{aligned}$$

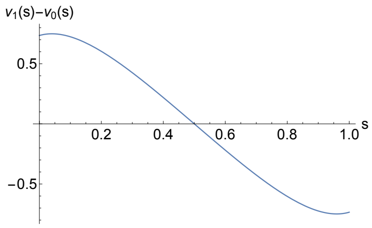
From (3), the inter-regional payoff difference is given by

$$\begin{aligned} v_1(s) - v_0(s) &= \ln\left(\frac{a_1 L_1 + b_1 L_0 - L_1 (1-s)(a_0 a_1 - b_0 b_1)}{a_0 L_0 + b_0 L_1 - L_0 s (a_0 a_1 - b_0 b_1)}\right) \\ &+ \frac{\alpha}{\sigma - 1}\ln\left(\frac{s\beta_1^{1-\sigma} + \rho_1 (1-s)\beta_0^{1-\sigma}}{(1-s)\beta_0^{1-\sigma} + \rho_0 s \beta_1^{1-\sigma}}\right). \end{aligned} \tag{6}$$

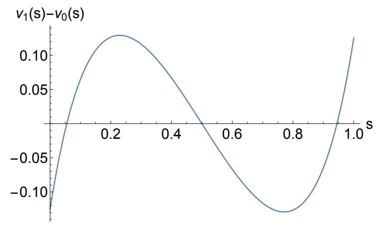
Eq. (6) is comparable to the utility-difference function Eq. (13) in Ottaviano (2001, p. 58).[5]

[4] We impose an additional parametric restriction to ensure that the traditional good is produced in both regions in positive quantities at equilibrium. This 'non-full-specialization' condition is given by $\max\left\{\frac{L_0}{L}, \frac{L_1}{L}\right\} < (1-\alpha)/\left[1 - \frac{\alpha}{\sigma}\right]$, see Ottaviano (2001), footnote 5, or Forslid and Ottaviano (2003), footnote 4. Observe a recurring typo in the literature (Baldwin et al., 2003; Fujita and Thisse, 2013).

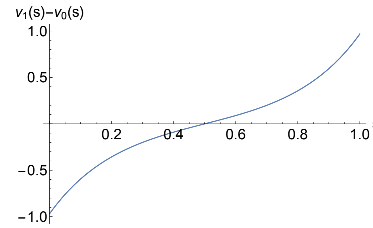
[5] The two functions coincide if two regions are symmetric, i.e., $\rho_0 = \rho_1$, $L_0 = L_1 = \frac{L}{2}$, and $\beta_0 = \beta_1$.



(a) $\sigma = 2.66$

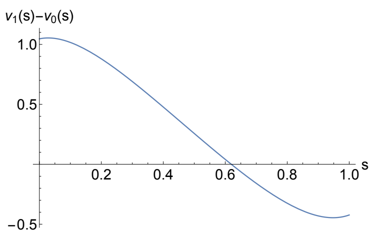


(b) $\sigma = 2.58$

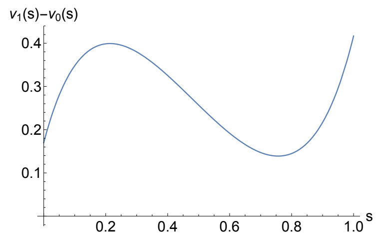


(c) $\sigma = 2.5$

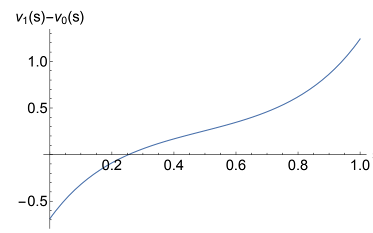
Figure 1: Inter-regional payoff difference, $v_1(s) - v_0(s)$, for different values of σ in the case of symmetric production technology ($\beta_0 = \beta_1 = 1$)



(a) $\sigma = 2.66$



(b) $\sigma = 2.58$



(c) $\sigma = 2.5$

Figure 2: Inter-regional payoff difference, $v_1(s) - v_0(s)$, for different values of σ in the case of asymmetric production technology ($\beta_0 = 1.01 > \beta_1 = 1$)

Observe that $\beta_0 \neq \beta_1$ implies that $v_1(1) \neq v_0(0)$, i.e., the wage of a skilled worker under full agglomeration can be different between two regions.[6] The following example plots the inter-regional payoff difference for various combination of parameter values.

Example 1. (Regional asymmetry) The inter-regional payoff difference can take three alternative shapes (see Ottaviano, 2001, pp. 59, corollary 2, and Fig 1). In Figures 1a, 1b, and 1c, we plot the payoff difference when the production technology is the same between regions. As discussed in Ottaviano (2001), the shape depicted in Figure 1a arises for relatively large σ, small α and large τ. The shape depicted in Figure 1c arises when the converse is true. The shape depicted in Figure 1b arises for intermediate values of the parameters. We use the following parameter values in Figure 1: $(L_0 = L_1 = 1, \alpha = 0.5, \beta_0 = \beta_1 = 1, \tau_{01} = \tau_{10} = 2)$. The elasticity of substitution σ is different across the three plots. We use $\sigma = 2.66$, $\sigma = 2.58$ and $\sigma = 2.5$ in Figures 1a, 1b, and 1c respectively. In Figures 2a, 2b, and 2c, we consider the same parametric specification, except that the production technologies are now different between regions. Specifically, we allow $\beta_1 = 1 < \beta_0 = 1.01$, which implies that production of a variety of modern good requires relatively more unskilled workers in region 0 than in region 1.

[6]Inter-regional differences in trade openness and size of unskilled workforce are not sufficient to create the wage difference.

2.2 A migration game

2.2.1 The framework

We develop a finite-horizon dynamic game of migration to study the mobility of the skilled workforce. Consider the population of the skilled workforce split in n groups of equal measure, referred to as players hereafter, and there are n periods.[7] Each player gets one opportunity to migrate and only one player migrates in any period. Unlike the previous literature, we assume a simple migration-cost structure.[8] In every period, one player has zero migration costs while other players have infinite migration costs. In effect, the player with zero migration cost has an opportunity to migrate. We consider an exogenous migration sequence. Without loss of generality, we label a player based on its position in the sequence.

The distribution of the skilled workforce is the common payoff-relevant variable across players and is, therefore, considered as the state variable. Let $s^t \in S := \{0, \frac{1}{n}, \ldots, 1\}$ denote the fraction of skilled workers in region 1 at the end of period t (or, at the beginning of period $t+1$, $t \in \{0, 1, 2, \ldots, n\}$. For analytical convenience, we consider migration games that start with full agglomeration in region 0, i.e., $s^0 = 0$. Each player has a common action space $A = \{0, 1\}$ such that action 1 refers to migrating to region 1 and action 0 refers to staying in region 0. Since only one player takes an action in each period, we denote the period-t action profile by $a^t \in A$, which is the action taken by player t in period t. Finally, the state-transition probabilities are

$$\Pr(s^t|s^{t-1}, a^t) = \begin{cases} 1 & \text{if } a^t = 1 \text{ and } s^t = s^{t-1} + \frac{1}{n} \\ 1 & \text{if } a^t = 0 \text{ and } s^t = s^{t-1} \\ 0 & \text{otherwise} \end{cases}, \tag{7}$$

and it gives the conditional probability that the state s^t is realized at the end of period t (or, beginning of period $t+1$), given the state s^{t-1} at the beginning of period t and an action a^t taken in period t.

A player's temporal utility depends on her location, action a^t and the state s^t in period t. Recall that $v_i(s)$ is the temporal utility of a player in region $i \in \{0, 1\}$ at the state value s. We assume that players discount future payoffs at a common rate δ. For a given state-transition path $\underline{s} = (s^1, s^2, \ldots, s^n) \in S^n$ and a composite action profile $\underline{a} = (a^1, a^2, \ldots, a^n) \in A^n$, player i's aggregate payoff, computed at time $t = 1$, is the discounted sum of utilities and can be written as

$$\pi_{i,1}(\underline{s}, \underline{a}) = \sum_{t=1}^{i-1} \delta^{t-1} v_0\left(s^t\right) + \mathbb{1}_{\{a^i=0\}} \sum_{t=i}^{n} \delta^{t-1} v_0\left(s^t\right) + \mathbb{1}_{\{a^i=1\}} \sum_{t=i}^{n} \delta^{t-1} v_1\left(s^t\right), \tag{8}$$

[7] To interpret the effect of having finitely many players in an otherwise model with infinite players, we assume that a player represents a strictly positive mass of population. We thus assume away the within-group coordination problem. In our experiment with finite players, a single player will represent a group, and so modeling within-group coordination is not relevant in our context.

[8] Observe, however, that both in our case as well as in the cases considered in previous literature, the cost structure essentially prevents workers from moving all together. See, e.g., Fujita and Thisse (2013, p. 311).

where $\mathbb{1}_{\mathbf{E}}$ takes value 1 if the event $\mathbf{E}$ occurs, and zero otherwise. Observe that player i moves only in period i, and effects of actions taken in the previous periods are entirely captured in the state-transition path. However, player i's continuation payoff from period i is location-specific and depends on her action in period i. Precisely, for a given state-transition path $\underline{s} \in S^n$ and an action profile $\underline{a} \in A^n$, player i's continuation payoff from period i is

$$\pi_{i,i}(\underline{s}, \underline{a}) = \mathbb{1}_{\{a^i=0\}} \sum_{t=i}^{n} \delta^{t-i} v_0\left(s^t\right) + \mathbb{1}_{\{a^i=1\}} \sum_{t=i}^{n} \delta^{t-i} v_1\left(s^t\right). \tag{9}$$

In general, strategies in a dynamic game can consider a player's action as a complicated function of the preceding history. It is, however, common to restrict attention to Markov strategies in which the past influences the current play only through its effect on the state variable. A (pure) Markov strategy for player i is a function $\sigma_i : S \to A$. A strategy profile $\underline{\sigma} = (\sigma_1, \ldots, \sigma_n)$ is a Markov perfect equilibrium (MPE) when σ_is are Markov strategies and the strategy profile constitutes a subgame-perfect equilibrium of this finite-horizon dynamic game (Mailath and Samuelson, 2006).[9] We consider MPE in pure strategies as the solution concept of the game. It is worth pointed out that the requirement of perfection in MPE is intimately linked to the idea of sequential rationality. It requires that the equilibrium strategies must reflect optimal behavior in the continuation game at any state even if that state may not necessarily be realized along the equilibrium path. Consequently, the set of MPE can be smaller than the set of all equilibria of the dynamic game.

2.2.2 Analysis

For the purpose of distinguishing behaviors under myopic and forward-looking considerations in a precise way, we make some simplifying assumptions.

Assumption 1. *$v_1(s)$ is strictly increasing in s and $v_0(s)$ is strictly decreasing in s.*

Assumption 1 also implies that inter-regional payoff difference increases monotonically with number of players already migrated to region 1; See, for example, the cases depicted in Figure 1c and Figure 2c. In the remainder of the paper, we assume that Assumption 1 holds. The perceived gain in utility from migration also depends on the horizon over which the future utility flows are considered. We study the equilibrium outcomes in two different cases:

1. Myopic Behavior (MB) $-$ the migration decision is based on one-period utility gain from migration. Specifically, every player considers $\delta = 0$ and it is common knowledge.

[9] Observe that only players $t+1, \ldots, n$ take actions period $(t+1)$ onward. Therefore, a strategy profile $\underline{\sigma} = (\sigma_1, \ldots, \sigma_n)$ is a subgame-perfect equilibrium of the $n-$periods game if, for any history of play $h_t = (a^1, \ldots, a^t)$, $t \in \{1, 2, \ldots, n\}$ ending in a state $s \in S$, the continuation strategy profile $\underline{\sigma}|_{h_t} = (\sigma_{t+1}, \ldots, \sigma_n)$ is a Nash equilibrium of the $(n-t)-$periods continuation game starting at the state s.

2. Forward-looking Behavior (FB) − the migration decision is based on the accumulated utility flows over all the remaining periods and under the belief that all other groups are forward-looking. Specifically, every player considers $\delta = 1$ and it is common knowledge.

MB

Since every player only cares about the current period payoff and only one player moves in each period, players' behaviors are non-strategic in MB and the analysis is trivial. Given a state value s, player i's payoff from migrating is $v_1(s + \frac{1}{n})$ and from not migrating is $v_0(s)$. The optimal strategy is straightforward and given by[10]

$$\sigma_i(s) = \sigma(s) = \begin{cases} 1 & \text{if } v_1(s + \frac{1}{n}) > v_0(s) \\ 0 & \text{otherwise} \end{cases}, \tag{10}$$

The strategy profile $(\sigma(s), \ldots, \sigma(s))$ constitutes the unique equilibrium of the $n-$player game. If $v_0(0) < v_1(\frac{1}{n})$, then player 1 migrates to region 1. Given Assumption 1, all the following players migrate. On the other hand, If $v_1(\frac{1}{n}) \leq v_0(0)$, none of the players find incentive to migrate. Therefore, there are only two possible outcomes − every player either stays in region 0 or migrates to region 1, depending on whether or not the following condition holds:

$$v_1(\frac{1}{n}) \leq v_0(0). \tag{MB_0}$$

The following proposition documents this finding. The proof is straightforward and skipped.

Proposition 2. *Consider the migration game with n myopic players. In the unique equilibrium, there will be full agglomeration either in region 0 or in region 1. If (MB_0) holds, no player migrates and $s^n = 0$. If (MB_0) does not hold, every player migrates and $s^n = 1$.*

The above proposition points out history dependency in the migration game with myopic players. To see this, suppose that $v_1(0) < v_0(0)$. Then, condition (MB_0) holds for sufficiently large n. Therefore, if the population is partitioned in sufficiently fine groups, the economy will remain at the initial agglomerated state. Suppose instead that $v_1(0) > v_0(0)$. Then, condition (MB_0) is violated for any n and the whole population of skilled workers move to region 1 in any $n-$player migration game. Therefore, an inter-regional real wage difference at the initial state drives the outcome of the migration game.

FB

We next analyze the migration game with forward-looking players (i.e., $\delta = 1$). In a finite-horizon dynamic game with perfect information, there always exists a pure-strategy MPE (see Fudenberg

[10] We use the tie-breaking rule that players do not migrate if they are indifferent between migration and no migration.

and Tirole, 1991, Chapter 13.2.2). The following lemma shows that in any MPE, players' optimal strategies are threshold strategies and the thresholds are increasing in the player's position in the migration sequence. We prove the lemma by backward induction and the proof is included in Appendix A.

Lemma 1. *There exist thresholds $\overline{s}_i$, $i \in \{1, 2, \ldots, n\}$ with $\overline{s}_i - \frac{1}{n} \leq \overline{s}_{i-1} < \overline{s}_i$ such that in any MPE, the optimal strategy of player i is given by*[11]

$$\sigma_i(s) = \begin{cases} 1 & \text{if } s > \overline{s}_i \\ 0 & \text{if } s \leq \overline{s}_i \end{cases}. \tag{11}$$

Further, the threshold $\overline{s}_i$, $i \in \{i, \ldots, n\}$ uniquely solves[12]

$$v_0(s) = \frac{1}{n-i+1} \sum_{t=1}^{n-i+1} v_1(s + \frac{t}{n}). \tag{12}$$

For player n, the threshold $\overline{s}_n$ solves $v_0(s) = v_1(s + \frac{1}{n})$ and it coincides with the corresponding threshold derived in MB; see (10). However, the preceding players have weaker thresholds $-$ they are willing to migrate at lower state values. This is because their incentives to migrate are driven by the expectation that future players would follow suit and all would benefit from increased migration to region 1. In particular, player 1 has the least demanding migration threshold $\overline{s}_1$, which solves $v_0(s) = \frac{1}{n} \sum_{t=1}^{n} v_1(s + \frac{t}{n})$. Building on Lemma (1), the following lemma shows that any pair of consecutive players must take the same action in any MPE. The proof is included in Appendix A.

Lemma 2. *In any MPE, player $i+1$ migrates if and only if player i migrates for any $i \in \{1, \ldots, n-1\}$.*

The above lemma implies that only two action profiles can occur in an MPE $-$ one in which every player migrates and the other in which no player migrates. The action of the first player determines which action profile we observe in equilibrium. Player 1 migrates if and only if $\overline{s}_1 < s^0 = 0$, which is, given Assumption 1, equivalent to the following condition:

$$v_0(0) < \frac{1}{n} \sum_{t=1}^{n} v_1(\frac{t}{n}). \tag{FB$_1$}$$

The following proposition characterizes the unique MPE of the game. The proof directly follows from the above discussion and is skipped.

[11] Similar to MB, here we consider the tie-breaking rule that players do not migrate if they are indifferent between migration and no migration.

[12] Although we solve the problem in case of no future discounting ($\delta = 1$), the results are quite similar in the general problem with a discount factor of $\delta \in [0, 1]$. The corresponding threshold $\overline{s}_i$ satisfies $v_0(s) \sum_{t=1}^{n-i+1} \delta^{t-1} = \sum_{t=1}^{n-i+1} \delta^{t-1} v_1(s + \frac{t}{n})$.

Proposition 3. *Consider the migration game with n forward-looking players. In the unique MPE, there will be full agglomeration either in region 0 or in region 1. If (FB_1) holds, every player migrates and $s^n = 1$. If (FB_1) does not hold, no player migrates and $s^n = 0$.*

The unique equilibrium in FB exhibits strong expectation-dependency − each player's migration decision depends on expectations of future utilities, which depend on actions of other players.

Non-perfect equilibrium in FB

The requirement of perfection and the assumptions of strict monotonicity of the indirect utility functions result in a unique MPE. There can be other equilibria in Markov strategies that do not satisfy the requirement of perfection in all possible continuation games. The following lemma shows that similar to the case of MPE, only two possible action profiles can be sustained in any non-perfect equilibrium in Markov strategy − either every players migrates or no one does. The key to proving this result is showing that whenever there is a pair of consecutive players taking different actions, a unilateral deviation by one of the pair is profitable. The technical proof is included in Appendix A.

Lemma 3. *In any Markov equilibrium, either $a^i = 0$ for all $i \in \{1, \dots, n\}$, or, $a^i = 1$ for all $i \in \{1, \dots, n\}$.*

Let us first consider the action profile $a^i = 0$ for all $i \in \{1, \dots, n\}$. In period i, player i has a continuation payoff of $(n - i + 1)v_0(0)$ by playing $a^i = 0$, and a unilateral deviation gives her a continuation payoff of $(n - i + 1)v_1(\frac{1}{n})$. Therefore, the condition for no unilateral deviation is

$$v_1(\frac{1}{n}) \leq v_0(0), \tag{NPE$_0$}$$

which is same as the condition under which we observe $s^n = 0$ in MB. The strategy profile that sustains the above action profile in a non-perfect equilibrium is not necessarily unique. One specific strategy profile of interest, because of symmetry and extremity, is the Markov strategy profile $(\sigma(s), \dots, \sigma(s))$ such that $\sigma(s) = 0$ for all $s \in [0, 1]$. This strategy profile constitutes an equilibrium if (NPE_0) holds.[13] However, the strategy profile violates subgame perfection.[14]

Next, consider the action profile $a^i = 1$ for all $i \in \{1, \dots, n\}$. Player i gets a continuation payoff of $\sum_{t=i}^{n} v_1(\frac{t}{n})$ by playing $a^i = 1$, and a unilateral deviation gives her a continuation payoff of $\sum_{t=i}^{n} v_0(\frac{t-1}{n})$. A unilateral deviation is not beneficial to player t if $\sum_{t=i}^{n} v_0(\frac{t-1}{n}) < \sum_{t=i}^{n} v_1(\frac{t}{n})$. From Assumption 1, it follows that if the no-unilateral-deviation condition holds for player i, it

[13] Similarly, a threshold Markov strategy profile $(\sigma_1(s), \dots, \sigma_n(s))$ satisfying (11), for which $\bar{s}_1 > 0$ and $\bar{s}_i > \frac{1}{n}$ for all $i \in \{2, \dots, n\}$, constitutes an equilibrium if (NPE_0) holds and we have $a^1 = a^2 = \dots = a^n = 0$ along the equilibrium path. The strategy, however, violates subgame perfection.

[14] For example, if $v_1(s + \frac{1}{n}) > v_0(s)$ for some $s > 0$, then a player will deviate from the strategy $\sigma(s) = 0$ at that s. In fact, if (FB_1) holds, then there will always be some $s > 0$ such that $v_1(s + \frac{1}{n}) > v_0(s)$ even if $v_0(0) > v_1(\frac{1}{n})$.

must hold for player $i+1$. Therefore, the condition for no unilateral deviation by any player is

$$\sum_{t=1}^{n} v_0(\frac{t-1}{n}) < \sum_{t=1}^{n} v_1(\frac{t}{n}). \tag{NPE$_1$}$$

As with the previous case, the strategy profile sustaining the above action profile in a non-perfect equilibrium is not unique. One specific profile of interest is an extreme strategy profile, in which every player decides to migrate in every possible state, i.e., $\sigma(s) = 1$ for all $s \in [0, 1]$. This strategy profile constitutes an equilibrium if (NPE$_1$) holds.

The two conditions (NPE$_0$) and (NPE$_1$) are collectively exhaustive but not mutually exclusive – for any parameter specification of the model, we will have at least one, and sometime both, of the two types of non-perfect equilibria present.[15] The following proposition documents the findings. The proof follows from the above discussion and is skipped.

Proposition 4. *There always exists a non-perfect equilibrium in Markov strategies in the migration game with n forward-looking players. If (NPE$_0$) holds, there always exists a non-perfect equilibrium such that no player migrates and $s^n = 0$. If (NPE$_1$) holds, there always exists a non-perfect equilibrium such that every player migrates and $s^n = 1$.*

Several observations are in order. First, (MB$_0$) and (NPE$_0$) produce the same condition and when it holds, in the unique equilibrium in MB and in a non-perfect equilibrium in FB, no player migrates. Both equilibria show strong history dependency – if the population is partitioned in sufficiently fine groups, a favorable real wage difference in region 0 at the initial state drives the outcomes in these equilibria.

Second, by Assumption 1, (FB$_1$) implies (NPE$_1$). Therefore, if (FB$_1$) is satisfied, in the unique MPE in FB and in a non-perfect equilibrium in FB, every player migrates. In both equilibria, a player's decision to migrate depends on expectations of future utilities, which depends on actions of other players.

Third, there always exists a non-perfect equilibrium of FB, the outcome of which coincides with the outcome of the unique MPE of FB.[16] It is, therefore, not possible to distinguish perfect and non-perfect behaviors from observing the outcome of the migration game.

Finally, when both (MB$_0$) and (FB$_1$) are satisfied, the unique equilibrium of MB and the unique MPE of FB predict different outcomes - one in which no one migrates, and the other in which every one does. In this case, since (NPE$_0$) and (NPE$_1$) are also satisfied, we have two non-perfect Markov equilibria each supporting one of two different outcomes. However, more importantly, the difference in outcome is closely linked to history versus the expectations hypothesis, given how history and expectations play their respective roles in driving these different

[15] The fact that (NPE$_0$) and (NPE$_1$) are collectively exhaustive can be proved by showing that (NPE$_1$) must hold if (NPE$_0$) does not hold. Further, both (NPE$_0$) and (NPE$_1$) are simultaneously satisfied if $v_1(\frac{1}{n}) < v_0(0) < \sum_{t=1}^{n} v_1(\frac{t}{n})$.

[16] This is because if (FB$_1$) holds, then (NPE$_1$) holds and if (FB$_1$) does not hold, then (NPE$_0$) holds.

outcomes under (MB_0) and (FB_1). We can, therefore, test whether history or expectations play the dominant role by studying the outcome of a migration game.

To this end, we consider parameter values to construct indirect utility functions, $v_1(s)$ and $v_0(s)$, that simultaneously satisfy (MB_0) and (FB_1):

$$v_1(\frac{1}{n}) < v_0(0) < \sum_{t=1}^{n} v_1(\frac{t}{n}). \tag{13}$$

We vary the number of players or, equivalently, the partitioning of the population, and study the outcome of the migration game in an experimental setup. Section 3 documents the experimental design.

3 Experimental study

We start with some numerical examples that we adopt in the experiment. Treatments are labeled reflecting the number of players in the game: $T2$ when 2 players, $T3$ when 3, and $T4$ when 4. A discussion of the experimental design to test the behavioral difference follows after the examples.

3.1 Numerical examples with parameters adopted in the experiment

The following examples consider indirect utility functions satisfying Assumption 1. Further, we consider parameter values to construct $v_1(s)$ and $v_0(s)$ satisfying

$$v_1(\frac{1}{n}) < v_0(0) < \sum_{t=1}^{n} v_1(\frac{t}{n}),$$

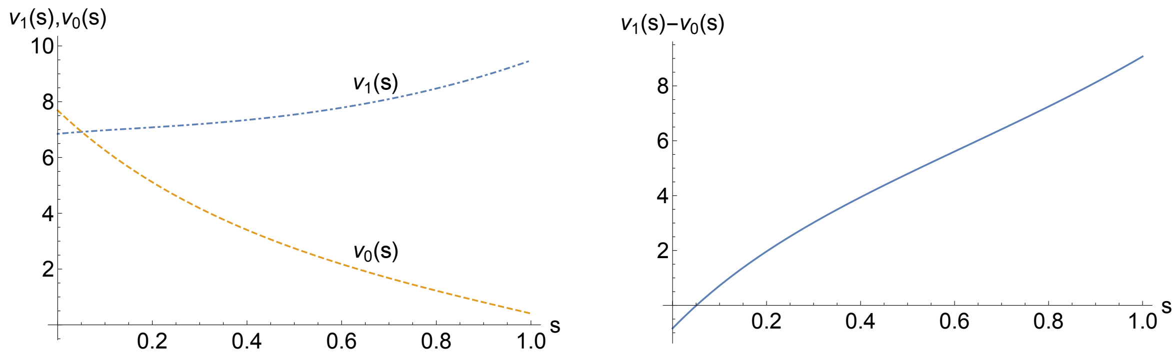
such that the unique equilibrium of MB is full agglomeration in region 0 (i.e., $s^n = 0$) and the unique MPE or a non-perfect equilibrium of FB is full agglomeration in region 1 (i.e., $s^n = 1$). We use the following parameter specifications to derive the indirect utility functions (equations (3), (4), and (5)):

$$(L_0 = 1, L_1 = 1.25, \alpha = 0.5, \beta_0 = 1.363, \beta_1 = 1.15, \sigma = 2, \tau_{01} = \tau_{10} = 2.55).$$

The indirect utility functions are illustrated in Figure 3a and the inter-regional difference in utility in Figure 3b. The examples differ in the number of players, i.e., the fraction of the population with migration opportunity at a period.

Example 2. (Treatment $T2$) Consider $n = 2$. The indirect utilities at various state values are given in Table 1 (where $n_i(s)$ refers to the number of players in region i at the state value s) The payoff functions satisfy the following condition:

$$v_1\left(\frac{1}{2}\right) < v_0(0) < \frac{v_1\left(\frac{1}{2}\right) + v_1(1)}{2}.$$



(a) Indirect-utility functions $v_0(s)$ and $v_1(s)$

(b) Utility difference: $v_1(s) - v_0(s)$

Figure 3: Indirect-utility functions and inter-regional difference in utility

Table 1: Payoff at different state values with $n = 2$

	$n_0(s)$	$v_0(s)$	$n_1(s)$	$v_1(s)$
$s = 0$	2	7.7	0	6.8
$s = 1/2$	1	2.7	1	7.5
$s = 1$	0	0.4	2	9.5

The next example considers the case with three players or groups.

Example 3. (Treatment $T3$) Consider $n = 3$. The indirect utilities at various state values are given in Table 2.

Table 2: Payoff at different state values with $n = 3$

	$n_0(s)$	$v_0(s)$	$n_1(s)$	$v_1(s)$
$s = 0$	3	7.7	0	6.8
$s = 1/3$	2	3.9	1	7.2
$s = 2/3$	1	1.8	2	8.0
$s = 1$	0	0.4	3	9.5

The payoff functions satisfy the following condition:

$$v_1\left(\frac{1}{3}\right) < v_0\left(0\right) < \frac{v_1\left(\frac{1}{3}\right) + v_1\left(\frac{2}{3}\right) + v_1\left(1\right)}{3}.$$

In the final example, we consider a population split in 4 groups, i.e. 4 players.

Example 4. (Treatment $T4$) Consider $n = 4$. The indirect utilities at various state values are given in Table 3.

The payoff functions satisfy the following condition:

$$v_1\left(\frac{1}{4}\right) < v_0\left(0\right) < \frac{v_1\left(\frac{1}{4}\right) + v_1\left(\frac{2}{4}\right) + v_1\left(\frac{3}{4}\right) + v_1\left(1\right)}{4}.$$

Table 3: Payoff at different state values with $n = 4$

	$n_0(s)$	$v_0(s)$	$n_1(s)$	$v_1(s)$
$s = 0$	4	7.7	0	6.8
$s = 1/4$	3	4.6	1	7.1
$s = 1/2$	2	2.7	2	7.5
$s = 3/4$	1	1.4	3	8.3
$s = 1$	0	0.4	4	9.5

3.2 Experimental design

The experiment was conducted at the Laboratorio de Economía Experimental (LEE) at Jaume I University (Spain). Experimental subjects gave their explicit informed consent to be included in the ORSEE database of LEE prior to being called to any session. The recruitment process of the laboratory was approved by the Deontology Commission of Jaume I University and subject data are stored following the data protection recommendations of the European Commission (GDPR, 2016).

The subjects were incentivized by earning real money depending on performance (paid in cash when leaving the lab): on average 24.40 euros, ranging from 13.60 to 42.70. The time spent in the lab was on average a little less than 2 hours. The experiment was implemented as a computerized laboratory experiment programmed using the standard software z-Tree (Fischbacher, 2007).

The experiment contains 3 different treatments, with controls for reasoning ability,[17] risk aversion,[18] and inequity aversion.[19] We will first give a general outline of the design and then turn to more details on the different treatments.

To keep the design clean, the treatments vary in one dimension only: the number of players (2, 3 or 4). Recall that, we denote treatments accordingly as $T2$, $T3$ and $T4$. $T2$ and $T3$ were run in November 2016 and $T4$ in March 2017. The baseline ($T2$) is described by low substituability (low σ) and 2 players, both initially in region 0 (none in region 1).

The theoretical prediction for all treatments is complete agglomeration in region 0 when behavior is strongly history dependent (HDB), more precisely when (MB_0) or (NPE_0) holds. The prediction is complete agglomeration in region 1 when behavior is strongly expectation dependent (EDB), more precisely when (FB_1) or (NPE_1) holds. Hence, the first outcome is inconsistent with MPE FB, whereas the second outcome is inconsistent with MB. Theoretical predictions

[17] Based on the reasoning ability scale of the Differential Aptitude Test. We use the Spanish version (Cordero and Corral, 2006): The 20 image series of the test are not programmed, they are presented on paper and only the answers are introduced within 20 minutes maximum time.

[18] The test by Sabater-Grande and Georgantzís (2002) was developed in our laboratory and is our standard measure of risk aversion. Using this test, Barreda-Tarrazona et al. (2011) obtain an estimate of a CRRA coefficient that is perfectly in line with the one estimated by Harrison et al. (2009) based on the more common Holt and Laury (2002) test.

[19] The Altruism scale (or inequity aversion test) consists of 4 situations that require an agent to sacrifice money to benefit another partner in a series of dictator like choices. The choices were taken from Charness and Rabin (2002).

were discussed in detail in Section 3.1.

In order to make the payoffs in the tables easy to compare for the subjects, we made a transformation with payoff equal to 200 x utility from the parametrized theoretical model minus 12.5. Payoff tables were made available to the subjects during the experiment and a comprehension test was run prior to the experiment in order to ensure that the task was fully understood.

We consider 20 independent observations per treatment variation a minimum for meaningful statistical inference. In the baseline treatment ($T2$), both players are initially in region 0. This calls for 40 subjects that play in either first or second position. $T3$ calls for 20 (independent observations) times 3 players per observation = 60 subjects. $T4$ requires another 80 subjects. With a pure between subject design, this implies 180 subjects in total playing a one-shot game.

In $T2$, the baseline treatment, the 40 subjects were randomly matched into 20 fixed pairs. In each pair, one subject was randomly designated as decision maker in the first period and the second subject left to make the decision in the second period.

In $T3$, the 60 subjects were randomly matched into 20 fixed triplets. To allow each subject to act as the single decision maker in each group in any period, the number of periods compared to the baseline treatment increased from 2 to 3.

In $T4$ we had 80 subjects randomly matched into 20 fixed quadruples. Each group played for 4 periods to let all subjects make decisions as they did in the previous treatments.

4 Results

In $T2$, only the first period decision matters for testing the EDB versus HDB hypotheses (see Table 4, first row). 17 out of 20 subjects (85 percent) decided in the first period to move to region 1, consistent with EDB (inconsistent with HDB). In the second period, in 2 out of the 3 pairs where the first period decision maker did choose to stay, the second period decision maker also made the decision to stay which is perfectly rational since payoff is 7.7 instead of 7.5 by moving. In one case, however, the second period decision maker made the decision to move.

In $T3$, as in the baseline treatment, the first period decision discriminates between EDB and HDB. But now, also the second period decision may discriminate between the two, provided the first-period decision in the group was consistent with HDB (see Table 4, second row). Just as in the baseline treatment, the last period decision is irrelevant for testing apart from discriminating between rational and irrational behavior. In the first period, 4 out of 20 subjects (20 percent) made the decision to stay in region 0, consistent with HDB. Comparing first round behavior to the baseline treatment, the increase from 15 to 20 percent is clearly not enough to be statistically significant (see Table 5). In the second period, conditional on first period decision to stay, a decision to stay is consistent with HDB and a decision to move consistent with EDB. The difference in payoff is small, but the decision context very simple. In all the 4 groups where the first period decision was to stay, the second period decision maker decided to move consistent with EDB. In the third period, rational behavior calls for a decision to move since at the beginning of this period there is at least already one subject in Region 1 (giving at least 8.0 by moving as opposed to maximum 3.9 by staying, according to Table 2). Again, there is one subject who fails to make the payoff maximizing decision.

In $T4$, unconditional discrimination between the two behavioral hypotheses is feasible in the first period as for all treatments. We may also compare second period decisions conditional on first period decisions consistent with HDB to $T3$. In $T4$, it may even be feasible to discriminate between HDB and EDB in the third period (see Table 4, row 3). Starting with the first period, now only 9 out of 20 decision makers chose to move. Hence, 11 out of 20 chose to stay consistent with HDB. This is up 30 percentage points compared to baseline and clearly significant (see Table 5). Is there any evidence for HDB also in the second period? In 2 out of the 11 groups with HDB in first period, the second period decision was also to stay consistent with HDB. Recall that in $T3$, none of the 4 groups with HDB in the first period exhibited second period HDB. Finally, in the third period, for 1 out of the 2 groups that were still agglomerated in region 0, the third period decision was to stay consistent with HDB.

Table 4: Decision to stay conditional on full agglomeration in region 0

Treatment	Period 1	Period 2	Period 3
$T2$	3/20		
$T3$	4/20	0/4	
$T4$	11/20	2/11	1/2

Note: Number of decision makers in each period is 20 in each treatment. In total 60 in period 1, 60 in period 2, 40 in period 3 ($T3$ and $T4$) and 20 in period 4 ($T4$). Only period 1 is relevant for discriminating between HDB and EDB in $T2$, period 1 and 2 are relevant for $T3$, and all periods except period 4 for $T4$. Only period 1 is relevant for all treatments.

Table 5: Treatment differences first period migration decisions

	T2	T4
$T3$	$p = 1.000$	$p = 0.048$
$T4$	$p = 0.018$	

Note: N=20 in each treatment. Wilcoxon signed rank tests (Mann Whitney U tests). The p-values have been Bonferroni corrected for multiple comparisons by multiplying by 2. The distribution of Period 1 migration decisions in the $T3$ treatment is not significantly different from the $T2$ baseline treatment, the $T4$ is (at the 2 percent level). $T3$ is significantly different from $T4$ (at the 5 percent level).

We now concentrate on the first period where the decision can be used to discriminate between HDB and EDB across all treatments. We start by asking if the first-period decision-makers are different across treatments in terms of background variables and the incentivized test results. Could difference in behavior in $T4$ compared to $T3$ and $T2$, be explained by an atypical sample of subjects? The answer is negative. Background variables are not too dissimilar across treatments, as can be seen from Table 6 (age, gender, laboratory experience, start of major, and standards of living). Neither is there any reason for concern regarding the test results (see Table 7).

Table 6: Subject characteristics for first period decision makers by treatment

Treatment	N	Age	Female Proportion	Lab experience	Start major	Standards of living
$T2$	20	21.80	0.45	2.75	2014	2.00
$T3$	20	22.45	0.30	2.50	2014	2.45
$T4$	20	22.55	0.55	2.80	2013	2.40

Note: Means. Lab experience measured from 1=no experience to 5=more than 9 times (3 is 4-6 times and 2 is 1-3 times). Living standards measured from 1=affluent to 4=very poor (2 is acceptable conditions and 3 is non- acceptable but slightly better than 4).

Table 7: Incentivized controls first period decision makers by treatment

Treatment	N	Cognitive ability	Risk aversion	Inequity aversion 1 (IA1)	Inequity aversion 2 (IA2)
$T2$	20	5.0	4.2	1.4	1.4
$T3$	20	4.5	3.3	1.5	1.4
$T4$	20	4.9	4.7	1.6	1.4

Note: Means. Cognitive ability is measured by the profit earned from solving the 40 tasks of the Differential Aptitude Test. Risk aversion is measured by a scale based on the four items used by Sabater-Grande and Georgantzís (2002) - a higher number implies higher risk aversion. Inequity aversion is based on the four items used by Charness and Rabin (2002). IA1 for the two first items (averse against getting less than the others) and IA2 for the last two (averse against getting more than the others).

In order to probe deeper into the possible effect of background variables and incentivized test results on the first period decision, we also did a regression analysis. Results are presented in Table 8. The results for the two tests for Inequity Aversion (IA1 interpreted as a measure of envy and IA2 interpreted as a measure of fairness) were clearly correlated (Spearman's rank correlation coefficient equal to 0.463 with p-value=0.000). We therefore integrated the two into one measure when we did the regressions.

In the logit regression pooled over treatments, we observe a very significant (at the 1 percent level) negative effect of the most complex Treatment 4 on the likelihood of first period decision makers to actually choose to move. In fact, the dummy variable for $T4$ is the only significant variable on the 5 percent level as we can observe from first column in Table 8.

Analyzing the drivers of the first mover decisions in $T4$, we observe from the second column in

Table 8 that both cognitive ability and economics background increase the likelihood of moving.

In short, our regression analysis confirms the result obtained in the Wilcoxon signed rank tests: The increase in the number of players is the main identifiable driver of the increase in HDB among treatments.

Table 8: Regressing decision by first period decision makers on treatments, incentivized controls and background variables

Dependent variable: Move	All treatments (N=60)	T4 (N=20)
$T3$	−0.725(0.98)	
$T4$	**−2.921*****(0.92)	
Altruism Scale	0.770*(0.41)	4.516(2.80)
Risk aversion Scale	−0.054(0.38)	0.645(2.47)
Cognitive ability	0.060(0.06)	**0.393****(0.16)
Female	0.521(0.72)	0.638(3.13)
Age	0.224(0.22)	0.092(0.18)
Economics Major	0.409(0.83)	**7.147****(3.03)
Lab Experience	−0.216(0.29)	−0.933*(0.49)
Financial Situation	0.028(0.43)	−0.950(1.06)
Constant	−4.118(4.57)	−14.855(8.30)
R-squared	0.21	0.48

Note: Logit Regressions for first period decision makers for all treatments (left) and for T4 only. Entries are coefficient estimates with robust standard errors . *** p<0.01, ** p<0.05, * p<0.1. $T2$ is left out in the pooled regression and will be picked up by the constant term. R-square for logit is a pseudo R-square.

5 Concluding remarks

In this paper, we study migration dynamics in the Core-Periphery model of New Economic Geography. More specifically, we look at history-driven behavior (HDB) versus expectation-driven behavior (EDB). By implication, we also shed light on myopic behavior and forward-looking behavior.[20] We use the analytically tractable elaboration by Forslid and Ottaviano (2003) of the original Core-Periphery model (Krugman, 1991b) as basis for developing a game theoretical framework adapted to experimental analysis.

The paper contributes to the literature in several important ways: The first contribution lies in adapting the Core-Periphery model to experimental testing (Section 2 and Appendix A). To do so, we introduce a group-based migration process in the standard New Economic Geography framework and proceed by operating with a finite number of agents reflecting that the number of subjects in the laboratory is always finite. We also introduce sufficient asymmetry to make

[20]EDB is shown to be inconsistent with myopic behavior and HDB inconsistent with Markov-perfect equilibrium forward looking behavior.

locations different with complete agglomeration in order to make places clearly distinctive for potential migrants. Our theoretical findings show that the outcome of the migration game can be different based on whether agents follow HDB or EDB.

The second contribution lies in testing the model predictions by designing and running a framed experiment that closely captures the migration incentives considered in our theoretical study (Section 3 and 4, and Appendix B). Our experimental findings show that EDB is less likely to prevail with a large number of participants in the migration game. More specifically, we find behavior consistent with EDB in treatments with 2 and 3 players ($T2$ and $T3$). However with 4 players ($T4$) a majority retreat to behavior consistent with HDB. It therefore seems that it does not take much complexity to reach a threshold where history becomes more important than expectations from a behavioral perspective.

Is HDB in our experiment likely due to myopic behavior or something else? At least two arguments could be suggested against myopic behavior. First, agents' behavior can be consistent with some non-perfect equilibrium with forward looking behavior. Specifically, in one of the non-Markov Perfect Equilibria, staying is an equilibrium on the belief that all are staying and in such a case, staying may therefore have nothing to do with myopic behavior. This is true, but then we may ask why subjects in the last treatment ($T4$) should have this belief and not the subjects in the other two treatments ($T2$ and $T3$)? The second argument could be that subjects have preferences not reflected in the theoretical model where only real wage differences are assumed to matter. But this also raises questions. We have tested for several incentivized controls (e.g., inequity aversion and risk aversion) without finding notable differences between subjects. We have therefore no indication that the subjects in the last treatment should have different preferences than the subjects in the first two treatments. Moreover, we find that higher reasoning ability significantly decreases the likelihood of behaving in a way consistent with HDB in the most complex treatment.

Number effects, similar to what we find, have also been found in other game theory experiments. Studying experimental oligopolies, Huck et al. (2004), using a neutral frame, find collusion in simultaneous games with 2 and 3 agents, but market outcomes at Cournot or above in games with 4 and more agents. Closer to our experiment, Dufwenberg and van Essen (2018) find behavior consistent with backward induction in a sequential game with two agents, but not when the number of agents is increased to 3 or 4. We may therefore ask if the number effect found in these very different settings could be the result of a more general phenomenon that could be revealed through additional experimental work.

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Appendix

A Proofs of propositions in the theoretical analysis

Proof of Proposition 1

Proof. The proof follows the standard techniques used in characterizing the equilibria of typical CP models. For notational convenience, in this proof, we will generically use x_i to refer to the size of the skilled workers in region $i \in \{0, 1\}$. For a given s, $x_0 = 1 - s$ and $x_1 = s$. Let p_i^A denote the price of the traditional good in sector $i \in \{0, 1\}$. The assumption of perfect competition in the traditional sector implies marginal cost pricing so that the price equals the wage of an unskilled worker. Further, the assumption of free trade of the traditional good implies that prices are the same between the regions. Without loss of generality, we consider the traditional good as numeraire, so that $p_i^A = w_i = 1$ for $i \in \{0, 1\}$. We let $p_{ij}(q)$ denote the price of a variety q of the modern good D, which is produced in region j but sold in region i. Given the CES-type demand by residents in region i, we can write the CES price index P_i in region i as

$$P_i = \left[\int_0^{n_i} p_{ii}(q)^{1-\sigma} dq + \int_0^{n_j} p_{ji}(q)^{1-\sigma} dq \right]^{\frac{1}{1-\sigma}}. \tag{A.1}$$

An individual consumer in region i has income m_i, which equals r_i if she is a skilled worker or 1 if she is an unskilled worker. The total income in region i as $M_i = x_i r_i + L_i$. An individual consumer maximizes her utility, given by (1), subject to the budget constraint $\int_0^{n_i} p_{ii}(q) d_{ii}(q) dq +$

$\int_0^{n_j} p_{ji}(q)d_{ji}(q)dq + A_i = m_i$. The solution of the utility-maximization problem gives the following individual demand:

$$d_{ji}(q) = \frac{p_{ji}(q)^{-\sigma}}{P_i^{1-\sigma}}\alpha m_i, \;\; A_i = (1-\alpha)m_i, \quad\; i,j \in \{0,1\}. \tag{A.2}$$

The CES composite D_i of the modern varieties is

$$\begin{aligned} D_i &= \alpha m_i \left[\int_0^{n_i} d_{ii}(q)^{\frac{\sigma-1}{\sigma}} dq + \int_0^{n_j} d_{ji}(q)^{\frac{\sigma-1}{\sigma}} dq\right]^{\frac{\sigma}{\sigma-1}} \\ &= \frac{\alpha m_i}{P_i^{1-\sigma}} \left[\int_0^{n_i} (p_{ii}(q)^{-\sigma})^{\frac{\sigma-1}{\sigma}} dq + \int_0^{n_j} (p_{ji}(q)^{-\sigma})^{\frac{\sigma-1}{\sigma}} dq\right]^{\frac{\sigma}{\sigma-1}} \\ &= \frac{\alpha m_i P_i^{-\sigma}}{P_i^{1-\sigma}} = \frac{\alpha m_i}{P_i} \end{aligned}$$

Therefore, the indirect utility of a skilled worker with income $m_i = r_i$ is

$$v_i(s) = \alpha \ln\left(\alpha \frac{r_i}{P_i}\right) + (1-\alpha)\ln\left((1-\alpha)r_i\right). \tag{A.3}$$

After simplifying, the inter-regional difference in utility can be expressed as

$$v_1(s) - v_0(s) = \ln\left(\frac{r_1}{r_0}\right) - \alpha \ln\left(\frac{P_1}{P_0}\right) \tag{A.4}$$

We next solve the producer's problem to find the equilibrium price index. Aggregating individual demand (A.2), we write the aggregate demand function of a variety q, which is consumed in region $i = 0, 1$ and produced in region $j = 0, 1$, as

$$y_{ji}(q) = \frac{p_{ji}(q)^{-\sigma}}{P_i^{1-\sigma}}\alpha M_i, \qquad i,j \in \{0,1\}. \tag{A.5}$$

A manufacturing firm, which is located in region i and produces the modern-good variety q, maximizes profit:

$$\Pi_i(q) = p_{ii}(q)y_{ii}(q) + p_{ij}(q)y_{ij}(q) - \beta_i\left[y_{ii}(q) + \tau_{ij}y_{ij}(q)\right] - r_i. \tag{A.6}$$

Using (A.5), maximization of (A.6) yields the equilibrium prices:

$$p_{ii}(q) = \frac{\beta_i\sigma}{\sigma-1}, \quad\; p_{ij}(q) = \frac{\beta_i\tau_{ij}\sigma}{\sigma-1}, \qquad i,j \in \{0,1\}. \tag{A.7}$$

The CES price index (A.1) is then given by $P_i = \frac{\sigma}{\sigma-1}\left[n_i\beta_i^{1-\sigma} + \rho_i n_j \beta_j^{1-\sigma}\right]^{\frac{1}{1-\sigma}}$. As production of each variety requires one skilled worker, we have $n_i = x_i$, and so we can write the price index as

$$P_i = \frac{\sigma}{\sigma-1}\left[x_i\beta_i^{1-\sigma} + \rho_i x_j \beta_j^{1-\sigma}\right]^{\frac{1}{1-\sigma}}. \tag{A.8}$$

Next, we solve for the equilibrium wage of a skilled worker. The assumption of free entry and exit implies that the revenue equals the wage bill. Using (A.6), we derive[21]

$$\begin{aligned}
r_i &= p_{ii}y_{ii} + p_{ij}y_{ij} - \beta_i\left[y_{ii} + \tau_{ij}y_{ij}\right] \\
&= \alpha\left[\frac{p_{ii}^{1-\sigma}M_i}{P_i^{1-\sigma}} + \frac{p_{ij}^{1-\sigma}M_j}{P_j^{1-\sigma}}\right] - \alpha\beta_i\left[\frac{p_{ii}^{-\sigma}M_i}{P_i^{1-\sigma}} + \tau_{ij}\frac{p_{ij}^{-\sigma}M_j}{P_j^{1-\sigma}}\right] \\
&= \alpha\left[\frac{p_{ii}^{1-\sigma}M_i}{P_i^{1-\sigma}} + \frac{p_{ij}^{1-\sigma}M_j}{P_j^{1-\sigma}}\right] - \alpha\left[\frac{\beta_i}{p_{ii}}\frac{p_{ii}^{1-\sigma}M_i}{P_i^{1-\sigma}} + \frac{\beta_i\tau_{ij}}{p_{ij}}\frac{p_{ij}^{1-\sigma}M_j}{P_j^{1-\sigma}}\right] \\
&= \alpha\left(1 - \frac{\sigma-1}{\sigma}\right)\left[\frac{p_{ii}^{1-\sigma}M_i}{P_i^{1-\sigma}} + \frac{p_{ij}^{1-\sigma}M_j}{P_j^{1-\sigma}}\right] \\
&= \frac{\alpha}{\sigma}\left[\frac{\beta_i^{1-\sigma}M_i}{x_i\beta_i^{1-\sigma} + \rho_i x_j\beta_j^{1-\sigma}} + \frac{\beta_i^{1-\sigma}\rho_j M_j}{x_j\beta_j^{1-\sigma} + \rho_j x_i\beta_i^{1-\sigma}}\right]
\end{aligned} \tag{A.9}$$

As the aggregate income M_i, which is $x_i r_i + L_i$, is a function of r_i, (A.9) gives us a system of equations for $i = 0, 1$, that can be simultaneously solved to find r_0 and r_1. Defining $a_i := \dfrac{\alpha\beta_i^{1-\sigma}}{\sigma\left[x_i\beta_i^{1-\sigma} + \rho_i x_j\beta_j^{1-\sigma}\right]}$ and $b_i := \dfrac{\alpha\beta_i^{1-\sigma}\rho_j}{\sigma\left[x_j\beta_j^{1-\sigma} + \rho_j x_i\beta_i^{1-\sigma}\right]}$, we can write the system of equations as

$$\begin{aligned}
r_1 &= a_1x_1r_1 + b_1x_0r_0 + a_1L_1 + b_1L_0, \\
r_0 &= a_0x_0r_0 + b_0x_1r_1 + a_0L_0 + b_0L_1.
\end{aligned} \tag{A.10}$$

Solving (A.10), we find

$$\begin{aligned}
r_1 &= \frac{a_1L_1 + b_1L_0 - L_1x_0\left(a_0a_1 - b_0b_1\right)}{1 - a_0x_0 - a_1x_1 + x_0x_1\left(a_0a_1 - b_0b_1\right)}, \\
r_0 &= \frac{a_0L_0 + b_0L_1 - L_0x_1\left(a_0a_1 - b_0b_1\right)}{1 - a_0x_0 - a_1x_1 + x_0x_1\left(a_0a_1 - b_0b_1\right)}.
\end{aligned} \tag{A.11}$$

[21]For notational simplicity, we suppress the functional argument indicating variety q in the expressions of price and quantity.

Further, using (A.8) and (A.11), we can express the inter-regional difference in utility (A.4) as

$$v_1(s) - v_0(s) = \ln\left(\frac{a_1 L_1 + b_1 L_0 - L_1 x_0 (a_0 a_1 - b_0 b_1)}{a_0 L_0 + b_0 L_1 - L_0 x_1 (a_0 a_1 - b_0 b_1)}\right) + \frac{\alpha}{\sigma - 1} \ln\left(\frac{x_1 \beta_1^{1-\sigma} + \rho_1 x_0 \beta_0^{1-\sigma}}{x_0 \beta_0^{1-\sigma} + \rho_0 x_1 \beta_1^{1-\sigma}}\right), \tag{A.12}$$

which is the functional form of the inter-regional payoff difference in (6). □

Proof of Lemma 1

Proof. We prove by backward induction. Consider player n. Since player n's strategy must be optimal for any state s in period n, she migrates to 1 if and only if $v_1(s + \frac{1}{n}) > v_0(s)$. By Assumption 1, the optimal strategy is indeed a threshold strategy. Further, $\overline{s}_n$, the state value at which she is indifferent between migration or not, is the unique solution of $v_1(s + \frac{1}{n}) = v_0(s)$.

Folding back, we consider player $n-1$. At $\overline{s}_{n-1}$ (will show below that it is uniquely defined), she is indifferent between migrating to region 1 and staying back in region 0. First, consider the possibility that $\overline{s}_{n-1} < \overline{s}_n - \frac{1}{n}$. Then, her payoff from migration at $s = \overline{s}_{n-1}$ is $2v_1(s+\frac{1}{n})$; because she expects player n will not migrate in the following period as $\overline{s}_n > \overline{s}_{n-1} + \frac{1}{n}$. On the other hand, her payoff from staying back is $2v_0(s)$. Therefore, $\overline{s}_{n-1}$ must satisfy $2v_1(s + \frac{1}{n}) = 2v_0(s)$, which, given Assumption 1, contradicts the fact that $\overline{s}_n$ is the unique solution of the same equation and we have considered $\overline{s}_{n-1} < \overline{s}_n - \frac{1}{n}$.

Hence, $\overline{s}_{n-1} \geq \overline{s}_n - \frac{1}{n}$. In this case, at $s = \overline{s}_{n-1}$, player $n-1$ gets $v_1(s + \frac{1}{n}) + v_1(s + \frac{2}{n})$ by migration, and gets $2v_0(s)$ by staying back. Therefore, she migrates if $v_1(s + \frac{1}{n}) + v_1(s + \frac{2}{n}) > 2v_0(s)$. By Assumption 1, the optimal strategy is indeed a threshold strategy and $\overline{s}_{n-1}$ uniquely solves $v_1(s+\frac{1}{n}) + v_1(s+\frac{2}{n}) = 2v_0(s)$. Further, $\overline{s}_{n-1} < \overline{s}_n$, since at $s = \overline{s}_n$, $v_1(s+\frac{1}{n}) + v_1(s+\frac{2}{n}) = v_0(s) + v_1(s + \frac{2}{n}) > 2v_0(s)$ by Assumption 1.

Next, consider player i and assume that the lemma holds for all $k \in \{i+1, \ldots, n\}$. At $\overline{s}_i$, she is indifferent between migrating and staying. If $\overline{s}_i < \overline{s}_{i+1} - \frac{1}{n}$, then her payoff from migration at $s = \overline{s}_i$ is $(n-i+1)v_1(s + \frac{1}{n})$; because she expects no player will migrate in the following periods as $\overline{s}_n > \ldots > \overline{s}_{i+1} > \overline{s}_i + \frac{1}{n}$. On the other hand, her payoff from staying back is $(n-i+1)v_0(s)$. Therefore, $\overline{s}_i$ must satisfy $v_1(s + \frac{1}{n}) = v_0(s)$, which leads to a contraction because of Assumption 1 and the fact that $\overline{s}_n$ is the unique solution of the same equation.

Hence, we must have $\overline{s}_i \geq \overline{s}_{i+1} - \frac{1}{n}$. Then, at $s = \overline{s}_i$, player i gets $v_1(s+\frac{1}{n}) + \ldots + v_1(s+\frac{n-i+1}{n})$ by migration, and gets $(n-i+1)v_0(s)$ by staying back. Therefore, she migrates if $\sum_{t=1}^{n-i+1} v_1(s + \frac{t}{n}) > (n-i+1)v_0(s)$. By Assumption 1, the optimal strategy is indeed a threshold strategy and $\overline{s}_i$ uniquely solves $\frac{1}{n-i+1}\sum_{t=1}^{n-i+1} v_1(s + \frac{t}{n}) = v_0(s)$. Further, $\overline{s}_i < \overline{s}_{i+1}$, since at $s = \overline{s}_{i+1}$, $\frac{1}{n-i+1}\sum_{t=1}^{n-i+1} v_1(s+\frac{t}{n}) > v_0(s)$ by Assumption 1. By the logic of induction, the lemma, therefore, holds true for all $i \in \{1, \ldots, n\}$. □

Proof of Lemma 2

Proof. At the beginning of period i, the state value is s^{i-1} and player i decides whether or not to migrate. Suppose that player i migrates. Therefore, $s^{i-1} > \overline{s}_i$ by Lemma (1), and $s^i = s^{i-1} + \frac{1}{n}$. Together, $s^i > \overline{s}_i + \frac{1}{n} \geq \overline{s}_{i+1}$. The last inequality follows since $\overline{s}_{i+1} - \frac{1}{n} \leq \overline{s}_i$, by Lemma (1). $s^i > \overline{s}_{i+1} \Rightarrow$ player $i+1$ migrates. Next, suppose player i does not migrate. Therefore, $s^{i-1} \leq \overline{s}_i$ by Lemma (1), and $s^i = s^{i-1}$. Together, $s^i \leq \overline{s}_i \leq \overline{s}_{i+1}$. The last inequality follows from Lemma (1). $s^i \leq \overline{s}_{i+1} \Rightarrow$ player $i+1$ does not migrate. □

Proof of Lemma 3

Proof. Note that to prove the lemma, it is sufficient to show that in any equilibrium in Markov strategy, it is not possible to have $s^n = k$ for some $k \in \{\frac{1}{n}, \dots, \frac{n-1}{n}\}$. We prove it by contradiction. Suppose, if possible, $s^n = k$ for $k \in \{\frac{1}{n}, \dots, \frac{n-1}{n}\}$. Let A_0 and A_1 denote the sets of players taking action 0 and action 1 respectively. Observe that if $s^n = k$ for $k \in \{\frac{1}{n}, \dots, \frac{n-1}{n}\}$, then both A_0 and A_1 are non-empty sets. Therefore, there must be at least one pair of consecutive players who take different actions. Let $(j, j+1), j \in \{1, \dots, n-1\}$ be the last of such pairs with different actions. Two possibilities can arise – case (i): $j \in A_1$ and all $j+1, \dots, n \in A_0$, and case (ii): $j \in A_0$ and all $j+1, \dots, n \in A_1$.

First, consider case (i). Given that $s^n = k$, $n \in A_0$ implies

$$v_0(\frac{k}{n}) \geq v_1(\frac{k+1}{n}). \tag{A.13}$$

Further, since j is the last player to take action 1, it implies that $(n-j+1)v_1(\frac{k}{n}) > (n-j+1)v_0(\frac{k-1}{n})$, or equivalently, $v_1(\frac{k}{n}) > v_0(\frac{k-1}{n})$. Then, by Assumption 1,

$$v_1(\frac{k+1}{n}) > v_1(\frac{k}{n}) > v_0(\frac{k-1}{n}) > v_0(\frac{k}{n}), \tag{A.14}$$

which contradicts (A.13), and so, case (i) is not a feasible scenario.

Next, consider case (ii): Given that $s^n = k$,

$$\begin{aligned}
n \in A_1 &\Rightarrow v_1(\frac{k}{n}) > v_0(\frac{k-1}{n}) \\
n-1 \in A_1 &\Rightarrow v_1(\frac{k-1}{n}) + v_1(\frac{k}{n}) > v_0(\frac{k-2}{n}) + v_0(\frac{k-1}{n}) \\
&\vdots \\
j+1 \in A_1 &\Rightarrow \sum_{i=k-n+j+1}^{k} v_1(\frac{i}{n}) > \sum_{i=k-n+j}^{k-1} v_0(\frac{i}{n})
\end{aligned} \tag{A.15}$$

Now, as j is the last player to take action 0, j finds the state at the beginning of period j to be $k-n+j$ (since she does not migrate and the following $n-j$ players migrate to make the terminal state to be k), and j's decision not to migrate would be optimal if

$$\sum_{i=k-n+j}^{k} v_0(\frac{i}{n}) > \sum_{i=k-n+j+1}^{k+1} v_1(\frac{i}{n}). \tag{A.16}$$

The right-hand-side of (A.16) can be written as $\sum_{i=k-n+j+1}^{k} v_1(\frac{i}{n})+v_1(\frac{k+1}{n})$ and the left-hand-side of (A.16) can be written as $\sum_{i=k-n+j}^{k-1} v_0(\frac{i}{n}) + v_0(\frac{k}{n})$. By Assumption 1 and (A.15),

$$v_1(\frac{k+1}{n}) > v_1(\frac{k}{n}) > v_0(\frac{k-1}{n}) > v_0(\frac{k}{n}),$$

and by (A.15), $\sum_{i=k-n+j+1}^{k} v_1(\frac{i}{n}) > \sum_{i=k-n+j}^{k-1} v_0(\frac{i}{n})$. Together, we get that the right-hand-side of (A.16) is greater than the left-hand-side of (A.16), which contradicts (A.16), and so, case (ii) is not a feasible scenario as well. We thus rule out all possibilities that can arise if $s^n = k$ for some $k \in \{\frac{1}{n}, \ldots, \frac{n-1}{n}\}$. Hence, we must have $s^n = 0$ or $s^n = 1$, in which case, either $a^i = 0$ for all $i \in \{1, \ldots, n\}$, or, $a^i = 1$ for all $i \in \{1, \ldots, n\}$. This completes the proof. □

B Instructions for the experiment

Experimental Instructions T4 (Translated from Spanish)

Welcome to the LEE. We are carrying out a research project on economic decision making. If you carefully follow the instructions and take good decisions you can earn a considerable amount of money. Your gains will be personally communicated to you and they will be paid in cash right at the end of the session. Your data will be confidentially treated and they will not be used for any purpose alien to this project. Your name will never be associated to your decisions when the results are published. Communication with other participants in the session will lead to immediate experiment termination for those participants breaching the rule. At the beginning of the session you will be assigned to a group with three other participants. You will never discover the identity of the other members of your group, as they also will never discover yours. The game will last four periods and it will not be repeated. Before the start of the paid periods you will answer a comprehension test about the instructions in your computer.

The Regions

There are 2 different regions regarding the wage (in experimental units) that they offer. The wage depends on the number of participants belonging to your group that there are in each region:

In each of the four periods that the game lasts you will get the wage corresponding to the region in which you are at the moment, which will be calculated depending on where the other three group members are. At the end of the session you will get in cash 0.55 euros for each experimental unit accumulated after the four periods.

Participants in region 0	Participants in region 1	Wage region 0	Wage region 1
4	0	7.7	6.8
3	1	4.6	7.1
2	2	2.7	7.5
1	3	1.4	8.3
0	4	0.4	9.5

In the upper region of the screen you will be shown in red colour information about how many participants of your group there are in that moment in each region.

Your Decision

You are now in region 0, as the other three members of your group. In each one of the four periods of the game, one member of your group will have to decide whether he or she prefers to remain in region 0 or move to region 1. The order of the decision will be random and will be determined at the beginning of the session. The participant who has to decide in a given perido will know the number of group members that there are in each region in that moment.

The Information

At the end of each period you will be informed about how many participants of your group there are in each region and which wage do get in this period those who are in each region, including yourself. You will also be reminded about the accumulated gains up to that moment.

Experimental Instructions T4 (Original in Spanish)

Bienvenido al LEE. Estamos realizando un proyecto de investigación sobre la toma de decisiones económicas. Si sigues cuidadosamente las instrucciones y tomas decisiones acertadas puedes ganar una considerable cantidad de dinero. Tus ganancias se te comunicarán personalmente y se te pagarán en efectivo al final de la sesión. Tus datos se tratarán de modo confidencial y no se utilizarán para fines ajenos a este proyecto. Tu nombre nunca se verá asociado a ninguna de tus decisiones cuando se publiquen los resultados. La comunicación con otros participantes en la sesión supondría la automática finalización de la misma sin ninguna ganancia para los participantes que infrinjan esta regla. Al inicio de la sesión serás asignado a un grupo con otros 3 participantes. No conocerás la identidad de los otros miembros de tu grupo como tampoco ellos conocerán la tuya. El juego durará cuatro periodos y no se repetirá. Antes de iniciar los periodos pagados realizarás un test de comprensión de las instrucciones en tu ordenador.

Las Regiones

Existen 2 regiones distintas en cuanto al salario (en unidades experimentales) que ofrecen. Dicho salario depende del número de participantes de tu grupo que haya en cada una de ellas:

Participantes en región 0	Participantes en región 1	Salario región 0	Salario región 1
4	0	7.7	6.8
3	1	4.6	7.1
2	2	2.7	7.5
1	3	1.4	8.3
0	4	0.4	9.5

En cada uno de los cuatro periodos que dura el juego recibirás el salario que te corresponda según la región en la que te encuentres y según dónde estén los otros tres miembros de tu grupo. Al finalizar la sesión se te pagará en efectivo 0.55 euros por cada unidad experimental que hayas acumulado en los cuatro periodos.

En la parte superior de la pantalla te aparecerá en rojo la información acerca de cuántos participantes de tu grupo se encuentran en ese momento en cada región.

Tu Decisión

Estás actualmente en la región 0, al igual que los otros tres miembros de tu grupo. En cada uno de los cuatro periodos del juego, un miembro de tu grupo habrá de decidir si desea permanecer en la región 0 o moverse a la región 1. El orden de las decisiones será aleatorio y se determinará al inicio de la sesión. El participante que deba decidir en un determinado periodo conocerá el número de miembros del grupo que hay en cada región en ese momento.

La Información

Al final de cada periodo se te informará de cuántos participantes de tu grupo hay en cada región y cuánto cobra en ese periodo quien esté en cada región y tú mismo. También se te recuerda las ganancias acumuladas hasta ese momento.