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# Three essays on the economics of social integration in an urban context

Lucie Letrouit

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# École des Hautes Études en Sciences Sociales

École doctorale n° 465 Économie Panthéon Sorbonne

Paris-Jourdan Sciences Économiques

DOCTORAT

Discipline: Analyse et Politique Économiques

**LUCIE LETROUIT**

## **Trois essais en économie de l'intégration sociale en contexte urbain**

**Thèse dirigée par : Thierry VERDIER et Miren LAFOURCADE**

**Date de soutenance : le 10 décembre 2020**

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# École des Hautes Études en Sciences Sociales

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PHD THESIS

Discipline: Economics

**LUCIE LETROUIT**

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**Thesis supervised by:** Thierry VERDIER and Miren LAFOURCADE

**Date of defense:** December 10, 2020

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Lucie LETROUIT

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# Summary

Social norms play a crucial role in shaping the functioning of markets and economic behaviors, notably in urban contexts by affecting location choices, trust between land buyers and sellers, and the productivity of interactions between individuals. This dissertation consists in three essays dealing with the complex nexus between social factors and economic outcomes.

The first essay proposes an evolutionary coordination game model on the emergence of ethno-cultural hierarchies in multi-cultural countries. In this multi-group multi-strategy model, hierarchies emerge through independent interactions between members of different ethno-cultural groups, whose “strategies” are their hierarchy views. Interactions between individuals who hold a same hierarchy view are more productive than interactions between disagreeing individuals. When individuals agree on an inegalitarian hierarchy view, the member of the dominant group obtains a higher payoff than the member of the dominated group. From time to time, individuals can change their hierarchy view, occasionally making “mistakes”. Hierarchy views in the population therefore evolve through time, eventually converging towards a common long-term hierarchy. The model predicts, consistently with empirical evidence from the literature, that societies with small ethno-cultural minorities tend to adopt inegalitarian hierarchy views in which minorities face different degrees of discrimination. It further suggests that an increase in the size of a minority may improve the minority’s status or hurt it, depending on its relative size with respect to the other ethno-cultural groups. Forces towards the fragmentation of minorities are also shown to exist, as the splitting of a minority, despite always being detrimental to the smallest new minority formed, may improve the status of the largest new one. Eventually, in a very simple extension of the model, it is shown that, if interactions between individuals holding equal statuses are more productive than interactions between unequal individuals, multi-cultural societies generally evolve towards inefficiently inegalitarian hierarchy views. This model is, to the best of my knowledge, the first to provide a comprehensive mechanism for the emergence of ethno-cultural hierarchies, in which both the majority’s and the different minorities’ incentives are taken into account, and the first to rely on the theoretical analysis of a parametric multi-group and multi-strategy ( $3 \times 4$ ) asymmetric evolutionary game model using graph theory.

The second essay, co-written with Harris Selod, Senior Economist at the World Bank, re-



lies on an urban economics model to study the land market failures associated with land tenure insecurity and information asymmetry in West African cities, as well as the role of trusted kinship and land registration in alleviating these failures. The model shows that land tenure insecurity and information asymmetry impede the development of cities. However, when buyers and sellers of land plots can pair along trusted kinship lines whereby deception (i.e., the nondisclosure by a seller of competing claims on a land plot) is socially penalized, information asymmetry is attenuated and overall participation in land markets, though still inefficiently small, is improved. When introducing, instead, a registration system which allows owners to pay to register their land plots in a cadaster and thus make them secure, both information asymmetry and tenure insecurity are reduced and overall market participation is improved, even so limited by registration costs. In a hybrid model where both trusted relationships and land registration are simultaneously available to residents, we show that matching along trusted kinship lines can partially substitute for costly registration and predict that economies will gradually shift towards the socially preferable registration system if registration costs can be sufficiently reduced.

The third essay, co-written with Florence Goffette-Nagot (CNRS-GATE) and Sylvain Charreton (Paris-Est Créteil University) consists in the empirical evaluation of an urban renewal program aimed at reducing geographical disparities and social polarization within cities by improving living conditions in deprived neighborhoods. The very large-scale urban renewal program under study, the PNRU (Programme National pour la Rénovation Urbaine), was launched in 2004 for the renovation of around 600 neighborhoods throughout the French territory, with a total budget of €47 billions. Relying on De Chaisemartin and D'Haultfœuille (forthcoming)'s methodology as well as on a classical difference-in-differences strategy, we find no significant effect of the program on the value of housing at the aggregate level of France, suggesting that the increase in prices was, in any case, comprised between zero and 3.5%. We do not find any significant effect of the program on the volume of transactions either. However, we do find that the program led to a positive shift in the socio-professional categories of housing buyers with respect to sellers, suggesting a sensible increase in renovated neighborhoods' attractiveness.

**Field:** Economics

**Keywords:** Housing and land markets, social norms, public policy evaluation, ethno-cultural relationships

# Résumé

Les normes sociales ont une influence importante sur le fonctionnement des marchés et des comportements économiques, notamment en contexte urbain en affectant les choix de localisation, le niveau de confiance entre vendeurs et acheteurs de terrains et la productivité des interactions entre individus. Cette dissertation de thèse se compose de trois articles portant sur le lien complexe entre facteurs sociaux et conséquences économiques.

Le premier article propose un modèle de théorie des jeux évolutionnaires sur l'émergence des hiérarchies ethno-culturelles dans un contexte multi-culturel. Dans ce modèle de coordination multi-groupes et multi-stratégies, les hiérarchies émergent par le biais d'interactions indépendantes entre les membres des différents groupes ethno-culturels. La "stratégie" d'un individu correspond à sa conception de la hiérarchie ethno-culturelle. Les interactions entre deux individus dont les conceptions hiérarchiques concordent sont plus productives qu'en cas de désaccord. Lors d'une interaction, si les deux individus concernés ont une même vision hiérarchique égalitaire (i.e. dans laquelle leurs deux groupes ont des statuts semblables), alors tous deux obtiennent le même bénéfice. Si les deux individus ont une même vision hiérarchique inégalitaire (i.e. dans laquelle leurs deux groupes ont des statuts différenciés), le membre du groupe dominant obtient un bénéfice plus élevé que celui du groupe dominé. De temps en temps, les individus peuvent changer leur conception hiérarchique, en faisant, occasionnellement des "erreurs". Les conceptions hiérarchiques dans la population évoluent donc dans le temps, en convergeant finalement vers une conception hiérarchique commune à tous. Le modèle prédit, conformément aux résultats issus de la littérature empirique, que les sociétés comportant de petites minorités ethno-culturelles tendent à adopter des conceptions inégalitaires de la hiérarchie ethno-culturelle, dans lesquelles les minorités font face à des degrés différents de discrimination. Il suggère aussi que l'accroissement de la taille d'une minorité peut améliorer le statut de cette minorité ou le réduire, selon les tailles relatives des différents groupes ethno-culturels. Par ailleurs, il montre l'existence de forces encourageant la fragmentation des minorités. En effet, la division d'une minorité, si elle se fait toujours au détriment de l'une des nouvelles minorités formées, peut améliorer le statut de l'autre. Enfin, dans une extension très simple du modèle, il est montré que, si les interactions égalitaires sont plus productives que les interactions inégalitaires, les sociétés multi-culturelles tendent à

évoluer vers des conceptions hiérarchiques inégalitaires inefficaces. Ce modèle est, à ma connaissance, le premier à proposer un mécanisme permettant d'analyser l'émergence de hiérarchies ethno-culturelles en prenant en compte les motivations du groupe majoritaire mais aussi des différentes minorités et à s'appuyer sur l'étude théorique d'un modèle de théorie des jeux évolutionnaires paramétrique et asymétrique à multiples groupes et multiple stratégies ( $3 \times 4$ ) en mobilisant la théorie des graphes.

Le deuxième article, co-écrit avec Harris Selod, économiste senior à la Banque Mondiale, s'appuie sur un modèle d'économie urbaine pour étudier les inefficacités associées à l'insécurité foncière et aux asymétries d'information sur les marchés fonciers des villes d'Afrique sub-Saharienne, ainsi que le rôle des liens sociaux de confiance et de l'enregistrement cadastral des terrains pour réduire ces inefficacités. Le modèle montre que l'insécurité foncière et les asymétries d'information entravent le développement des villes. Cependant, quand acheteurs et vendeurs de terrains peuvent s'apparier selon des liens de confiance qui impliquent une punition sociale en cas de tromperie (i.e. si un vendeur ne dévoile pas à l'acheteur l'existence de revendications concurrentes sur sa propriété), l'asymétrie d'information est atténuée et la participation totale au marché foncier, bien que toujours insuffisante, est accrue. Quand un système d'enregistrement est introduit à la place des liens de confiance, les vendeurs de terrains peuvent payer pour enregistrer leur terrain dans un cadastre et assurer ainsi leur propriété. Dans ce cas, l'asymétrie d'information et l'insécurité foncière sont réduites et la participation au marché foncier, bien que limitée par les coûts d'enregistrement, est améliorée. Dans un modèle hybride où acheteurs et vendeurs peuvent avoir recours aux liens de confiance et à l'enregistrement des terrains, nous montrons qu'un appariement selon les liens de confiance peut se substituer partiellement à l'enregistrement coûteux des terrains, et nous prédisons que les économies en développement vont progressivement évoluer vers un système d'enregistrement des terrains socialement préférable si les coûts d'enregistrement sont suffisamment réduits.

Le troisième article, écrit en collaboration avec Florence Goffette-Nagot (CNRS-GATE) et Sylvain Chareyron (Université Paris-Est Créteil) consiste en l'évaluation empirique d'un programme de rénovation urbaine dont l'objectif était de réduire les disparités géographiques et la polarisation sociale au sein des villes en améliorant les conditions de vie dans les quartiers pauvres. Le programme de rénovation urbaine à grande échelle étudié, le PNRU (Programme National pour la Rénovation Urbaine), a été lancé en 2004 pour la rénovation d'environ 600 quartiers répartis sur tout le territoire français, avec un budget total de 47 milliards d'euros. En s'appuyant sur la méthodologie proposée par De Chaisemartin and D'Haultfœuille (à paraître dans l'AER) ainsi que sur une méthodologie plus classique de différence-de-différence, nous ne trouvons pas d'effet significatif agrégé du programme sur les valeurs immobilières dans les quartiers rénovés sur la période 2004-2014, ce qui suggère que l'accroissement des prix

entraîné par le programme est compris entre 0 et 3%. Nous ne trouvons pas plus d'effet significatif sur le volume de transactions. Cependant, nos résultats indiquent que le programme a mené à un glissement vers le haut des catégories socio-professionnelles des acheteurs de logements par rapport aux vendeurs, ce qui semble traduire une amélioration sensible de l'attractivité des quartiers rénovés.

**Discipline:** Économie

**Mots-clés:** Marchés immobiliers et fonciers, normes sociales, évaluation de politiques publiques, relations ethno-culturelles

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# General introduction

In urban economics' traditional models, the role of social interactions and social norms in the functioning of cities is entirely set aside (Fujita, 1989). Yet, as argued by Glaeser (2000), the mere existence of cities relies on the efficiency of interactions between a large number of individuals, which is highly dependent on social norms. That's why in recent years urban economists started to analyze, through theoretical and empirical approaches, how social interactions and social norms shape the economic functioning of cities and condition their economic success.<sup>1</sup>

In the present international context, in which segregation is on the rise in European, US and Chinese cities<sup>2</sup> and in which new voices raise against discriminations (e.g. ethnic and gender discriminations) in Western countries, it becomes all the more essential to better understand how social norms affect social cohesion and cooperation within these countries' cities and, in turn, how they determine these cities' productivity and economic sustainability. In developing country cities, social norms may even play a more crucial role than in Western cities, due to the widespread recourse to informal activities and markets, the limited functions of formal institutions and the strong traditional kinship links that structure social interactions (Glaeser and Henderson, 2017). The stakes associated with a good harnessing of social norms to foster the emergence of creative and productive developing country cities are thus exacerbated.

With globalization, cities are becoming increasingly ethno-culturally diverse. This increasing diversity appears to stimulate the productivity of natives and growth.<sup>3</sup> However, it also gives rise to the emergence of inegalitarian ethno-cultural hierarchies, which threaten fruitful cooperation between groups and sustainability (Waring and Bell, 2013). Understanding how these hierarchies emerge in a multi-cultural context and the conditions for the development of efficient egalitarian hierarchy views thus constitutes an important challenge. Chapter 1 of this dissertation tackles this question through a multi-group multi-strategy evolutionary game

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1. See Helsley and Zenou (2014a); Büchel and von Ehrlich (2017); Picard and Zenou (2018); Bailey et al. (2020); Kim et al. (2017); Bezin and Moizeau (2017); Verdier and Zenou (2004); Calvó-Armengol, Verdier and Zenou (2007) and Moizeau (2015).

2. See Musterd et al. (2015); Cassiers and Kesteloot (2012); Shen and Xiao (2020); Lichter, Parisi and Taquino (2015); Massey et al. (2003); Taylor and Fry (2012); Wheeler and La Jeunesse (2006) and Watson (2009).

3. See Ottaviano and Peri (2006); Boubtane, Dumont and Rault (2016) and Ortega and Peri (2014).

model and some insights from graph theory. It shows how evolutionary forces tend to favor the emergence, in typical western multi-cultural societies with a large majority and several minority ethno-cultural groups, of stratified ethno-cultural hierarchy views, even though a large body of empirical evidence suggests that it is economically inefficient. It also explains how the growth of a minority may improve or worsen its social status, depending on the broader ethno-cultural context, thereby providing an explanation for the very mixed empirical evidence regarding the link between a minority's size and its status. When analyzing the impact of the arrival of a new minority group, the model suggests that it tends to improve the status of old minorities. Eventually, the model demonstrates that individual incentives encouraging the division of minorities exist, despite the generally negative economic impact of such divisions.

In Chapter 2, which corresponds to an article written in collaboration with Harris Selod (Senior Economist at the World Bank), the economic role of another social norm, trust relationships, is analyzed in the context of developing country cities and, more specifically, of West African cities. Trust relationships between specific ethnic groups, family names and villages play a crucial role in the structuring of social interactions in numerous developing countries.<sup>4</sup> In this context, this chapter proposes, to the best of our knowledge, the first urban economics model to integrate the following critical features of developing country cities: informal and risky land markets, information asymmetries between land buyers and sellers and trust relationships between specific social groups. It shows how informality affects city structure and can, when associated with information asymmetries, generate market failures. It then investigates the ability of two possible institutional settings to solve market failures: a land administration allowing for the formal registration of land plots (and the alleviation of risk and information asymmetries) and a trust norm linking specific social groups in the society and implying the social punishment of land sellers who deceive their buyers (thus reducing information asymmetries). Both institutions are shown to improve overall city development and substitutabilities between the two institutions are identified, suggesting that developing economies can be expected to gradually shift from trust norms towards the economically preferable registration system if registration costs can be reduced sufficiently.

Eventually, Chapter 3, co-written with Florence Goffette-Nagot (CNRS-GATE) and Sylvain Chareyron (Paris-Est Créteil University), analyzes the persistence of a social norm stigmatizing specific neighborhoods and the difficulty for public place-based policies to counter such a norm. It takes advantage of a very large scale urban renewal program (the "Programme National pour la Rénovation Urbaine", also denoted by PNRU) of €47 billion invested in 600 deprived neighborhoods in France to empirically evaluate, using a cutting-edge methodology introduced by De Chaisemartin and D'Haultfœuille (forthcoming), its effects on housing market values, volumes of transactions and socio-professional categories of housing buyers

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4. See Mauss (1923); Dunning and Harrison (2010) and Canut and Smith (2006).

and sellers. Whereas significant impacts on housing values have been found for previous urban renewal programs led in the United States,<sup>5</sup> our study finds no significant effect of the program on housing prices and transaction volumes between 2004 and 2014, thereby corroborating the weaker or non-significant effects of urban renewal programs measured in European cities' contexts.<sup>6</sup> However, we do find a significant positive impact of renovation on the socio-professional categories of housing sellers and buyers, with sellers in renovated neighborhoods increasingly selling to buyers of higher socio-professional categories, suggesting some hint of improvement in the attractiveness of these neighborhoods.

In the following of this general introduction, I will first give an overview of the literature on the links between social norms, identity and economics, focusing on the questions that are relevant to this thesis. I will then summarize more specifically the urban economics literature on social interactions and norms. I will eventually briefly outline the articulation of the three chapters with the literature and their contributions.

## **Social norms, identity and economic outcomes: an overview**

Although the founders of the economics discipline recognized the importance of social norms and, more generally, of culture in the determination of economic decisions,<sup>7</sup> these factors have long been neglected in economic analyzes during the last century. Only in recent decades did interest in them grow again among economists, as deep factors influencing economic outcomes. Figure 1 presents a lightened version of Williamson (2000)'s chart that describes the successive impacts of informal institutions such as social norms (Level 1) on formal executive, legislative, judicial and bureaucratic institutions (Level 2), which, in turn, influence governance (Level 3) and, *in fine*, economic outcomes (Level 4).

### **Importance of social norms in shaping economic outcomes**

Social norms deeply influence all our social and economic behaviors. Young (2015b) thus explains that:

*“Social norms govern our interactions with others. They are the unwritten codes and informal understandings that define what we expect of other people and what they expect of us. Norms establish standards of dress and decorum, obligations to family members, property rights,*

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5. See Collins and Shester (2013); Rossi-Hansberg, Sarte and Owens III (2010); Santiago, Galster and Tatian (2001) and Ding, Simons and Baku (2000).

6. See Barthélémy, Michelangeli and Trannoy (2007); Ahlfeldt, Maennig and Richter (2017).

7. See Mill (1965); Marshall (2009) and Benhabib, Bisin and Jackson (2010).

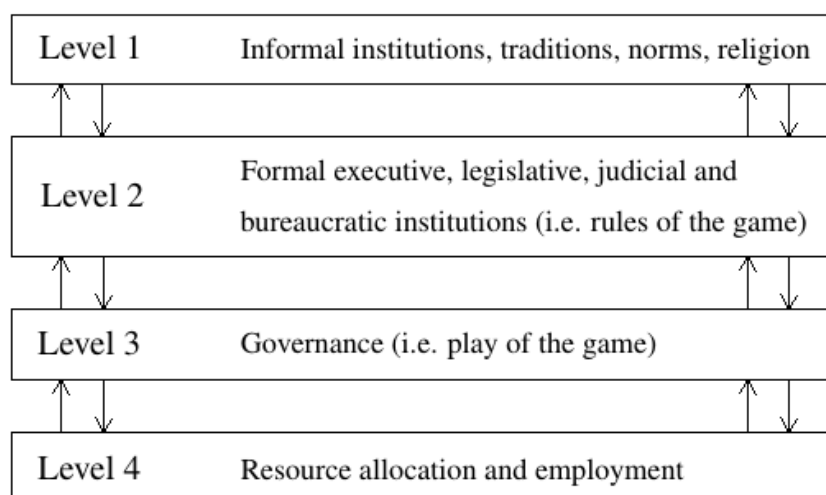


Figure 1 – The four levels of social analysis in Williamson (2000)

*contractual words. They are the building blocks of social order. Despite their importance, however, they are so embedded in our ways of thinking and acting that we often follow them unconsciously and without deliberation; hence we are sometimes unaware of how crucial they are to navigating social and economic relationships.”*

In general, sanctions ensure the enforcement of social norms. They may come from individuals affected by the norm transgression, individuals who are not affected but want to perpetuate the norm, or the person who transgressed the norm herself, through norm internalization (Eggertsson, 2001).

Theoretically, social norms can be expected to affect economic outcomes through several channels (Young, 2007). First, norms create a unique salient solution to a coordination problem, which allows to coordinate expectations, reduce transaction costs and reduce risks of coordination failure.<sup>8</sup> Norms can therefore be seen as a form of social capital (Coleman, 1987). Secondly, some norms may not have direct welfare consequences (e.g. table manners) but may instead allow individuals to signal the importance they attribute to norms and thus indirectly increase their reliability in the eyes of others. Lastly, some norms can also impose too much conformity on behaviors and thus lead to inefficiencies (e.g. excess conformity in contracts between tenants and landlords in late twentieth-century Illinois agriculture, Young and Burke (2001)). A same norm can be welfare-enhancing or welfare-damaging, depending on the context and on the economic incentives in presence. For example, Huck, Kübler and Weibull (2012) show in a simple model of a firm that social norms enhance efficiency under

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8. See Wärneryd (1994) and Roth (1985).

a team-pay contract but reduce efficiency in contracts based on relative performance incentives.

In practice, in the literature, culture and social norms are shown to affect a wide array of economic outcomes.

To start with, a number of studies analyze the impact of norms on economic development. This line of research was originally launched by sociologists and psychologists<sup>9</sup> but then raised the interest of economists. Greif (1994) demonstrates the historical importance of cultures in economic development differences. Algan and Cahuc (2010) and Tabellini (2010) highlight the effect of trust and confidence in individual self-determination on economic growth. Greif (1993, 2006*a,b*) and Greif and Tabellini (2010, 2017) show the role played by nuclear families in the Middle Ages in the development of corporations in Europe, which, in turn, encouraged the adoption of norms favoring economic growth such as individualism, the rule of law, respect for minority rights and trust between strangers. On the other hand, extended kinship groups prevalent in China encouraged trade relationships based on trust between kins rather than based on contracts. This difference may contribute to explain the different historical growth paths followed by Europe and China. Eventually, Jayachandran (2020) studies the link between gender norms, female employment and economic development.

Norms have also been shown to impact entrepreneurial activities, the organization of firms and occupational choices. Doepke and Zilibotti (2014) analyze, through a model, how risk tolerance and patience can affect the allocation of labor between entrepreneurial and non-entrepreneurial activities, which consecutively affects economic growth. Stephan and Uhlaner (2010) and Hopp and Stephan (2012) show that cultures promoting individual success and long-run investments have higher levels of entrepreneurship. Seror (2018), Alesina and Giuliano (2010) and Fernandez and Fogli (2009) respectively investigate the role of religious norms, family ties and gender norms in the determination of occupational choices. Kontogiannis, Litina and Varvarigos (2019) demonstrate, with a monetary growth model, how a status norm attributing different levels of respectability to different entrepreneurial projects can affect the production of capital goods. Finally, Gorodnichenko and Roland (2017) and Acemoglu, Akcigit and Celik (2014) show how individualist cultures and openness to disruptive ideas foster innovation and Bloom, Sadun and Van Reenen (2012) produce evidence that social capital, proxied by trust, raises aggregate productivity by affecting the organization of firms.

Finally, norms have been demonstrated to affect cooperation, trade and political efficiency. Waring and Bell (2013) establish that ethnic dominance harms cooperation more than ethnic diversity. Ostrom (1990) studies how altruism and collective action norms affect institutions for collective action. Guiso, Sapienza and Zingales (2009) show that bilateral trust between two countries affects the intensity of trade, foreign direct investments and portfolio invest-

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9. See Weber (1905) and McClelland et al. (1961).

ments between them. The effect on the intensity of trade is reinforced for goods that are more trust intensive. La Porta et al. (1999) provide evidence that religion and social trust influence political efficiency. Bethencourt and Kunze (2020) propose a model to explain the empirical evidence that low-income countries experience both high levels of labor and capital income tax evasion: they show that a social norm of tax compliance can generate a complementarity between capital and labor income tax evasion, thus explaining the decline of both the share of evaders in the population and the amount of tax evasion when countries accumulate capital.

Thus, norms affect all aspects of a society's economy. When a society relies on economically inefficient norms, it may leave them if other societies with superior norms displace the inefficient ones (through conquest, growth or migration), if it decides to imitate the norms of more successful societies or if individual changes in expectations within the society gradually lead to a transition to a new norm (Young, 2007).

## **The evolution of norms and cultures**

A few features of norms are crucial for the analysis of their evolution (Young, 2015*b*). First, norms are self-enforcing at the group level. Therefore, the benefit from adhering to a norm increases with the number of individuals already following this norm. Second, norms evolve at the level of largely independent individuals through a progressive process involving experimentation, errors and adaptation. Thirdly, norms can take various forms, depending on the historical and social context.

There exists a rich literature on the dynamics of norms, with contributions from the economics but also the sociology, philosophy and political sciences fields. This literature largely relies on game theory to explain the emergence of norms. Schelling (1978) is one of the founders of this literature. He uses game theory to analyze norms through the concepts of coordination equilibria and tipping points. Mackie (1996) extends his framework to explain the persistence of inefficient norms and Akerlof (1980, 1997) show how social interactions and social pressure to follow prevalent norms can lead to inefficient equilibria which are then hard to leave. In more recent papers, evolutionary game theory was proven to be particularly useful for the analysis of norm dynamics.<sup>10</sup> Indeed, it allows to analyze how groups of interacting individuals can progressively adopt a common norm or shift from one norm to another, due to changes in payoffs. It has been applied to the study of contractual norms in the agricultural sector (Young and Burke, 2001), socio-linguistic conventions (Naidu, Hwang and Bowles, 2017), norms regarding social hierarchies (Hwang, Naidu and Bowles, 2016), norms of medical practice (Burke, Fournier and Prasad, 2010), property right norms (Bowles and Choi, 2013, 2019) and religion signaling norms (Carvalho, 2013).

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10. See Young (1993, 1998); Kandori, Mailath and Rob (1993) and Young, Jindani et al. (2019).

Parallel to this literature, another strand of literature focusing on the dynamics of cultures micro-founds the evolution of cultural traits in a theory of inter-generational cultural transmission. It was initiated by the works of Cavalli-Sforza and Feldman (1981) and Boyd and Richerson (1988) and then extended by Bisin and Verdier in a series of papers<sup>11</sup> through the introduction of parental socialization choice. This theory relies on a double mechanism for the transmission of culture: *vertical transmission* (i.e. cultural traits are transmitted from parents to children) and *horizontal transmission* (i.e. cultural traits are transmitted by the rest of the society). It has been applied in several empirical studies.<sup>12</sup>

Eventually, a third approach founded by Güth and Yaari (1992) focuses on the evolution of preferences explained through an *indirect evolutionary approach*. This approach is based on the assumption that players behave rationally for given preferences but that their preferences follow an evolutionary process. It has been applied to the study of the evolutionary stability of preferences<sup>13</sup> and to the analysis of the co-evolution of political institutions and cultural values.<sup>14</sup>

Norm dynamics as studied in these three approaches possess a few specific features (Young, 2015*b*). Norms are persistent in time and their dynamics often exhibit tipping points (points where norms suddenly change), punctuated equilibria (norms spend long periods in equilibrium separated by short periods of transition) and compression (more homogeneity in behaviors than would be expected in the absence of norms). They also lead to behaviors characterized by conformity at the local level and diversity at the global one.

## The key role of identity in the adoption of social norms

The adoption of social norms is largely based on “a sense of belonging to an identity” (Akerlof and Kranton, 2010), so that the study of social norms’ economic impacts and the study of identity formation are inevitably linked. The analysis of the emergence of identities and of their effects on economic processes is the subject of a relatively recent strand of economic literature referred to as “Identity Economics” launched by the seminal paper Akerlof and Kranton (2000). In identity economics models, three time scales are at play (Kranton, 2016). In the short run, individuals make their economic decisions considering norms, social categories and identities as given. In the medium term, individuals can alter their identity as well as social categories and norms and, in the long term, nothing is fixed anymore.

Three main families of mechanisms have been proposed to understand the formation of identities. In the first, identities emerge from an evolutionary process of mutations and selec-

11. See Bisin and Verdier (1998, 2000*b,a*, 2001).

12. See Bisin and Topa (2003); Bisin, Topa and Verdier (2004) and Giavazzi, Petkov and Schiantarelli (2019).

13. See Robson (1990); Güth and Yaari (1992); Bester and Güth (1998); Alger (2010); Alger and Weibull (2010, 2013); Ok and Vega-Redondo (2001) and Dekel, Ely and Yilankaya (2007).

14. See Wu (2016) and Besley and Persson (2019).



tion that equips individuals with utility functions and learning processes that tend to maximize their fitness. Generally, a principal-agent perspective is adopted, in which the principal is the natural selection process and the agent is an individual with a set of genes.<sup>15</sup> The second mechanism posits that identities emerge because individuals directly benefit from them. This benefit can come, for example, from increased self-esteem due to compatibility with group values.<sup>16</sup> Eventually, the third mechanism explains the formation of identities through inter-generational transmission.<sup>17</sup>

## Social interactions and public policies in urban economics

The economics of cities is largely shaped by interactions between individuals and by the social norms that condition these interactions. This influence is increasingly taken into account in urban economics empirical and theoretical analyzes. In what follows, I give a brief overview of various branches of urban economics in which social interactions and norms play a prominent role.

### Urban economics and economics of agglomeration

First, an important strand of literature in urban economics analyzes how social interactions lead to the emergence of city centers through positive spatial externalities. It investigates how spatial externalities affect the location of households and firms, urban density and economic productivity.<sup>18</sup> For example, Mossay and Picard (2011*a*) and Mossay, Picard et al. (2013) use a social interaction framework to study the conditions leading to the emergence of different types of city structures. Roca and Puga (2017) empirically show that more valuable experience is accumulated by workers in large cities as compared to smaller ones.

### Peer effects, social networks and urbanization

Then, a small strand of literature analyzes the role of social networks in cities<sup>19</sup> from a theoretical point of view. For example, Kim et al. (2017) demonstrate that the geographical location of individuals and their social capital affects the formation of social links. From an empirical point of view, studies on the role of distance in the formation of social ties mainly come from the computer science and statistical mechanics fields and are aimed at measuring the shape of

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15. See Robson (2001); Rayo and Becker (2007*a,b*) and Robson and Samuelson (2011).

16. See Bénabou and Tirole (2006); Benabou and Tirole (2011) and Akerlof (2017).

17. See Lizzeri and Siniscalchi (2008); Doepke and Zilibotti (2017) and Seror (2019).

18. See Beckmann (1976); Ogawa and Fujita (1980); Lucas and Rossi-Hansberg (2002); Helsley and Strange (2014); Behrens, Duranton and Robert-Nicoud (2014); Glaeser (1999); Helsley and Strange (2004); Berliant, Peng and Wang (2002) and Berliant and Wang (2008).

19. See Brueckner and Largey (2008); Helsley and Strange (2007); Zenou (2013*a*); Mossay and Picard (2011*b*); Helsley and Zenou (2014*b*); Sato and Zenou (2015) and Kim et al. (2017).



the statistical relationship between the probability of a social link and geographical distance.<sup>20</sup>

### **Neighborhood effects, endogenous socioeconomic segregation and culture**

A related strand of literature deals with neighborhood effects and endogenous socioeconomic segregation. It focuses on explaining how local interactions lead to spatial segregation and persistent income inequality.<sup>21</sup> In these articles, the evolution of income inequality between neighborhoods is explained by differences in human-capital accumulation, which itself is determined by human-capital transmission between parents and children and local spatial spillovers. As an illustration, Borjas (1998) explains the emergence of ethnic segregation between neighborhoods by the existence of ethnic spillovers in the human-capital accumulation process.

This endogenous socioeconomic segregation has been established to interact with culture. Bisin et al. (2011) and Zimmermann, Constant and Schüller (2014) show how urban segregation impacts ethnic identity and Wilson (1987), Anderson (2000) and Small and Lamont (2008) demonstrate how the segregation of ethnic minorities in poor neighborhoods generates a “culture of poverty” by isolating these minorities from the common social norms. Accordingly, Falk and Zehnder (2013) measure different levels of trust, depending on the location within the city of Zurich. Reciprocally, Cutler, Glaeser and Vigdor (2008) empirically establish that the cultural distance between an immigrant group and the rest of the population significantly impacts the level of segregation. Indeed, cultural transmission is one of the key determinants in parents’ choice of schools or neighborhoods.<sup>22</sup> Given those results, Moizeau (2015) proposes an urban economics model that allows to investigate how segregation and cultural transmission interact and can either lead to a city where opposing social norms persist or to a city where a unique norm is eventually adopted by everyone.

### **Neighborhood status**

The endogenous nature of urban segregation implies that neighborhood statuses, which may be interpreted as social norms, evolve through time. This phenomenon has been investigated by a number of studies.<sup>23</sup> These studies have shown that, even though the economic status of many neighborhoods persists through time, changes in neighborhoods’ statuses are not rare. The corresponding dynamics are influenced by numerous factors, such as the progressive degradation of housing stock or transportation infrastructure, natural advantages, amenities, government policy and self-reinforcing spillovers.

20. See Liben-Nowell et al. (2005); Lambiotte et al. (2008); Goldenberg and Levy (2009); Krings et al. (2009) and the following reviews of Barthélemy (2011); Kaltenbrunner et al. (2012) and Ioannides (2013).

21. See, for instance, Loury (1976); Benabou (1993, 1996*b,a*); Borjas (1998) and Durlauf (1996).

22. See Ioannides, Zanella et al. (2008); Tinker and Smart (2012).

23. See Card, Mas and Rothstein (2008), Rosenthal (2008) and Rosenthal and Ross (2015) for a review.

### **Spatial mismatch**

Another consequence of urban segregation is well-known as the “spatial mismatch hypothesis”, first formulated by Kain (1968).<sup>24</sup> It posits that Black minority workers tend to live far from major centers of employment and that this distance constitutes a strong barrier preventing them from obtaining and keeping a well-paid job. The theoretical mechanisms proposed to explain this situation mostly rely on search models and show that more distant workers tend to search less and therefore stay unemployed for longer periods.<sup>25</sup>

### **Urban public policies**

In view of the significant impacts that social interactions have on economic outcomes within cities, public policies have been led to improve the social environment in some particularly deprived neighborhoods, either by targeting these geographical areas specifically through *place-based policies* or by targeting poor individuals who disproportionately live in these neighborhoods through *people-based policies*. In Europe, governments strongly rely on place-based policies as compared to people-based policies. However, there exists a long lasting debate among economists regarding the relative efficiency of the two approaches. Several arguments claim in favor of place-based policies. Indeed, these policies may foster agglomeration economies, due to increased opportunities for “sharing, matching and learning” (Duranton and Puga, 2004). They can also be expected to address the “spatial mismatch” issue (Gobillon, Selod and Zenou, 2007). Yet, place-based policies also come with serious shortcomings. They may lead to “diversion effects” by benefiting a neighborhood at the expense of another, but also to “windfall effects” if they benefit agents who did not need them and would have moved in deprived neighborhoods anyway. Other examples of issues are linked with “mailbox effects”, i.e. firms applying strategies for fiscal optimization to take advantage of Employment Zone programs, and “stigma effects”, leading to the avoidance of target neighborhoods or of their inhabitants (Briant, Lafourcade and Schmutz, 2015). Numerous empirical studies have been led to assess the efficiency of various place-based policies and, in particular, Enterprise Zone programs. The evidence regarding the effect of the latter is very mixed (see Neumark and Simpson (2015) on this matter).

After this overview of numerous strands of economic literature linked with this dissertation, I now detail more precisely the contributions of the three essays.

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24. See overviews by Ihlanfeldt and Sjoquist (1998); Ihlanfeldt (2006) and Zenou (2008).

25. See Coulson, Laing and Wang (2001); Wasmer and Zenou (2002) and Zenou (2013b).

## **Contributions and outline of the dissertation**

In the literature on the evolution of social norms, evolutionary game theory approaches have been used to analyze the emergence and persistence of social hierarchy norms between social groups.<sup>26</sup> These approaches allow to explain how evolutionary processes often lead to the emergence and persistence of unequal and inefficient norms, whereby one group dominates the other. However, the proposed mechanisms only concern the context of a country made of two social groups and cannot describe inter-group interactions in the broader context of a multi-cultural country with multiple ethno-cultural minorities that may have reciprocal influences on each other. In particular, they cannot properly describe the effects of immigration of a new minority group or of a minority's split into two distinct social groups on the prevalent ethno-cultural hierarchy. What's more, they cannot explain the non-linear relationship between a minority's size and its status suggested by the results obtained in the empirical literature.

Drawing on these observations, the first essay of this dissertation proposes an evolutionary coordination game model suited for the analysis of the emergence of ethno-cultural hierarchies in multi-cultural countries. In the proposed multi-group multi-strategy model, each member of the society belongs to one ethno-cultural group and holds personal views regarding the ethno-cultural hierarchy, i.e. the relative statuses of the different ethno-cultural groups. At each period, each individual is matched with a number of other individuals. When two individuals are matched, they interact according to a coordination game in which their respective strategies correspond to their social hierarchy views. If the two matched individuals belong to different groups and hold the same hierarchy view (i.e. there is coordination), they both obtain a strictly positive payoff. If this common hierarchy view is egalitarian, both individuals get the same payoff. If this view grants a higher status to one group, the payoff of the dominant group's member is larger than that of the dominated individual. If the two matched individuals belong to different groups and hold different hierarchy views, both get a null payoff. At the beginning of each period of time, one individual is given the chance to actualize his social hierarchy views. With a very large probability, this individual adopts his best response to the distribution of hierarchy views in the society at the previous period. With a very small probability that tends toward zero, he adopts a random hierarchy view (i.e. he "mutates" randomly). The distribution of social hierarchy views in the population thus evolves through time according to a Markovian process that converges toward a unique stationary distribution of hierarchy views.

The model predicts, consistently with empirical evidence from the literature,<sup>27</sup> that soci-

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26. See Naidu, Hwang and Bowles (2017) and Hwang, Naidu and Bowles (2016).

27. See Hagendoorn (1995); Hofer et al. (2013); Berry and Kalin (1979); Pager, Bonikowski and Western (2009); Tenenbaum and Ruck (2007); Parrillo and Donoghue (2013); Brewer and Campbell (1976); Sautman (1994); Maurer-Fazio (2012); Chua, Mathews and Loh (2016); Booth, Leigh and Varganova (2012); Kalin and Berry (1996); Storm, Sobolewska and Ford (2017); Heath and Di Stasio (2019) and Zschirnt and Ruedin (2016).

eties with small ethno-cultural minorities tend to adopt inegalitarian hierarchy views in which minorities face different degrees of discrimination. It further suggests that an increase in the size of a minority may improve the minority's status or hurt it, depending on its relative size with respect to the other ethno-cultural groups. This may explain the mixed results obtained in empirical studies regarding the link between minority size and level of prejudice against this minority.<sup>28</sup> The model also demonstrates the existence of forces towards the fragmentation of minorities. Indeed, the splitting of a minority, despite always being detrimental to the smallest new minority formed, may improve the status of the largest new one, encouraging it to trigger a split. Eventually, in a very simple extension of the model, it is shown that, if interactions between individuals holding equal statuses are more productive than interactions between unequal individuals as the literature suggests,<sup>29</sup> multi-cultural societies generally evolve towards inegalitarian and inefficient hierarchy views.

This model is, to the best of my knowledge, the first to propose a comprehensive mechanism for the emergence of ethno-cultural hierarchies in a multi-cultural context, taking into account the majority's and the different minorities' incentives. It is also the first to analyze the evolution of norms relying on the theoretical analysis of a parametric multi-group and multi-strategy ( $3 \times 4$ ) asymmetric evolutionary game model using graph theory.

Although social interactions and norms are increasingly taken into account in recent urban economics models as seen in the previous overview of the literature, most of these models are not adapted to the analysis of developing country cities and, more specifically, of West African ones. Contrarily to developed country cities, in developing country cities land markets remain largely informal and a large share of land plots are not registered with the land administration, mainly due to prohibitive registration costs. This situation leads to land tenure insecurity and, in turn, to reduced investment in land, labor market participation and tradability of land,<sup>30</sup> as well as increased social ills, including crime, poor health from low housing quality, and negative human capital externalities.<sup>31</sup> Another specificity of West African cities is the important role of social norms implying reciprocal duties between specific social groups referred to as "allies", "kins" or "cousins".<sup>32</sup> These norms can be relied on to reduce insecurity in land transactions.

The second essay of this dissertation, co-written with Harris Selod, Senior Economist at

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28. See Coenders (2001); Fossett and Kiecolt (1989); Pettigrew and Cramer (1959); Quillian (1995, 1996); Scheepers, Gijsberts and Coenders (2002); Semyonov, Rajman and Gorodzeisky (2006); Coenders, Lubbers and Scheepers (2005); Evans and Need (2002); Semyonov et al. (2004); Strabac and Listhaug (2008); Hood III and Morris (1997) and Lubbers, Coenders and Scheepers (2006).

29. See Waring and Bell (2013); Anderson, Mellor and Milyo (2008); Nishi et al. (2015); Fehr (2018); Dickinson, Masclet and Peterle (2018) and Sadrieh and Verbon (2006).

30. See Besley (1995) and Field (2007).

31. See Galiani and Schargrodsky (2010); Galiani et al. (2017) and Nakamura (2017).

32. See Mauss (1923); Raphaël (1992); Smith (2004, 2006); Diallo (2006) and Dunning and Harrison (2010).

the World Bank, is, to the best of our knowledge, the first to focus on the interaction between social norms and land markets, and how land transactions among trusted parties can address the information asymmetry that has come to characterize today's urban land markets in sub-Saharan Africa.<sup>33</sup> In our model, purchasing informal land is risky for buyers, as plot ownership might be contested in the future. In an ideal world, competing land ownership claims could be extinguished through adjudication and registration of land ownership in a cadaster leading to the issuance of a property title. In practice, it can be very costly to register one's land plot and this solution is only chosen by a fraction of the population. The objective of this essay is thus to investigate how urban households who do not pay for land registration may rely on a trust norm instead, in order to address tenure insecurity when transacting informal land. More specifically, we study a mechanism whereby buyers and sellers match in the informal market according to a trusted ethnic relationship that reduces the information asymmetry and the likelihood of purchasing an insecure plot.

We formalize these ideas in an urban land use model with tenure insecurity and information asymmetry, where we study equilibrium land market transactions and associated inefficiencies. In our framework, plots are of two types: risky plots, which ownership may be contested in the future, and risk-free plots, which ownership cannot be contested. In addition, buyers and sellers of land plots may have reciprocal duties based on trusted ethnic kinship. If a risky plot is exchanged between individuals linked by ethnic kinship without disclosure of the risk to the buyer, the seller will be considered to have violated his duty and a social penalty will be imposed on him. In that context, a buyer expects that a seller he is ethnically related with will be more likely to sell him a secure plot and he will consequently be ready to pay a premium. Knowing this, sellers may decide whether to transact with kin or non-kin members, depending on the intrinsic risk on their plot, the social penalty and the trust premium. An important prediction of the model is that although matching along ethnic lines reduces information asymmetry, it also lowers overall market participation. Alternatively, when owners are offered the possibility to make plots secure by paying to register them in a cadaster, both information asymmetry and tenure insecurity are reduced, but the cost of registration limits transactions at the periphery of the city. We compare the overall surplus under these two polar cases and under a hybrid version of the model, where both registration and trusted relationships are available options, as is the case in many sub-Saharan-African cities.

To our knowledge, our model is the first land use model with interpersonal transactions, an important feature that was largely missing in the theoretical literature on land markets in developing countries, in spite of its likely high prevalence. The introduction of ethnic matching allows us to assess and compare the respective advantages of transactions sanctioned by property rights registration and of transactions conducted under trusted relationships. It also allows

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33. See Durand-Lasserve, Durand-Lasserve and Selod (2015) and Bank (2019).

us to study the coexistence of the two practices within a single city. Our framework generates novel predictions regarding the prevalence of ethnic matching in land markets where registration is very costly, the substitutability between trusted relationships and registration, and the probable gradual evolution of economies towards full cadastral coverage and weakened trust norms, with the reduction of registration costs.

Among the various place-based policies implemented by governments to reduce spatial inequalities within cities and improve living conditions in deprived neighborhoods, a sizable number of urban renewal policies have been implemented in Western countries over the last decades.<sup>34</sup> Yet, compared to other place-based policies, such as Enterprise Zones programs,<sup>35</sup> only few empirical studies of urban renewal's impacts relying on a causal identification strategy have been conducted. What's more, most preceding studies employ empirical strategies based on difference-in-differences estimations that are likely to lead to biased estimates if the effect of renovation is heterogeneous across neighborhoods or time periods, or if there is some unbalanceness in treatment status along these dimensions (see De Chaisemartin and D'Haultfœuille (forthcoming) for a discussion of this issue). Additionally, previous empirical analyzes of urban renewal programs have generally focused on small-scale programs involving only a few neighborhoods, generally within a single city. To the best of my knowledge, the only recent nationwide renewal program which impact has been empirically investigated at the local scale was implemented in the Netherlands (Koster and Van Ommeren, 2019). But its level of financing was limited, with about €1 billion invested between 2007 and 2012.

In this context, the third essay of this PhD dissertation, co-written with Florence Goffette-Nagot (CNRS-GATE) and Sylvain Chareyron (Paris-Est Créteil University), analyzes a very large-scale urban renewal program, the *Programme National de Rénovation Urbaine (PNRU)*, launched in 2004 in France. In order to prevent potential biases in the estimates of the program's impacts due to the probable heterogeneity in treatment effects across neighborhoods and time periods, we apply the novel methodology proposed by De Chaisemartin and D'Haultfœuille (forthcoming) for this very purpose. Our paper, to the best of our knowledge, is the first to do so in the context of urban renewal. In addition, the PNRU program involved the renovation of around 600 neighborhoods throughout the French territory, including overseas departments, and more than €47 billions have been invested in this program. This large scale has three main advantages. First, the country scale makes the estimates more reliable because the large number of control areas reduces the sensitivity of the counterfactual to unobserved shocks as shown by Ahlfeldt, Maennig and Richter (2017). Second, the large number of treated areas and observations makes it possible to explore potential heterogeneous effects

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34. e.g. in the United States, the Netherlands, Spain, the United Kingdom, France.

35. See Briant, Lafourcade and Schmutz (2015) and Fisman (2001).

of the program and thus to identify eventual determinants of program effectiveness. To finish with, our housing transactions dataset possesses a rare feature: it includes information regarding buyers and sellers, such as their socio-professional category. This feature allows us to complement the analysis of housing prices and transaction volumes, which are generally focused on in analyses of urban renewal programs, by a study of the evolution of buyers' and sellers' characteristics.

The PNRU program consisted in the renovation, demolition and construction of hundreds of thousands of public housing buildings and public facilities. We study its impacts on the (private) housing market in renovated neighborhoods between 2004 and 2014. Our estimate is therefore an estimate of the program's externalities and not a direct evaluation of the program's effects on the value of renovated housing units. We first measure the overall impacts on private housing values, obtained by pooling all the neighborhoods together. We then study heterogeneities of effects on housing values, first, based on the level of funding per (initially existing) housing unit received by the neighborhoods, then on the initial share of public housing in the neighborhood, and eventually on the size of the urban unit (i.e. separating neighborhoods located in one of the four largest French urban units, namely Paris, Lyon, Marseille and Lille, and neighborhoods located in the other urban areas). After that, we turn to the evaluation of the program's impact on the volume of transactions in renovated neighborhoods and on the socio-professional category of housing buyers and sellers.

Our results indicate that renovation did not lead to a significant increase in housing values in renovated neighborhoods at the aggregate level of France in the time frame considered. The result appears to be robust to various sensitivity tests. Furthermore, we find no substantial differences in estimated impacts, neither with respect to the level of funding per housing unit received by the neighborhood, nor with respect to the initial share of public housing in the neighborhood or the size of the urban unit in which the renovated neighborhood is located. It is nevertheless possible that the program had a small impact on housing values, albeit sufficiently small not to be captured by our analysis, which means below 3.5%. We also find no impact on the volume of transactions in renovated neighborhoods. However, we do find that the program significantly affected the social profile of housing buyers and sellers in renovated neighborhoods. Indeed, we find evidence that it led to an increased number of upward transitions of housing units (from a blue-collar seller to an intermediate category buyer or from an intermediate category seller to an executive buyer) and to a reduction of housing transactions among executives, suggesting an increased interest of upper socio-professional categories to invest in the renovated neighborhoods or to remain in them.





# Introduction générale

Dans les modèles traditionnels d'économie urbaine, le rôle des interactions et normes sociales dans le fonctionnement des villes n'est pas pris en compte (Fujita, 1989). Cependant, comme le souligne Glaeser (2000), l'existence même des villes repose sur l'efficacité des interactions entre un grand nombre d'individus qui elle-même dépend largement des normes sociales. C'est pourquoi, ces dernières années, les économistes urbains ont commencé à analyser, au moyen d'approches théoriques et empiriques, comment les interactions et normes sociales façonnent le fonctionnement économique des villes et conditionnent leur succès économique.<sup>36</sup>

Dans le contexte international actuel, où la ségrégation s'accroît au sein des villes européennes, américaines et chinoises<sup>37</sup> et où de nouvelles voix s'élèvent contre les discriminations (e.g. ethnique et sexuelle) dans les pays occidentaux, il devient d'autant plus important de mieux comprendre comment les normes sociales affectent la cohésion sociale et la coopération dans les villes de ces pays et comment elles conditionnent, en conséquence, la productivité de ces villes et leur soutenabilité économique. Dans les villes des pays en développement, les normes sociales pourraient même jouer un rôle plus crucial que dans les villes des pays occidentaux en raison du rôle central des activités et marchés informels, des fonctions limitées des institutions formelles et de l'intensité des liens traditionnels de confiance qui structurent les interactions sociales (Glaeser and Henderson, 2017). Les enjeux liés à une bonne compréhension et exploitation des normes sociales pour favoriser l'émergence de villes créatives et productives dans les pays en développement en sont donc exacerbés.

Avec la mondialisation, les villes deviennent de plus en plus multi-culturelles. Cette diversité grandissante semble stimuler la productivité des autochtones et la croissance.<sup>38</sup> Cependant, elle conduit aussi à l'émergence de hiérarchies ethno-culturelles inégalitaires qui mettent en danger la coopération harmonieuse entre groupes et la soutenabilité des villes (Waring and

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36. Voir Helsley and Zenou (2014a); Büchel and von Ehrlich (2017); Picard and Zenou (2018); Bailey et al. (2020); Kim et al. (2017); Bezin and Moizeau (2017); Verdier and Zenou (2004); Calvó-Armengol, Verdier and Zenou (2007) et Moizeau (2015).

37. Voir Musterd et al. (2015); Cassiers and Kesteloot (2012); Shen and Xiao (2020); Lichter, Parisi and Taquino (2015); Massey et al. (2003); Taylor and Fry (2012); Wheeler and La Jeunesse (2006) et Watson (2009).

38. Voir Ottaviano and Peri (2006); Boubtane, Dumont and Rault (2016) et Ortega and Peri (2014).

Bell, 2013). Il est donc important de chercher à mieux comprendre comment ces hiérarchies émergent dans un contexte multi-culturel ainsi qu'à identifier les conditions nécessaires pour le développement de hiérarchies égalitaires. Le Chapitre 1 de cette thèse aborde cette question par le biais d'un modèle de théorie des jeux évolutionnaires à plusieurs groupes et plusieurs stratégies en mobilisant quelques enseignements issus de la théorie des graphes. Ce modèle montre comment un processus évolutionnaire peut tendre à favoriser l'émergence, dans un contexte typique de société multi-culturelle occidentale avec un large groupe majoritaire et plusieurs petites minorités, d'une hiérarchie ethno-culturelle stratifiée, même si de nombreuses études empiriques suggèrent que ces hiérarchies sont économiquement inefficaces. Le modèle explique aussi comment la croissance d'une minorité peut améliorer ou détériorer son statut social, en fonction du contexte ethno-culturel, ce qui explique les résultats très contrastés obtenus par les études empiriques portant sur le lien entre la taille d'une minorité et son statut social. Il suggère, en outre, que l'arrivée d'une nouvelle minorité tend à bénéficier aux anciennes minorités et que les intérêts individuels des membres des minorités encouragent l'émergence de divisions au sein de celles-ci, malgré l'effet économique global généralement négatif de ces divisions.

Dans le Chapitre 2, co-écrit avec Harris Selod (Senior économiste à la Banque Mondiale), le rôle économique d'autres normes sociales, les normes de confiance, est analysé dans le contexte des villes des pays en développement et, plus précisément, des villes d'Afrique de l'Ouest. Dans ces villes, les relations de confiance entre certaines groupes ethniques, noms de famille et villages jouent un rôle crucial dans la structuration des interactions sociales.<sup>39</sup> En s'appuyant sur ce constat, le Chapitre 2 propose ce qui représente, à notre connaissance, le premier modèle d'économie urbaine intégrant les caractéristiques suivantes, spécifiques aux villes des pays en développement : l'importance des marchés fonciers informels associés à des risques sur les transactions, la présence d'asymétries d'information entre acheteurs et vendeurs de terrains concernant les risques de conflits fonciers et la prévalence des relations de confiance entre certains groupes sociaux. Ce modèle montre comment l'informalité affecte la structure de la ville et peut, quand elle est associée à des asymétries d'information, générer des failles de marché. Il permet l'analyse des effets de deux institutions visant à résoudre ces failles de marché : un système d'enregistrement des terrains (permettant la suppression du risque et des asymétries d'information) et une norme de confiance entre certains groupes impliquant une punition sociale pour les vendeurs de terrains qui trompent leur acheteur (permettant une réduction des asymétries d'information). Les deux institutions accroissent le développement de la ville et sont partiellement substituables, ce qui suggère que l'on peut s'attendre à ce que les économies en développement abandonnent progressivement leur normes de confiance au profit d'un système d'enregistrement économiquement préférable si les coûts d'enregistrement

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39. Voir Mauss (1923); Dunning and Harrison (2010) et Canut and Smith (2006).

peuvent être suffisamment réduits.

Enfin, le Chapitre 3, co-écrit avec Florence Goffette-Nagot (CNRS-GATE) et Sylvain Charreton (Université Paris-Est Créteil), analyse la persistance d'une norme sociale stigmatisant certains quartiers et montre la difficulté pour les politiques publiques ciblées sur les territoires de contrecarrer une telle norme. Nous étudions les effets d'un programme de rénovation urbaine de très grande ampleur, le PNRU (Programme National pour la Rénovation Urbaine) lancé en France en 2004 pour la rénovation de 600 quartiers pauvres de France. Plus précisément, nous mobilisons une méthode tout récemment proposée par De Chaisemartin and D'Haultfœuille (à paraître dans l'AER) pour évaluer les effets du programme sur les valeurs immobilières, les volumes de transactions et les catégories socio-professionnelles des acheteurs et vendeurs de logements. Alors que des effets significatifs sur les valeurs immobilières ont été mesurés dans le cadre d'autres programmes de rénovation urbaine menés aux États-Unis,<sup>40</sup> notre étude ne mesure pas d'effet significatif du programme sur les prix immobiliers et les volumes de transactions sur la période 2004-2014, ce qui va dans le sens des effets plus faibles ou non significatifs mesurés dans le cadre de programmes de rénovation urbaine menés dans des villes européennes.<sup>41</sup> Cependant, nous trouvons un effet significatif de la rénovation sur les catégories socio-professionnelles des acheteurs et vendeurs de logements, avec des vendeurs qui vendent de plus en plus souvent à des acheteurs de catégories socio-professionnelles plus élevées, ce qui suggère une sensible amélioration dans l'attractivité de ces quartiers.

Dans la suite de cette introduction générale, je donnerai d'abord une vue d'ensemble de la littérature sur les liens entre normes sociales, identité et économie, en me concentrant sur les questions pertinentes pour cette thèse. Je synthétiserai ensuite plus spécifiquement la littérature sur le rôle des interactions et normes sociales en économie urbaine. Enfin, je résumerai brièvement l'articulation des trois chapitres de cette thèse avec la littérature ainsi que leurs contributions à celle-ci.

## **Normes sociales, identité et conséquences économiques : une vue d'ensemble**

Alors que les fondateurs de la discipline économique reconnaissaient l'importance des normes sociales et, plus généralement, de la culture dans la détermination des décisions économiques,<sup>42</sup> ces facteurs ont longtemps été négligés dans les analyses économiques durant le siècle dernier. Ce n'est qu'au cours des dernières décennies que les économistes ont commencé

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40. Voir Collins and Shester (2013); Rossi-Hansberg, Sarte and Owens III (2010); Santiago, Galster and Tatian (2001) et Ding, Simons and Baku (2000).

41. Voir Barthélémy, Michelangeli and Trannoy (2007); Ahlfeldt, Maennig and Richter (2017).

42. Voir Mill (1965); Marshall (2009) et Benhabib, Bisin and Jackson (2010).

à leur manifester un intérêt croissant, en tant que facteurs profonds conditionnant les résultats économiques. La Figure 2, version allégée du tableau proposé par Williamson (2000), représente les impacts successifs des institutions informelles telles que les normes sociales (Niveau 1) sur les institutions formelles exécutives, législatives, judiciaires et bureaucratiques (Niveau 2), puis sur la gouvernance (Niveau 3) et, enfin, sur les résultats économiques (Niveau 4).

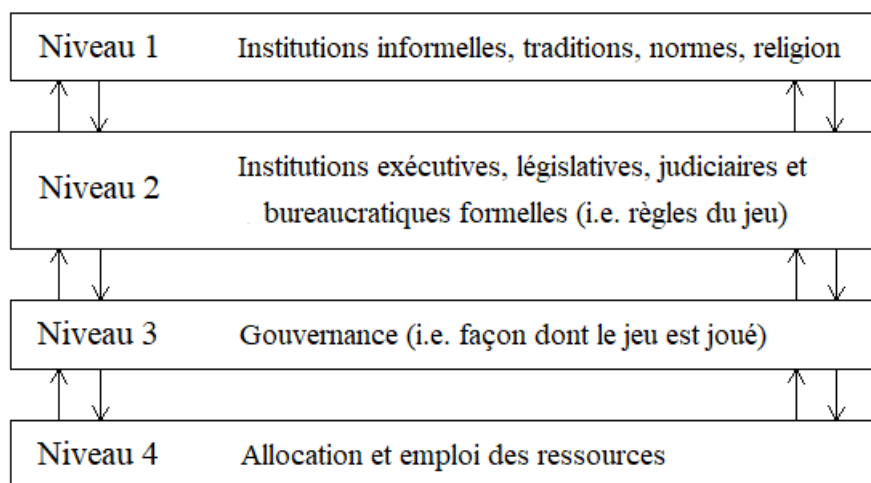


FIGURE 2 – Les quatre niveaux d’analyse sociale dans Williamson (2000)

## Importance des normes sociales dans la détermination des résultats économiques

Les normes sociales influencent profondément tous nos comportements sociaux et économiques. Young (2015b) explique ainsi que :

*“Les normes sociales gouvernent nos interactions avec les autres. Ce sont les codes tacites et accords informels qui définissent ce que nous attendons des autres et ce qu’ils attendent de nous. Les normes établissent des codes vestimentaires, un décorum, des obligations envers les membres de notre famille, des droits de propriété, des termes contractuels. Elles constituent les fondations de l’ordre social. Cependant, malgré leur importance, elles sont si bien intégrées dans nos modes de pensée et d’action que nous les suivons souvent inconsciemment et involontairement ; ainsi nous ne sommes souvent pas conscients de leur rôle crucial dans les relations sociales et économiques.”*

En général, des sanctions assurent le respect des normes sociales. Elles peuvent être appliquées par des individus affectés par la transgression de la norme, par des individus qui ne sont pas affectés mais veulent perpétuer la norme, ou par la personne qui a transgressé la norme elle-même, en cas d'internalisation de la norme (Eggertsson, 2001).

Du point de vue théorique, on peut s'attendre à ce que les normes affectent les résultats économiques par plusieurs canaux (Young, 2007). Tout d'abord, les normes créent une unique solution saillante à un problème de coordination, ce qui permet de coordonner les attentes individuelles et de réduire les coûts de transaction et les risques de défaillance de la coordination.<sup>43</sup> Les normes peuvent donc être vues comme une forme de capital social (Coleman, 1987). Par ailleurs, il arrive que certaines normes n'aient pas de conséquences directes sur le bien-être (e.g. les bonnes manières à table) mais permettent aux individus de signaler l'importance qu'ils attribuent aux normes ce qui accroît indirectement leur fiabilité aux yeux des autres. Enfin, certaines normes peuvent imposer trop de conformité dans les comportements et ainsi conduire à des inefficacités (e.g. trop d'homogénéité dans les contrats entre propriétaires terriens et exploitants agricoles à la fin du XX<sup>e</sup> siècle dans l'État de l'Illinois mène à des contrats mal calibrés, Young and Burke (2001)). Il est à noter qu'une même norme peut améliorer le bien-être ou le réduire, en fonction du contexte et des motivations économiques en présence. Par exemple, Huck, Kübler and Weibull (2012) montrent dans un modèle simple d'entreprise que les normes sociales améliorent l'efficacité quand les individus sont rémunérés selon un contrat dépendant de la performance de l'équipe mais réduisent l'efficacité si le contrat est fondé sur les performances relatives entre individus.

En pratique, la littérature académique montre que culture et normes sociales affectent un large panel d'indicateurs économiques.

Pour commencer, un certain nombre d'études analysent l'impact des normes sur le développement économique. Cet axe de recherche a été originellement initié par des sociologues et psychologues<sup>44</sup> mais a ensuite suscité l'intérêt des économistes. Greif (1994) démontre l'importance historique des cultures dans les différences de développement entre pays. Algan and Cahuc (2010) et Tabellini (2010) mettent en évidence l'effet du niveau de confiance et de la croyance dans l'auto-détermination des individus sur la croissance économique. Greif (1993, 2006a,b) et Greif and Tabellini (2010, 2017) montrent le rôle joué par les familles nucléaires au Moyen-Âge dans le développement des corporations en Europe, ce qui a ensuite encouragé l'adoption de normes favorisant la croissance économique telles que l'individualisme, l'Etat de droit, le respect des droits des minorités et la confiance entre étrangers. A l'inverse, les groupes familiaux élargis prévalents en Chine ont encouragé les relations commerciales fon-

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43. Voir Wärneryd (1994) et Roth (1985).

44. Voir Weber (1905) et McClelland et al. (1961).

dées sur la confiance entre parents éloignés plutôt que sur les contrats. Cette différence peut contribuer à expliquer les trajectoires historiques de croissance différentes suivies par l'Europe et la Chine. Enfin, Jayachandran (2020) étudie le lien entre normes de genre et développement économique.

Il a aussi été documenté que les normes affectent les activités entrepreneuriales, l'organisation des entreprises et les choix professionnels. Doepke and Zilibotti (2014) analysent, au moyen d'un modèle, comment la tolérance au risque et la patience peuvent affecter l'allocation du travail entre activités entrepreneuriales et non-entrepreneuriales, ce qui influe ensuite sur la croissance économique. Stephan and Uhlaner (2010) et Hopp and Stephan (2012) montrent que les cultures qui promeuvent le succès individuel et les investissements de long terme ont des niveaux plus élevés d'entrepreneuriat. Seror (2018), Alesina and Giuliano (2010) et Fernandez and Fogli (2009) examinent respectivement le rôle des normes religieuses, des liens familiaux et des normes de genre dans la détermination des choix d'occupation. Kontogiannis, Litina and Varvarigos (2019) démontrent, au moyen d'un modèle de croissance monétaire, comment une norme de statut qui attribue différents niveaux de respectabilité à différents projets entrepreneuriaux peut affecter la production de capitaux. Enfin, Gorodnichenko and Roland (2017) et Acemoglu, Akcigit and Celik (2014) mettent en évidence comment les cultures individualistes et l'ouverture aux idées disruptives favorisent l'innovation et Bloom, Sadun and Van Reenen (2012) montrent que le capital social, approximé par la confiance, accroît la productivité en affectant l'organisation des entreprises.

Enfin, plusieurs articles montrent que les normes influent sur la coopération, le commerce et l'efficacité politique. Waring and Bell (2013) établissent que la dominance ethnique a plus d'effets sur la coopération que la diversité ethnique. Ostrom (1990) étudie comment l'altruisme et les normes d'action collective affectent les institutions d'action collective. Guiso, Sapienza and Zingales (2009) montrent que le niveau de confiance bilatérale entre deux pays affecte l'intensité du commerce, les investissements étrangers directs et les investissements de portefeuille entre eux. L'effet sur l'intensité du commerce est renforcé dans le cas des biens reposant davantage sur la confiance entre acheteurs et vendeurs. La Porta et al. (1999) montrent que la religion et la confiance sociale influencent l'efficacité politique. Bethencourt and Kunze (2020) proposent un modèle expliquant le constat que les pays à faible revenu ont un niveau élevé d'évasion fiscale à la fois pour l'impôt sur le revenu du travail et l'impôt sur le revenu du capital : ils montrent qu'une norme sociale de conformité fiscale peut conduire à une complémentarité entre évasions fiscales en matière d'impôt sur le revenu du travail et du capital, ce qui explique le déclin de la proportion de fraudeurs fiscaux et du montant de la fraude fiscale quand les pays s'enrichissent.

Ainsi, il est clair que les normes affectent tous les aspects de l'économie. Quand une société repose sur des normes inefficaces, celles-ci peuvent être abandonnées si d'autres sociétés avec

des normes supérieures la remplacent (par conquête, croissance ou migration), si elle décide d'imiter les normes de sociétés plus prospères ou si des changements individuels de comportement au sein de la société mènent à l'émergence d'une nouvelle norme (Young, 2007).

## L'évolution des normes et cultures

Quelques caractéristiques des normes sont cruciales pour l'analyse de leur évolution (Young, 2015*b*). Tout d'abord, les normes se renforcent d'elles-mêmes à l'échelle d'un groupe. Par conséquent, le bénéfice tiré de l'adhésion à une norme s'accroît avec le nombre d'individus qui y adhèrent. Ensuite, les normes évoluent à partir de comportements individuels indépendants par un processus progressif d'expérimentation, d'erreurs et d'adaptation. Enfin, les normes peuvent prendre diverses formes, en fonction du contexte historique et social.

Il existe une riche littérature sur la dynamique des normes, avec des contributions venues de l'économie, la sociologie, la philosophie et des sciences politiques. Cette littérature repose largement sur la théorie des jeux pour expliquer l'émergence de normes sociales. Schelling (1978) est l'un des précurseurs dans ce domaine. Il utilise la théorie des jeux pour analyser les normes en mobilisant les concepts d'équilibre coordonné et de point de bascule. Mackie (1996) étend ce cadre d'analyse pour expliquer la persistance de normes inefficaces et Akerlof (1980, 1997) montre comment les interactions sociales et la pression sociale contraignant à suivre les normes prévalentes peuvent conduire à des équilibres inefficaces qui sont ensuite difficiles à quitter. Dans des articles plus récents, la théorie des jeux évolutionnaires s'est révélée particulièrement utile pour l'analyse de la dynamique des normes.<sup>45</sup> En effet, elle permet d'analyser comment des individus interagissant les uns avec les autres peuvent progressivement adopter une norme commune ou passer d'une norme à une autre, en raison de changement des préférences individuelles. Cette théorie a été appliquée à l'étude des normes contractuelles dans le secteur agricole (Young and Burke, 2001), des conventions socio-linguistiques (Naidu, Hwang and Bowles, 2017), des hiérarchies sociales (Hwang, Naidu and Bowles, 2016), des normes de pratique médicale (Burke, Fournier and Prasad, 2010), des normes concernant les droits de propriété (Bowles and Choi, 2013, 2019) et des normes concernant le port de signes religieux (Carvalho, 2013).

Parallèlement à cette littérature, une autre approche de l'analyse de la dynamique des cultures explique l'évolution des traits culturels par une théorie de transmission culturelle inter-générationnelle. Celle-ci a été initiée par les travaux de Cavalli-Sforza and Feldman (1981) et Boyd and Richerson (1988), puis étendue par Bisin et Verdier dans une série d'articles<sup>46</sup> par l'ajout d'un choix parental de socialisation des enfants. Cette théorie s'appuie sur un double mécanisme de transmission culturelle : *la transmission verticale* (i.e. les traits culturels sont

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45. Voir Young (1993, 1998); Kandori, Mailath and Rob (1993) et Young, Jindani et al. (2019).

46. Voir Bisin and Verdier (1998, 2000*b,a*, 2001).



transmis de parents à enfants) et *la transmission horizontale* (i.e. les traits culturels sont transmis par le reste de la société). Elle a été appliquée dans plusieurs études empiriques.<sup>47</sup>

Enfin, une troisième approche fondée par Güth and Yaari (1992) se concentre sur l'évolution des préférences expliquée par une *approche évolutionnaire indirecte*. Cette approche se fonde sur l'hypothèse que les joueurs se comportent de façon rationnelle pour un ensemble de préférences donné, mais que ces préférences évoluent selon un processus évolutionnaire. Elle a été appliquée à l'étude de la stabilité évolutionnaire des préférences<sup>48</sup> et à l'analyse de l'évolution conjointe des institutions politiques et des valeurs culturelles.<sup>49</sup>

La dynamique des normes telle qu'étudiée avec ces trois approches possède quelques caractéristiques spécifiques (Young, 2015*b*). Les normes sont persistantes dans le temps et leur dynamique possède souvent des points bascule (points où les normes se mettent soudainement à changer), des équilibres ponctués (les normes passent de longues périodes à l'équilibre séparées par de courtes périodes de transition) et un niveau de compression important (plus d'homogénéité dans les comportements qu'en l'absence de norme). Elle conduit aussi à des comportements caractérisés par beaucoup de conformité à l'échelle locale et de diversité à l'échelle globale.

## **Le rôle clé de l'identité dans l'adoption des normes sociales**

L'adoption de normes sociales est largement fondée sur "un sentiment d'appartenir à une identité" (Akerlof and Kranton, 2010), si bien que l'étude de l'impact économique des normes sociales et l'étude de la formation des identités sont inévitablement liées. L'analyse de l'émergence d'identités et de leurs effets sur les processus économiques est le sujet d'une branche de la littérature relativement récente, l'"économie de l'identité" lancée par l'article fondateur d'Akerlof and Kranton (2000). Dans les modèles d'économie de l'identité, trois échelles de temps sont en jeu (Kranton, 2016). Dans le court terme, les individus prennent des décisions économiques en considérant les normes, catégories sociales et identités comme données. Dans le moyen terme, les individus peuvent changer leur identité, leur catégorie sociale et les normes. Enfin, dans le long terme, plus rien n'est fixé.

Trois principaux types de mécanismes ont été proposés pour comprendre la formation des identités. Dans le premier, les identités émergent à partir d'un processus évolutionnaire de mutations et sélection qui équipe chaque individu d'une fonction d'utilité et de processus d'apprentissage qui tendent à maximiser son niveau d'adaptation à son environnement. En général, une perspective de principal-agent est adoptée, dans laquelle le principal est le processus na-

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47. Voir Bisin and Topa (2003); Bisin, Topa and Verdier (2004) et Giavazzi, Petkov and Schiantarelli (2019).

48. Voir Robson (1990); Güth and Yaari (1992); Bester and Güth (1998); Alger (2010); Alger and Weibull (2010, 2013); Ok and Vega-Redondo (2001) et Dekel, Ely and Yilankaya (2007).

49. Voir Wu (2016) et Besley and Persson (2019).



turel de sélection et l'agent est un individu avec un ensemble de gènes.<sup>50</sup> Selon le deuxième mécanisme, les identités émergent car les individus en bénéficient directement. Ce bénéfice peut venir, par exemple, d'une confiance en soi accrue par une bonne compatibilité avec les valeurs du groupe.<sup>51</sup> Enfin, le troisième mécanisme explique la formation des identités par une transmission inter-générationnelle.<sup>52</sup>

## Les interactions sociales et politiques publiques en économie urbaine

L'économie des villes est largement influencée par les interactions entre individus et par les normes sociales qui conditionnent ces interactions. Cette influence est de plus en plus souvent prise en compte dans les analyses empiriques et théoriques en économie urbaine. Dans ce qui suit, je donne une brève vue d'ensemble des différentes branches de l'économie urbaine dans lesquelles les interactions et normes sociales jouent un rôle important.

### Économie urbaine et économie d'agglomération

Tout d'abord, un certain nombre d'articles d'économie urbaine analysent comment les interactions sociales conduisent à l'émergence de centres urbains par le biais d'externalités spatiales positives. Ils étudient comment les externalités spatiales affectent la localisation des ménages et des entreprises, la densité urbaine et la productivité économique.<sup>53</sup> Par exemple, Mossay and Picard (2011a) et Mossay, Picard et al. (2013) modélisent les interactions sociales pour étudier les conditions menant à l'émergence de différents types de structures urbaines. Roca and Puga (2017) montrent empiriquement que les individus accumulent une expérience de plus grande valeur (monétaire) en travaillant dans de grandes villes plutôt que dans de petites villes.

### Influence des pairs, réseaux sociaux et urbanisation

Une petite partie de la littérature analyse le rôle des réseaux sociaux dans les villes<sup>54</sup> d'un point de vue théorique. Par exemple, Kim et al. (2017) démontrent que la localisation géographique des individus et leur capital social ont des effets sur la formation de liens sociaux. D'un point de vue empirique, la plupart des études sur le rôle de la distance dans la formation des liens sociaux viennent des domaines des sciences informatiques ou de la mécanique statistique et

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50. Voir Robson (2001); Rayo and Becker (2007a,b) et Robson and Samuelson (2011).

51. Voir Bénabou and Tirole (2006); Benabou and Tirole (2011) et Akerlof (2017).

52. Voir Lizzeri and Siniscalchi (2008); Doepke and Zilibotti (2017) et Seror (2019).

53. Voir Beckmann (1976); Ogawa and Fujita (1980); Lucas and Rossi-Hansberg (2002); Helsley and Strange (2014); Behrens, Duranton and Robert-Nicoud (2014); Glaeser (1999); Helsley and Strange (2004); Berliant, Peng and Wang (2002) et Berliant and Wang (2008).

54. Voir Brueckner and Largey (2008); Helsley and Strange (2007); Zenou (2013a); Mossay and Picard (2011b); Helsley and Zenou (2014b); Sato and Zenou (2015) et Kim et al. (2017).

visent à mesurer la forme de la relation statistique entre probabilité d'un lien social et distance géographique.<sup>55</sup>

### **Effets de voisinage, ségrégation socio-économique endogène et culture**

Une branche de la littérature proche de la précédente traite des effets de voisinage et de ségrégation socio-économique endogène. Elle cherche à expliquer comment les interactions locales conduisent à des situations persistantes de ségrégation spatiale et d'inégalités de revenu.<sup>56</sup> Dans ces articles, l'évolution des inégalités de revenu entre quartiers s'explique par des différences d'accumulation de capital humain par le biais d'une transmission inter-générationnelle de capital humain entre parents et enfants et par des effets de diffusion spatiale locale. A titre d'exemple, Borjas (1998) explique l'émergence de ségrégation ethnique entre quartiers par l'existence de diffusion ethnique dans le processus d'accumulation de capital humain.

Des études ont montré que cette ségrégation socio-économique endogène interagit avec la dimension culturelle. Ainsi, Bisin et al. (2011) et Zimmermann, Constant and Schüller (2014) analysent comment la ségrégation urbaine affecte l'identité ethnique et Wilson (1987), Anderson (2000) et Small and Lamont (2008) démontrent que la ségrégation des minorités ethniques dans les quartiers pauvres génère une "culture de la pauvreté" en isolant ces minorités des normes sociales les plus répandues. Dans le même ordre d'idées, Falk and Zehnder (2013) mesurent différents niveaux de confiance dans différentes zones de la ville de Zürich. Réciproquement, Cutler, Glaeser and Vigdor (2008) établissent empiriquement que la distance culturelle entre une minorité immigrée et le reste de la population affecte significativement le niveau de ségrégation. En effet, la transmission culturelle est l'un des déterminants clés du choix d'école ou de quartier réalisé par les parents.<sup>57</sup> Étant donné ces résultats, Moizeau (2015) propose un modèle d'économie urbaine qui permet d'analyser comment la ségrégation et la transmission culturelle interagissent et peuvent soit mener à une ville où des normes opposées coexistent soit à une ville où une norme unique est adoptée par tous.

### **Statuts des quartiers**

La nature endogène de la ségrégation urbaine implique que les statuts des quartiers, qui peuvent être interprétés comme des normes sociales, évoluent dans le temps. Ce phénomène a été analysé par plusieurs études.<sup>58</sup> Celles-ci ont montré que, même si le statut économique de nombreux quartiers persiste dans le temps, il n'est pas rare d'observer des changements de statut. Ces évolutions sont déterminées par de nombreux facteurs, tels que la dégradation progressive

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55. Voir Liben-Nowell et al. (2005); Lambiotte et al. (2008); Goldenberg and Levy (2009); Krings et al. (2009) et les revues de littérature suivantes : Barthélemy (2011); Kaltenbrunner et al. (2012) et Ioannides (2013).

56. Voir, par exemple, Loury (1976); Benabou (1993, 1996*b,a*); Borjas (1998) et Durlauf (1996).

57. Voir Ioannides, Zanella et al. (2008); Tinker and Smart (2012).

58. Voir Card, Mas and Rothstein (2008), Rosenthal (2008) et Rosenthal and Ross (2015) pour une vision d'ensemble.

du stock de logements et des infrastructures de transport, les avantages naturels, les aménités, les politiques publiques et les effets de diffusion qui s'auto-amplifient.

### **L'inadéquation géographique**

Une autre conséquence de la ségrégation urbaine est la bien connue "hypothèse de l'inadéquation géographique" (i.e. "spatial mismatch hypothesis"), d'abord formulée par Kain (1968).<sup>59</sup> Cette hypothèse repose sur l'observation que les travailleurs appartenant aux minorités noires tendent à vivre loin des principaux centres d'emploi. Cette distance est considérée comme la barrière majeure empêchant ces minorités d'obtenir et de conserver des emplois bien rémunérés. Les mécanismes théoriques proposés pour expliquer cette situation s'appuient sur des modèles de recherche d'emploi (i.e. "search models"). Ils montrent que les travailleurs les plus distants ont tendance à moins s'investir dans la recherche d'un emploi et restent donc au chômage plus longtemps.<sup>60</sup>

### **Politiques publiques urbaines**

Au regard des effets économiques importants des interactions sociales au sein des villes, nombre de politiques publiques ont été menées pour améliorer l'environnement social dans les quartiers les plus pauvres, soit en ciblant spécifiquement ces zones géographiques au moyen de *politiques ciblées sur les territoires* (i.e. *place-based policies*), soit en ciblant directement les individus pauvres qui sont particulièrement représentés dans ces quartiers au moyen de *politiques ciblées sur les personnes* (i.e. *people-based policies*). En Europe, les gouvernements s'appuient davantage sur des politiques ciblées sur les territoires que sur les personnes. Cependant, l'efficacité relative de ces deux approches est depuis longtemps âprement débattue par les économistes. Plusieurs arguments plaident en faveur de l'usage de politiques ciblées sur les territoires. En effet, ces politiques peuvent favoriser le développement d'économies d'agglomération, par le biais d'opportunités accrues de "partage, appariement et apprentissage" (Duranton and Puga, 2004). Elles peuvent aussi résoudre le problème de l'"inadéquation géographique" (Gobillon, Selod and Zenou, 2007). Cependant, les politiques ciblées sur les territoires sont aussi associées à d'importantes limitations. Elles peuvent conduire à des "effets de diversion" en bénéficiant à un quartier aux dépens d'un autre, mais aussi à des "effets d'aubaine" si elles bénéficient à des agents qui n'en avaient pas besoin et se seraient installés dans les quartiers pauvres de toute façon. D'autres problèmes liés à ces politiques sont les "effets boîte aux lettres" ("mailbox effects", typiquement dans le cas où des entreprises appliquent des stratégies d'optimisation fiscale pour tirer profit des programmes de Zones d'Emploi), et les "effets de stigmatisation" conduisant à l'évitement des quartiers ciblés ou de leurs habitants (Briant, Lafourcade and Schmutz, 2015). De nombreuses études empiriques ont été menées

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59. Voir les synthèses proposées par Ihlanfeldt and Sjoquist (1998); Ihlanfeldt (2006) et Zenou (2008).

60. Voir Coulson, Laing and Wang (2001); Wasmer and Zenou (2002) et Zenou (2013b).

afin d'évaluer l'efficacité de diverses politiques ciblées sur les territoires et, en particulier, des programmes de Zones d'Emploi. Les résultats obtenus concernant, en particulier, l'efficacité de ces derniers sont très mitigés (voir Neumark and Simpson (2015) sur ce sujet).

Après ce survol des nombreuses branches de la littérature économique liées à cette dissertation de thèse, je détaille plus précisément, dans ce qui suit, les contributions des trois essais de la dissertation.

## **Contributions et grandes lignes de la dissertation**

Dans la littérature sur l'évolution des normes sociales, un certain nombre d'articles s'appuient sur des modèles de théorie des jeux évolutionnaires pour analyser l'émergence et la persistance de hiérarchies sociales entre groupes sociaux.<sup>61</sup> Ces modèles permettent d'expliquer pourquoi les processus évolutionnaires conduisent souvent à l'émergence et à la persistance de normes inégalitaires (un groupe dominant l'autre) et inefficaces. Toutefois, les mécanismes proposés concernent uniquement le contexte d'un pays composé de deux groupes sociaux et ne peuvent pas décrire les interactions entre groupes dans le contexte plus large d'un pays multi-culturel avec plusieurs minorités influençant réciproquement le statut des autres. En particulier, ces mécanismes ne permettent pas d'analyser les effets sur la hiérarchie ethno-culturelle de l'immigration d'une nouvelle minorité ou de la division d'une minorité en deux groupes sociaux distincts. En outre, ils ne peuvent pas expliquer la relation non-linéaire entre la taille d'une minorité et son statut suggérée par les résultats fournis par la littérature empirique.

A partir de ces constats, le premier essai de cette dissertation propose un modèle de coordination de théorie des jeux évolutionnaires adapté à l'analyse de l'émergence de hiérarchies ethno-culturelles dans des pays multi-culturels. Dans ce modèle multi-groupes et multi-stratégies, chaque membre de la société appartient à un groupe ethno-culturel et a une vision personnelle de la hiérarchie ethno-culturelle, i.e. des statuts relatifs des différents groupes ethno-culturels. A chaque période, chaque individu est apparié avec un certain nombre d'autres individus. Quand deux individus sont appariés, ils interagissent selon un jeu de coordination dans lequel leurs stratégies respectives correspondent à leurs visions de la hiérarchie ethno-culturelle. Si les deux individus appariés appartiennent à des groupes différents et ont la même vision hiérarchique (i.e. il y a coordination), ils obtiennent tous deux un bénéfice strictement positif. Si cette vision hiérarchique commune est égalitaire, les deux individus obtiennent le même bénéfice. Si cette vision accorde un statut supérieur à un groupe, le bénéfice du membre du groupe supérieur est plus élevé que celui du membre du groupe dominé. Si les deux individus appariés appartiennent à des groupes différents et ont des conceptions hiérarchiques

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61. Voir Naidu, Hwang and Bowles (2017) et Hwang, Naidu and Bowles (2016).

différentes, tous deux obtiennent un bénéfice nul. Au début de chaque période, un individu a la possibilité d'actualiser sa conception hiérarchique. Avec une probabilité très élevée, cet individu adopte sa meilleure réponse à la distribution des conceptions hiérarchiques dans la société à la période précédente. Avec une probabilité très faible qui tend vers zéro, il adopte une conception hiérarchique aléatoire (i.e. il mute aléatoirement). La distribution des conceptions hiérarchiques dans la population évolue donc avec le temps selon un processus de Markov qui converge vers une unique distribution stationnaire des conceptions hiérarchiques.

Le modèle prédit, en accord avec les résultats de la littérature empirique,<sup>62</sup> que les sociétés avec de petites minorités ethno-culturelles tendent à adopter une hiérarchie ethno-culturelle inégalitaire dans laquelle les minorités font face à divers degrés de discrimination. Il suggère aussi qu'un accroissement de la taille d'une minorité peut améliorer le statut de cette minorité ou le réduire, en fonction de la taille relative de cette minorité par rapport aux autres minorités. Cela pourrait expliquer les résultats contradictoires obtenus sur cette question dans la littérature empirique.<sup>63</sup> Le modèle démontre, par ailleurs, l'existence de forces poussant à la fragmentation des minorités. En effet, la division d'une minorité, même si elle est toujours désavantageuse dans le modèle pour le plus petit nouveau groupe créé, peut améliorer le statut du nouveau groupe le plus large, ce qui l'encourage à se séparer du reste de la minorité. Pour finir, dans une extension très simple du modèle, il est montré que, si les interactions entre individus de statut égal sont plus productives que les interactions entre individus inégaux comme la littérature le suggère,<sup>64</sup> les sociétés multi-culturelles évoluent généralement vers une hiérarchie sociale inégalitaire et inefficace.

Ce modèle est, à ma connaissance, le premier à proposer un mécanisme permettant d'analyser l'émergence de hiérarchies ethno-culturelles dans un contexte multi-culturel en prenant en compte à la fois les motivations des membres du groupe majoritaire et des différentes minorités. Il est aussi le premier à analyser l'évolution de normes au moyen d'un modèle paramétrique et asymétrique de théorie des jeux évolutionnaires multi-groupes et multi-stratégies ( $3 \times 4$ ) en faisant appel à la théorie des graphes.

Alors que les interactions et normes sociales sont de plus en plus souvent prises en compte dans les modèles récents d'économie urbaine comme nous l'avons vu dans le résumé de la

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62. Voir Hagendoorn (1995); Hofer et al. (2013); Berry and Kalin (1979); Pager, Bonikowski and Western (2009); Tenenbaum and Ruck (2007); Parrillo and Donoghue (2013); Brewer and Campbell (1976); Sautman (1994); Maurer-Fazio (2012); Chua, Mathews and Loh (2016); Booth, Leigh and Varganova (2012); Kalin and Berry (1996); Storm, Sobolewska and Ford (2017); Heath and Di Stasio (2019) et Zschirnt and Ruedin (2016).

63. Voir Coenders (2001); Fossett and Kiecolt (1989); Pettigrew and Cramer (1959); Quillian (1995, 1996); Scheepers, Gijsberts and Coenders (2002); Semyonov, Rajman and Gorodzeisky (2006); Coenders, Lubbers and Scheepers (2005); Evans and Need (2002); Semyonov et al. (2004); Strabac and Listhaug (2008); Hood III and Morris (1997) et Lubbers, Coenders and Scheepers (2006).

64. Voir Waring and Bell (2013); Anderson, Mellor and Milyo (2008); Nishi et al. (2015); Fehr (2018); Dickinson, Masclet and Peterle (2018) et Sadrieh and Verbon (2006).

littérature précédent, la plupart de ces modèles ne sont pas adaptés à l'analyse des villes des pays en développement et, plus spécifiquement, à l'analyse des villes d'Afrique de l'ouest. Contrairement aux villes des pays développés, dans les villes des pays en développement, une proportion importante des terrains fonciers n'est pas enregistrée auprès de l'administration foncière en raison notamment de coûts d'enregistrement très élevés. Cette situation crée de l'insécurité foncière et, par suite, réduit l'investissement foncier, le niveau de participation au marché du travail et la négociabilité des terrains,<sup>65</sup> tout en amplifiant certains maux sociaux tels que la criminalité, les problèmes de santé liés à une mauvaise qualité des logements, et le faible niveau de capital humain.<sup>66</sup> Une autre spécificité des villes d'Afrique sub-Saharienne est le rôle important des normes sociales impliquant des devoirs réciproques entre certains groupes sociaux désignés par les termes "alliés", "parents" ou "cousins".<sup>67</sup> Ces normes peuvent servir, notamment, à la réduction de l'insécurité lors des transactions foncières.

Le deuxième essai de cette dissertation, co-écrit avec Harris Selod, Économiste Senior à la Banque Mondiale, est, à notre connaissance, le premier à analyser l'interaction entre normes sociales et marchés fonciers et à étudier comment la réalisation de transactions foncières entre personnes de confiance peut résoudre les asymétries d'information associées aux transactions informelles sur les marchés urbains d'Afrique sub-Saharienne.<sup>68</sup> Dans notre modèle, acheter un terrain informel est risqué pour les acheteurs car la propriété foncière pourrait être contestée dans le futur. Dans un monde idéal, il serait possible d'éviter d'avoir des revendications de propriété contradictoires en permettant l'enregistrement des propriétés foncières dans un cadastre et l'émission consécutive de titres de propriété. En pratique, il peut être très coûteux d'enregistrer un terrain foncier auprès de l'administration et cette solution n'est choisie que par une portion limitée de la population. Dans ce contexte, l'objectif de cet essai est d'analyser comment les ménages urbains qui n'enregistrent pas leur terrain peuvent, par mesure de substitution, s'appuyer sur une norme sociale de confiance et ainsi réduire l'insécurité lors de transactions de terrains informels. Plus spécifiquement, nous étudions un mécanisme par lequel acheteurs et vendeurs peuvent s'apparier sur le marché informel selon des liens ethniques de confiance qui réduisent l'asymétrie d'information et la probabilité d'acheter un terrain risqué.

Nous formalisons ces idées dans un modèle d'économie urbaine avec insécurité foncière et asymétrie d'information, dans lequel nous étudions les transactions sur le marché foncier à l'équilibre et les inefficacités associées. Dans notre modèle, les terrains sont de deux types possibles : les terrains risqués dont la propriété peut être contestée dans le futur et les terrains non risqués dont la propriété ne peut pas être contestée. De plus, les acheteurs et vendeurs de terrains peuvent avoir des devoirs réciproques fondés sur des liens ethniques de confiance. Si

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65. Voir Besley (1995) et Field (2007).

66. Voir Galiani and Schargrotsky (2010); Galiani et al. (2017) et Nakamura (2017).

67. Voir Mauss (1923); Raphaël (1992); Smith (2004, 2006); Diallo (2006) et Dunning and Harrison (2010).

68. Voir Durand-Lasserve, Durand-Lasserve and Selod (2015) et Bank (2019).



un terrain risqué est échangé entre deux individus liés par un lien de confiance sans que le vendeur fasse part de ce risque à l'acheteur, il sera considéré que le vendeur n'a pas fait son devoir et une punition sociale lui sera infligée. Par conséquent, un acheteur s'attend à ce qu'un vendeur avec lequel il a un lien de confiance ethnique ait plus de chances de lui vendre un terrain sûr et il sera donc prêt à payer une prime pour le terrain. Sachant cela, les vendeurs peuvent décider de réaliser une transaction avec un allié ou non, en fonction du risque pesant sur leur terrain, de la punition sociale et de la prime ethnique. Une prédiction importante du modèle est que, même si l'appariement selon les liens ethniques réduit l'asymétrie d'information, il réduit aussi la participation globale au marché. Si, à l'inverse, les propriétaires se voient donner la possibilité de sécuriser leur propriété foncière en payant pour l'enregistrer dans un cadastre, l'asymétrie d'information et l'insécurité foncière sont toutes deux réduites, mais le coût d'enregistrement limite les transactions à la périphérie de la ville. Nous comparons le surplus total dans ces deux cas pris indépendamment et dans une version hybride du modèle où l'enregistrement et les liens de confiance sont tous deux possibles, comme c'est le cas dans de nombreuses villes d'Afrique sub-Saharienne.

A notre connaissance, ce modèle est le premier modèle d'occupation des sols avec des transactions interpersonnelles, une caractéristique importante qui faisait grandement défaut dans la littérature théorique sur les marchés fonciers des pays en développement malgré l'importance plus que probable de ce type de transactions. L'introduction d'un appariement ethnique nous permet d'évaluer et de comparer les avantages respectifs des transactions sanctionnées par un enregistrement des titres de propriété et des transactions conduites dans le cadre de relations de confiance. Elle nous permet aussi d'étudier la coexistence de ces deux pratiques dans une même ville. Notre modèle génère de nouvelles prédictions concernant la prévalence de l'appariement ethnique dans les marchés fonciers où l'enregistrement est très coûteux, la substituabilité entre relations de confiance et enregistrement, et l'évolution progressive des économies vers une couverture cadastrale complète avec des normes de confiance affaiblies, au fur et à mesure que les coûts d'enregistrement des terrains seront réduits.

Parmi les diverses politiques ciblées sur les territoires implémentées par les gouvernements pour réduire les inégalités spatiales au sein des villes et améliorer les conditions de vie dans les quartiers défavorisés, un certain nombre de politiques de rénovation urbaine ont été mises en œuvre dans les pays occidentaux durant ces dernières décennies.<sup>69</sup> Cependant, en comparaison avec les autres politiques ciblées sur les territoires, telles que les programmes de Zones d'Emploi,<sup>70</sup> peu d'études empiriques des impacts de la rénovation urbaine s'appuyant sur une stratégie d'identification causale ont été conduites. De plus, la plupart des études an-

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69. e.g. aux États-Unis, aux Pays-Bas, en Espagne, au Royaume-Uni et en France.

70. Voir Briant, Lafourcade and Schmutz (2015) et Fisman (2001).

térieures mobilisent des stratégies empiriques essentiellement fondées sur des différences de différences. Or, celles-ci sont sujettes à des biais d'estimation si l'effet de la rénovation est hétérogène entre quartiers ou périodes temporelles ou s'il y a un déséquilibre dans le statut de traitement selon ces dimensions (voir De Chaisemartin and D'Haultfœuille, à paraître dans l'AER, pour une discussion de ce problème). Enfin, les analyses empiriques antérieures ont généralement concerné des programmes de petite échelle mettant en jeu peu de quartiers, généralement au sein d'une unique ville. A ma connaissance, le seul programme de rénovation mené à l'échelle nationale dont l'impact ait été étudié empiriquement à l'échelle locale a été conduit aux Pays-Bas (Koster and Van Ommeren, 2019). Mais son niveau de financement était limité à 1 milliard d'euros investis entre 2007 et 2012.

Dans ce contexte, le troisième essai de cette dissertation de thèse, co-écrit avec Florence Goffette-Nagot (CNRS-GATE) et Sylvain Chareyron (Université Paris-Est Créteil), analyse un programme de rénovation urbaine de très grande ampleur, le *Programme National de Rénovation Urbaine (PNRU)*, lancé en 2004 en France. Afin de prévenir les biais potentiels dans l'estimation des effets du programme évoqués ci-dessus, nous appliquons la toute nouvelle méthode proposée par De Chaisemartin and D'Haultfœuille (à paraître dans l'AER). Notre article est, à notre connaissance, le premier à appliquer cette méthode dans le cadre de la rénovation urbaine. De plus, le PNRU a mobilisé un investissement de plus de 47 milliards d'euros pour la rénovation d'environ 600 quartiers répartis sur l'ensemble du territoire français, Outre-mer compris. Cette grande échelle a trois avantages principaux. Tout d'abord, l'échelle nationale rend les estimations plus précises car un grand nombre de quartiers contrôles permet de réduire la sensibilité du contrefactuel à des chocs non observés, comme le montrent Ahlfeldt, Maennig and Richter (2017). Ensuite, le nombre important des quartiers rénovés rend possible l'exploration de potentielles hétérogénéités d'effets du programme et donc de potentiels déterminants de l'efficacité de la rénovation. Enfin, notre base de données de transactions possède une caractéristique rare : elle contient des informations concernant les acheteurs et les vendeurs de logement, telles que leur catégorie socio-professionnelle. Cette caractéristique nous permet de compléter notre analyse des prix immobiliers et volumes de transactions, qui font l'objet de la plupart des analyses des effets de programmes de rénovation urbaine, par une étude de l'évolution du profil socio-professionnel des acheteurs et vendeurs.

Le programme PNRU a consisté en la rénovation, démolition et construction de centaines de milliers de logements sociaux et d'équipements publics. Nous étudions ses impacts sur les marchés fonciers des quartiers rénovés (i.e. logements privés). Il s'agit donc d'une évaluation des externalités du programme sur le parc privé et non d'une évaluation directe des effets du programme sur la valeur des logements rénovés. Nous commençons par mesurer les effets globaux du programme sur les valeurs foncières dans l'ensemble des quartiers rénovés. Nous étudions ensuite les hétérogénéités d'effets sur les valeurs foncières, d'abord en fonction du



niveau de financement par unité de logement (i.e. unité de logement présente dans le quartier avant le début du programme) reçu par les quartiers, puis en fonction de la proportion initiale de logements sociaux dans le quartier et, enfin, en fonction de la taille de l'unité urbaine (i.e. en séparant les quartiers situés dans l'une des 4 plus grandes unités urbaines françaises, Paris, Lyon, Marseille ou Lille, et les quartiers situés dans les autres unités urbaines françaises). Après cela, nous évaluons les effets du programme sur le volume de transactions et sur les catégories socio-professionnelles des acheteurs et vendeurs de logements.

Nos résultats indiquent que la rénovation n'a pas conduit à un accroissement significatif des valeurs immobilières dans les quartiers rénovés au niveau de la France entière entre 2004 et 2014. Le résultat est robuste à divers tests de sensibilité. De plus, nous ne trouvons pas de différences substantielles dans les impacts estimés, que ce soit en fonction du niveau de financement par unité de logement reçu par le quartier, de la proportion initiale de logements sociaux dans le quartier ou de la taille de l'unité urbaine dans laquelle le quartier est situé. Il est possible, néanmoins, que le programme ait eu un faible impact sur les prix immobiliers, mais celui-ci a dû être suffisamment faible pour ne pas être capturé par notre analyse, c'est-à-dire inférieur à 3.5%. Nous ne trouvons pas non plus d'effets sur le volume de transactions. Cependant, nos résultats indiquent que le programme a affecté significativement le profil socio-professionnel des acheteurs et vendeurs de logements dans les quartiers rénovés. Nous observons, en effet, un glissement vers le haut des catégories socio-professionnelles des acheteurs de logements par rapport aux vendeurs, ce qui semble traduire une amélioration sensible de l'attractivité des quartiers rénovés.



# Chapitre 1

## ***Why can't we be friends ? An evolutionary approach to the emergence of ethno-cultural hierarchies*** \*

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**Abstract :**

The productivity of a society largely depends on the quality of interactions between its members, which is deeply influenced by existing social norms and, in particular, ethno-cultural hierarchies. Understanding how ethno-cultural hierarchies emerge and persist through individual interactions is thus of crucial importance for economists. This paper proposes a three-group (one majority and two ethno-cultural minorities) evolutionary game model for the emergence of ethno-cultural hierarchies in a multi-cultural society. Its main predictions are : (1) societies with small ethno-cultural minorities tend to adopt inegalitarian hierarchy views in which minorities each hold a distinct dominated social status (as opposed to egalitarian hierarchy views in which all groups hold similar social statuses), (2) an increase in the size of a minority affects hierarchy views in a complex way that may improve or hurt this minority's status, depending on the size of the other ethno-cultural groups, (3) the splitting of a minority into two smaller groups may improve the status of the largest new group, but is always detrimental to the smallest new one, (4) if interactions between individuals holding equal statuses are more productive than interactions between unequal individuals, multi-cultural societies generally evolve towards inefficient inegalitarian hierarchy views. This model is, to the best of my knowledge, the first to propose a comprehensive mechanism for the emergence of ethno-cultural hierarchies, in which both the majority's and the different minorities' incentives are taken into account. It is also the first to rely on the theoretical analysis of a parametric multi-group and multi-strategy ( $3 \times 4$ ) asymmetric evolutionary game model using graph theory.

**Keywords :** Evolutionary game, Ethno-cultural hierarchies, Institutions

**JEL :** C73, D02, J15

## 1.1 Introduction

Social hierarchies constitute one of the most common type of social organization, both in human and nonhuman primate groups<sup>1</sup>. They tend to emerge rapidly from short-term social interactions<sup>2</sup> and are pervasive in our daily life activities. They play a determinant role in shaping our understanding of the world, our feelings, as well as our social and economic behaviors.<sup>3</sup> It is therefore critical to understand how they emerge and why they are so persistent, as well as to study whether they lead to economically efficient outcomes .

Hitherto, the existing literature concerning the determinants of ethno-cultural discriminations and hierarchies provides a number of psychological and sociological explanations for the existence of discrimination against outgroups.<sup>4</sup> However, it does not provide a theory for the persistence, in each country, of a wide consensus within and across ethno-cultural groups over a common ethno-cultural hierarchy and does not analyze how minorities affect each other's social statuses. Indeed, studies have been focusing on bilateral differences (e.g. in culture, income level and phenotype) between a given minority and the country's majority group, while overlooking the broader ethno-cultural context in which these two groups interact. Yet, this context is crucial, as it may lead to competition or alliances between minority groups, which can affect hierarchy views. For instance, Asian Americans are generally considered as a "model minority" in the United States (Chao et al., 2013). But, would they be perceived so positively if African Americans and Latino Americans, who are associated with a less advantageous image, did not make up one third of the country's population? Though it appears to be very unlikely, the existing literature concerning the determinants of ethnic group discriminations does not provide, to my knowledge, any convincing theory to analyze this question.

This oversight can be seen as problematic for several reasons. First, much anecdotal evidence suggests that the delineation of ethno-cultural groups and perceived cultural similarities between them are affected by the overall distribution of ethno-cultural characteristics within a country. For example, different ethno-cultural minority groups originating from a same country, where they used to enjoy very different statuses, can be considered as a single group in the diaspora and associated with a common social status (e.g. ethnic Turks and Turkish Kurds living in Germany<sup>5</sup>). Perceived cultural similarities with other groups may have important

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1. See Halevy, Y. Chou and D. Galinsky (2011)

2. See Anderson and Kilduff (2009).

3. For example, they have been empirically shown to impact the productivity of individuals, their consumption and occupational choices, the economic opportunities they face on various markets, as well as aggregate market outcomes (Hoff and Pandey, 2004; Afridi, Li and Ren, 2015; Charles, Hurst and Roussanov, 2009; Fershtman and Weiss, 1991; Dubois and Ordabayeva, 2015; Ball et al., 2001).

4. See Sidanius and Pratto (2001) for a review.

5. See Germane (2015)

consequences for a group's status. For example, Mendelsohn (1987) shows how Jews' status in inter-war Latvia was negatively affected by their perceived similarities with former German and Russian oppressors (Mendelsohn, 1987).

Second, evidence also suggests that the arrival of a new minority in a country may have a durable impact on the status of old minorities. As an illustration, Ignatiev (2012) discusses how the long-term improvement of the Irish minority's status in the United States was linked with the progressive immigration of culturally more distant groups.

Eventually, two minority ethno-cultural groups may have converging or diverging interests with regards to social status. They may choose to ally to advance common claims. For instance, according to Sudbury (2001), multiracial blackness (African, Caribbean and Pakistani) in Britain seems to form a unified identity that Black women activists can recourse to in order to catalyze collective action. By contrast, cases of competition between minorities have been reported, in particular, in the context of Black-Latino relations in the United States (McClain and Karnig, 1990).

The present paper aims at providing a theoretical framework for the analysis of the emergence and persistence of ethno-cultural hierarchies in the context of a multi-cultural country. To this aim, an evolutionary game theory model featuring three ethno-cultural groups (one majority and two minorities) coordinating on their hierarchy views is proposed.

In this model, each member of the society belongs to one ethno-cultural group and holds a personal view regarding the ethno-cultural hierarchy, i.e. the relative statuses of the different groups. At each period, each individual is matched with a given number of other individuals. When two individuals are matched, they interact according to a coordination game in which their respective strategies correspond to their social hierarchy views. If the two matched individuals belong to different groups and hold the same hierarchy views (i.e. there is coordination), they both obtain a strictly positive payoff. If this common hierarchy view grants the same status to the two individuals, they both get the same payoff. If this common hierarchy view grants a higher status to one of them, the payoff of the dominant individual is larger and the payoff of the dominated individual is smaller. If the two matched individuals belong to different groups and hold different hierarchy views, both get a zero payoff. Eventually, if the two matched individuals belong to the same ethno-cultural group, their ethno-cultural hierarchy views are assumed to be irrelevant to their interaction so that they both get a constant payoff, irrespective of their hierarchy views. At the beginning of each period of time, one individual is given the chance to actualize his view on the social hierarchy. With a very large probability that tends to 1, this individual adopts his best response to the distribution of hierarchy views in the society at the previous period. With a very small probability that tends to zero, he adopts a random hierarchy view (it is said that the individual mutates randomly). The distribution of social hie-

rarchy views in the population evolves through time according to a Markovian process that converges toward a unique stationary distribution.

This paper shows, in the context of a multicultural society, how different ethno-cultural hierarchies may emerge from independent interactions between members of various ethno-cultural groups. It analyzes the complex mechanisms through which the size of a minority may affect its status or the status of another minority and allows to understand how, depending on the relative sizes of the different ethno-cultural groups, several groups' interests may diverge or coincide, leading to *de facto* "decentralized alliances" or competition between them. In this model, the arrival of a new minority in a country improves or does not impact the status of old minorities. Additionally, forces encouraging the emergence of divisions within minorities exist, as members of a discriminated minority may benefit from the splitting of this minority into smaller differentiated groups, some of which holding a higher status than others after the division. Eventually, if interactions between individuals holding equal statuses are more productive than interactions between unequal individuals, as the empirical literature suggests, the model shows that multi-cultural societies generally evolve towards inefficient inegalitarian hierarchy views.

From a methodological point of view, this model is solved using the steps proposed by Young (1993).<sup>6</sup> The presence of three groups of individuals, strictly more than three hierarchy views and parameters for the different group sizes constitutes a specific challenge, as it renders computations extremely burdensome if done manually. It therefore requires the recourse to computer programming in order to calculate transition costs between equilibria depending on the parameters, and to apply Edmond's algorithm for the determination of the long run equilibrium. To the best of my knowledge, this paper is the first to mobilize these tools to analytically solve an evolutionary game model.

In the following of this paper, Section 1.2 proposes a brief review of the literature related to this model. Section 1.3 presents a simplified version of the main (three-group) evolutionary game model in the presence of only two groups : one majority and one minority. Then, Section 1.4 provides an analysis of the general version of the model with three groups : one majority and two minorities. Section 1.5 discusses the model's predictions regarding the impact of a new minority's arrival, the impact of a minority's division and the economic efficiency of long-term

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6. Young (1993)'s methodology consists in the following steps : 1) first, all the pure Nash equilibria (i.e. distributions of hierarchy views in the society in which no individual would want to unilaterally alter his strategy) are determined, 2) then, transition costs between each pair of Nash equilibria (i.e. the number of mutations in hierarchy views necessary to trigger a transition from one Nash equilibrium to each other Nash equilibrium) are computed, depending on the model's parameters, 3) an oriented graph where nodes correspond to Nash equilibria and oriented edges' weights correspond to transition costs is built, 4) the minimum spanning arborescence (or minimum spanning tree) leading to each Nash equilibrium is determined, using Edmond's algorithm, 5) the long run equilibrium then corresponds to the Nash equilibrium associated with the lowest cost minimum spanning arborescence.

hierarchy views. Section 1.6 concludes.

## 1.2 Literature

This paper is linked with several strands of the economics, sociology and psychology literature.

First, it is most closely related with the evolutionary game theory literature pertaining to the emergence of unequal, miscoordinated or suboptimal social norms.

Two main papers tackle the question of unequal norms' perpetuation through the lens of evolutionary game theory. Naidu, Hwang and Bowles (2017) analyze a battle of the sexes coordination game regarding the choice of linguistic conventions in a population composed of two classes. In this model, if the dominated population is large relative to the elite and linguistic innovations are intentional (rather than random mutations), then ambiguous and unequal linguistic conventions are likely to emerge and persist in the long run. In a related work, Hwang, Naidu and Bowles (2016) explain how, in a general bipartite network linking all individuals of a population composed of an elite and a dominated group, inefficient norms may persist, if most of the dominated group's interactions are local, while elite's interactions are more "cosmopolitan". The present model expands the same kind of evolutionary coordination game in the more complex context where the number of groups and social norms are multiplied.

A number of evolutionary game theory models instead focus on explaining the persistence of miscoordination on social norms or behaviors.<sup>7</sup> For example, Carvalho (2017) studies a  $2 \times N$  asymmetric coordination game (i.e. a game with two players/groups and  $N$  strategies possible per player) and shows that, due to differing constraints on the choices of actions faced by the two groups, miscoordination prevails in spite of strong incentives to coordinate behaviors (due to the risk-dominance of non-coordinated behaviors). Another small group of papers deals with the persistence of suboptimal social norms (Belloc and Bowles, 2013; Hwang, Naidu and Bowles, 2013; Wu, 2017). Note that all of these papers focus on  $2 \times N$  games.

Second, the present model consists in a  $3 \times 4$  asymmetric evolutionary game model (i.e. with three players/groups and four strategies) and is therefore also linked with multi-player and multi-strategy evolutionary game theory (i.e. the study of evolutionary games with strictly more than two players/groups and strictly more than two strategies per player). A major specificity of multi-player and multi-strategy evolutionary games is that, while in  $2 \times 2$  symmetric coordination games a Nash equilibrium is stochastically stable if and only if it is risk dominant, it is not the case in games with more players (Young, 1993). Most models in the multiple-

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7. See Myatt and Wallace (2004); Neary (2012).



player and multi-strategy evolutionary game theory literature are symmetric in the sense that all players/groups have the same preferences.<sup>8</sup> Samuelson (1994), however, studies a  $N \times M$  asymmetric evolutionary game. He shows that the stochastically stable distribution may include states in which dominated strategies are played. The most relevant contribution for the resolution of the present paper's model is provided by Young (1993). In this article, Young proposes a general methodology to determine the long-term equilibria (i.e. the stochastically stable equilibria) of a  $N \times M$  asymmetric evolutionary game, under a specified adaptive process. He also analyzes, as an illustration, a simple example of a  $3 \times 3$  asymmetric evolutionary game with constant payoffs (i.e. no parameters). Beside these few articles, we can note that mathematicians and computer scientists have also been studying games with multiple players and multiple strategies, called "polymatrix games", but to address questions that are very different from economists' (like the estimation of the probability to obtain a certain number of equilibria).<sup>9</sup> The present paper is, to the best of my knowledge, the first to solve analytically and discuss a multi-player (in fact three players) multi-strategy evolutionary asymmetrical game model with parameters.

Thirdly, this paper is also tightly connected with a rich array of theories from psychology and sociology explaining group inequality (Sidanius and Pratto, 2001). Some of these theories, like the Terror Management Theory<sup>10</sup> and the Value Conflict Theory,<sup>11</sup> may help explain why each given ethno-cultural group may grant different social statuses to the other groups. Indeed, according to these theories, if a group perceives some other groups as threatening because they are associated with more distant cultural views or values, it may discriminate against these groups' members more strongly than against members of less threatening groups. This perceived cultural distance can be based on more or less rational indicators, such as social distance (Parrillo and Donoghue, 2013), skin color, mastery of the language, name and clothing (Fetzer, 2013; Verkuyten and Kinket, 2000). However, these theories do not explain why groups eventually adopt a very similar ranking of the other ethno-cultural groups, how the presence of several minorities affects statuses and how the arrival of new minorities may modify hierarchy views.

Fourth, a large strand of empirical literature, in the economics and sociology fields, attempts to estimate, in a number of countries,<sup>12</sup> the level of discrimination against different mi-

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8. See Ellison (2000); Broom, Cannings and Vickers (1997); Gokhale and Traulsen (2014)

9. See Howson Jr (1972); Eaves (1973).

10. This theory hypothesizes that human beings, to counter existential anxiety, sustain cultural views that provide a meaningful way of understanding life and the universe. In this context, people consider those with different cultural world views as existentially threatening.

11. According to this theory, intergroup discrimination depends on the perceived compatibility of some cultural groups with largely accepted values such as social equality and individual freedom.

12. See Hagendoorn (1995); Hofer et al. (2013); Berry and Kalin (1979); Pager, Bonikowski and Western (2009); Tenenbaum and Ruck (2007); Parrillo and Donoghue (2013); Brewer and Campbell (1976); Sautman (1994); Maurer-Fazio (2012); Chua, Mathews and Loh (2016); Booth, Leigh and Varganova (2012); Kalin and

minority groups or the social distance between a country's different ethno-cultural groups. This literature indicates a high level of consensus within groups with respect to hierarchy views (i.e. individuals tend to widely agree on the ranking of the different minorities), and a high level of consensus across groups in countries with a large majority and smaller minorities. It also shows that perceived cultural distances between groups as well as discrimination levels tend to be cumulative, with some minorities being considered as more distant and associated with a lower status than others.

### **1.3 Two-group model**

Before presenting the general model with three ethno-cultural groups, which constitutes the main contribution of the present paper, a two-group version of the model is analyzed, in order to provide a benchmark for the assessment of the general model's results. This two-group version is largely inspired from Naidu, Hwang and Bowles (2017) and Hwang, Naidu and Bowles (2016)'s models.<sup>13</sup> It is very stylized and simple, to allow for a better understanding of the mechanisms at play and for its subsequent generalization.

In this two-group model, a society composed of a majority ethno-cultural group  $A$  of size  $N_A$  and a minority ethno-cultural group  $B$  of size  $N_B$  is considered, with  $N_A > N_B$ . Each ethno-cultural group is characterized by a cultural identity, made of the set of values, beliefs, world views and behavioral prescriptions shared by the group (Akerlof and Kranton, 2000), and by a specific phenotype. Groups are assumed to persist through time (i.e. they don't merge into one unique group, their differences do not get blurred, no new group arrives...). This assumption, though debatable when considering a timespan of several centuries, seems to be reasonable over a shorter time horizon of about one century, as argued by Guiso, Sapienza and Zingales (2006). Indeed, individuals "cannot alter their ethnicity, race or family history, and only with difficulty can they change their country or religion. Because of the difficulty of changing culture and its low depreciation rate, culture is largely a 'given' to individuals throughout their lifetimes." (Becker, 1996). The model will therefore focus on a timespan of around one century. Each individual in the society belongs to one of the two ethno-cultural groups. This belonging is assumed to be exogenous (i.e. an individual is exogenously assigned to a group, once and for all), exclusive (i.e. an individual belongs to only one group) and unambiguous (i.e. two individuals who meet know to which group each of them belongs). The assumption of unambiguity im-

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Berry (1996); Storm, Sobolewska and Ford (2017); Heath and Di Stasio (2019); Zschirnt and Ruedin (2016).

13. More specifically, it differs from them by a further simplification of the structure of payoffs (which are characterized through only two parameters here,  $\theta$  and  $\gamma$ ) and by the absence of intentional mutations (which represent one of the main contributions of Naidu, Hwang and Bowles (2017) and Hwang, Naidu and Bowles (2016)). The role of intentional mutations will be briefly discussed in one of the general model's extensions.

plies that ethnic groups are easily identifiable during interactions, through phenotype, clothes, family and first names or other characteristics. In reality, cultural and ethnic characteristics in a society may probably be better described by a continuum, so that ethno-cultural groups include individuals with sensibly different cultural practices, geographical origins, genotypes and phenotypes. Yet, Social Categorization Theory (Tajfel, 1969) stresses that individuals organize their understanding of the social world on the basis of categorical distinctions that transform continuous variables into discrete classes. This categorization has the effect of minimizing perceived differences within categories and accentuating inter-category differences. Thus, to keep the model tractable, it seems reasonable to assume clearly delineated groups. As the time period under study is of approximately one century, questions linked with the different degrees of social closure, political salience and historical stability of cultural groups are also set aside.

In this society, each individual holds a personal view of the ethno-cultural hierarchy between the two groups (i.e. of their relative social status or, put simply, of whether these groups are equal or one dominates the other). Two distinct ethno-cultural hierarchy views are possible. The first one is inegalitarian and posits that group  $A$  has a social status superior to group  $B$ 's. It is denoted by  $H_{A>B}$ . The second hierarchy view is egalitarian and grants an equal social status to the two groups. It is denoted by  $H_{A=B}$ . For example, if group  $A$  corresponds to the White majority in a Western country such as France or the United States and group  $B$  corresponds to the Black minority, a White individual adopting hierarchy view  $H_{A>B}$  believes that Blacks are inferior to Whites, a Black individual adopting hierarchy view  $H_{A>B}$  believes that Whites are superior to Blacks, and a Black or White individual adopting  $H_{A=B}$  believes that Blacks and Whites are equal. In practice, one can illustrate  $H_{A>B}$  by the strongly inegalitarian hierarchy view that prevailed in the 1950s' United States, which largely favored White Americans over African Americans, and  $H_{A=B}$  can be exemplified by the close to egalitarian hierarchy between the Swiss-German speaking majority and the French speaking minority in today's Switzerland (Minority Rights Group International, 2020).

At each period of time  $t = 1, 2, \dots$ , each individual in the society interacts with  $\xi$  other individuals. Among these  $\xi$  individuals, the proportions of members of group  $A$  and  $B$  are assumed to reflect the relative sizes of the two groups. An individual interacting with a member of the other ethno-cultural group gets a payoff that is dependent on the hierarchy views of both interacting parties : (i) if the two individuals hold differing hierarchy views, they both get a zero payoff, (ii) if the two individuals hold the (same) egalitarian hierarchy view, they both get a payoff equal to  $\theta > 0$ , (iii) if they both hold the (same) inegalitarian hierarchy view, then the member of the dominant group,  $A$ , gets a payoff of  $\theta + \gamma$  and the member of the dominated group,  $B$ , gets a payoff of  $\theta - \gamma$ . This characterization of payoffs is summarized in the following table :

		Group A	
		$H_{A>B}$	$H_{A=B}$
Group B	$H_{A>B}$	$\theta - \gamma, \theta + \gamma$	0,0
	$H_{A=B}$	0,0	$\theta, \theta$

An individual interacting with a member of its own ethno-cultural group, on the opposite, obtains a constant payoff  $C \geq 0$  independent of the hierarchy views of the two interacting members, i.e it is assumed that ethno-cultural hierarchy views do not affect interactions between the members of a same ethno-cultural group.<sup>14</sup> This constant payoff  $C$  can be normalized to zero without any loss of generality, as it does not affect any of the model's results. Note that, in the coordination game thus defined, the egalitarian hierarchy view is always risk-dominant, as  $\theta^2 > (\theta + \gamma)(\theta - \gamma)$ .

These assumptions on payoffs imply that members of two different ethno-cultural groups, if they disagree on their relative statuses, will not be able to interact efficiently (leading to a zero payoff for both).<sup>15</sup> This assumption conforms with the two last factors cited by Halevy, Y. Chou and D. Galinsky (2011) to explain why hierarchies facilitate organizational success : (i) a common hierarchy supports an efficient division of labor and, (ii) it reduces conflict. The lower payoff obtained in case of miscoordination may also be interpreted as "cognitive dissonance" (Festinger, 1962), whereby confrontation with a differing point of view (regarding the social hierarchy) triggers discomfort and is therefore costly. If, on the opposite, the members of two different groups hold the same hierarchy views, their interaction will be effective and produce  $2\theta$ . If the common hierarchy view is egalitarian, the product will be equally shared between the two interacting individuals, but if it is inegalitarian, the dominant group will hog a larger part of the product. Note that it is assumed that cultural identities have no effect on the productivity of individuals. Thus, the social hierarchies that emerge are not based on the average productivity of social groups (there is no statistical discrimination). Further note that interactions implying egalitarian and inegalitarian hierarchies have exactly the same productivity  $2\theta$ . The impact of having different productivities for these two types of interactions is discussed in one of the extensions.

We will assume, in the following of the paper, that  $\theta > \gamma$ , which implies that individuals

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14. This assumption is in line with Carvalho (2017); Naidu, Hwang and Bowles (2017); Hwang, Naidu and Bowles (2016). It can be relaxed by assuming, instead, that if the members of a same ethno-cultural group holding a same hierarchy view interact, they get a payoff of  $\delta > 0$  with  $\delta < \frac{2\theta - \gamma}{2}$ , and that if they do not hold the same hierarchy view, they get a zero payoff. It essentially means that interactions between same group members are much less affected by disagreement on hierarchy views than interactions between different group members, which appears to be realistic. Under these assumptions, all the (qualitative) results presented in this paper are preserved. Note that adding a constant  $C$  to all payoffs of interactions between same group members has absolutely no effect on the model's results.

15. Once more, as the model's results are not affected by the addition of a constant to all payoffs of interactions between members of different groups, the zero payoff in case of miscoordination could as well be any positive or negative constant.

interacting with members of another ethno-cultural group always obtain a higher payoff in case of coordination (i.e. agreement of the two parties on a common hierarchy view) than in case of miscoordination (i.e. disagreement of the two parties), even if coordination is on a hierarchy in which they are dominated.

Denoting by  $p_{j,h}$  the proportion of group  $j$  members who hold hierarchy view  $h$  during the period of time  $t$  and  $V_{i,j}(h)$  the payoff extracted from an interaction by a member of group  $i$  interacting with a member of group  $j$  when there is coordination on  $h$  (as reported in the previous table), the average payoff of an individual belonging to group  $i \neq j$  and holding hierarchy view  $h$  during period  $t$  is :

$$U_i(h) = \xi \frac{N_j}{N_i + N_j} p_{j,h} V_{i,j}(h) \quad (1.1)$$

where  $\xi \frac{N_j}{N_i + N_j}$  corresponds to the number of interactions that the individual has with members of group  $j$ .

For example, the payoff of a group  $A$  member holding hierarchy view  $H_{A>B}$  is  $U_A(H_{A>B}) = \xi \frac{N_B}{N_A + N_B} p_{B,H_{A>B}} (\theta + \gamma)$ . Remark that, in this framework, the status of an individual is not idiosyncratic but linked with its belonging to a particular ethno-cultural group. This is in line with Weiss and Fershtman (1998)'s survey, in which they observe that "Social status is often gained by association with a particular group, and shared by all members of the group, regardless of their individual characteristics". We have the following pure Nash equilibria :

**Lemma 3.1 :** *The above presented  $2 \times 2$  static coordination game admits exactly two pure Nash equilibria :*<sup>16</sup>

- *An inegalitarian equilibrium,  $E_{A>B}$ , in which all individuals adopt the inegalitarian hierarchy view  $H_{A>B}$ .*
- *An egalitarian equilibrium,  $E_{A=B}$ , in which all individuals adopt the egalitarian hierarchy view  $H_{A=B}$ .*

**Proof of Lemma 3.1 :** *This is a classical result associated with coordination games.*

The two pure Nash equilibria correspond to the full adoption of each of the two possible hierarchy views. Note that, the inegalitarian equilibrium is clearly preferred over the egalitarian one by the majority group, while the egalitarian equilibrium is clearly preferred by the minority.

The following dynamic is assumed for the evolution of the distribution of hierarchy views in the population. At the beginning of each period of time  $t$ , one individual randomly drawn

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16. Note that the game also admits one mixed Nash equilibrium in which  $p_{A,H1} = \frac{\theta}{2\theta - \gamma}$  and  $p_{B,H1} = \frac{\theta}{2\theta + \gamma}$ .

from the population gets a chance to adopt a new hierarchy view, while all other individuals keep the hierarchy views they had at  $t - 1$ . The randomly drawn individual adopts with probability  $1 - \varepsilon$  (for  $\varepsilon$  very small) his best response to the distribution of hierarchy views in the population at  $t - 1$ . This decision is myopic in the sense that the individual adopts his short-term best response without anticipating how the distribution of hierarchy views in the society will evolve in the future. With probability  $\varepsilon$ , the randomly drawn individual instead randomly adopts one of the (two) possible hierarchy views.

At each period of time  $t$ , the state of the society can be characterized by a  $(N_A + N_B)$ -uple denoted by  $z_t$ , in which each element corresponds to the hierarchy view of a specific individual in the society. The corresponding state space,  $\mathcal{H}^{N_A + N_B}$  where  $\mathcal{H} = \{H_{A>B}, H_{A=B}\}$ , is clearly finite. Additionally, the above described dynamic defines a Markov chain that is both irreducible and aperiodic. This Markov chain therefore admits a unique stationary distribution  $\mu^\varepsilon$ . The stochastically stable state (or states) of the Markov chain is (or are) the one (or the ones) that has (or have) a strictly positive mass in the stationary distribution when  $\varepsilon \rightarrow 0$ .<sup>17</sup> In practice, as the noise level  $\varepsilon$  becomes arbitrarily small, the adaptive process spends virtually all of the time, when  $t \rightarrow \infty$ , in the evolutionarily stable state(s) and, among them, in the state(s) that can be reached with the lowest transition cost (i.e. through the lowest number of  $\varepsilon$ -mutations).<sup>18</sup>

It is interesting to note that, in this model, a social hierarchy between ethno-cultural groups emerges at the decentralized level of individuals, through independent interactions. This feature contrasts with Wu (2017), where the social hierarchy between individuals belonging to two groups is decided through a collective Nash bargaining process between the two groups. While the latter model necessitates a large level of cohesion and coordination within each group, the model proposed in the present paper accounts for the emergence of a social hierarchy, even in the absence of coordination within groups or, said differently, it accounts for ethnic mobilization even in the absence of strong ethnic solidarity.<sup>19</sup> Indeed, when individuals interact with members of other groups, they are, whether they want it or not, identified with their ethno-cultural group. Therefore, the interest of an individual is aligned with the one of all his ethno-cultural group's members.<sup>20</sup>

Additionally, it is important to remark that this model does not assume a Darwinian process of selection on individuals themselves nor on their genes. Indeed, it has been largely acknow-

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17. See Foster and Young (1990)

18. Note that it can easily be shown that the mixed Nash equilibrium in a coordination game cannot be evolutionarily stable so that transition costs away from it and towards it do not have to be computed.

19. This feature seems quite realistic, as Barth (1969) and Hobsbawm and Ranger (1992) argue.

20. It is a little similar to Akerlof and Kranton (2005)'s model, where individuals working in a firm have identities (they belong to one group within the firm) and therefore try to reach an equilibrium that is better for the group to which they belong by exploring other equilibria. In this article, individuals have a disutility when diverging from the ideal effort level for their group, which incentivizes them to act in their group's interest.

ledged that the Darwinian theory hardly applies today in that sense, due to the elevation of living standards. Instead, the model assumes a Darwinian process of selection on individuals' views regarding the country's ethno-cultural hierarchy, in which the most successful views are progressively adopted by more and more individuals and spread within the population.

Now, I turn to the determination of transition costs. The minimum number of  $\varepsilon$ -mutations necessary to transit from equilibrium  $E_{A=B}$  to  $E_{A>B}$  (that will be called the “transition cost from equilibrium  $E_{A>B}$  to  $E_{A=B}$ ” and denoted by  $C_{E_{A=B} \rightarrow E_{A>B}}$ ) is the minimum between the number of  $\varepsilon$ -mutations of group  $A$  members necessary to make group  $B$  members indifferent between  $H_{A=B}$  and  $H_{A>B}$  and the number of  $\varepsilon$ -mutations of group  $B$  members necessary to make group  $A$  members indifferent. Indeed, once one group becomes indifferent between the initial and the final hierarchy and starts preferring the final hierarchy, its members progressively switch to the final hierarchy through best-response adjustment at no cost (with probability  $1 - \varepsilon \approx 1$  at each period of time). The members of the other group then also switch to the final hierarchy through best-response adjustments, as the final equilibrium is a Nash equilibrium. The transition cost from  $E_{A=B}$  to  $E_{A>B}$  is therefore :<sup>21</sup>

$$C_{E_{A=B} \rightarrow E_{A>B}} = \min \left( \frac{\theta N_A}{2\theta - \gamma}, \frac{\theta N_B}{2\theta + \gamma} \right) = \frac{\theta N_B}{2\theta + \gamma} \quad (1.4)$$

Similarly, the transition cost from equilibrium  $E_{A>B}$  to  $E_{A=B}$  is :

$$C_{E_{A>B} \rightarrow E_{A=B}} = \min \left( \frac{(\theta - \gamma)N_A}{2\theta - \gamma}, \frac{(\theta + \gamma)N_B}{2\theta + \gamma} \right) \quad (1.5)$$

We can note that transitions from the egalitarian to the inegalitarian equilibrium are always triggered by mutations of group  $B$  members that lead group  $A$  members to switch to the inegalitarian hierarchy view through best response adjustments. In such a case, group  $B$  will be called the “mutating group” and group  $A$  the “switching group”. Transitions to the egalitarian equilibrium, on the opposite, may be triggered by mutations of one group or the other, depending on the relative sizes of the two groups. If the minority is small enough with respect to the majority (i.e.  $\frac{N_B}{N_A} < \frac{(\theta - \gamma)(2\theta + \gamma)}{(2\theta - \gamma)(\theta + \gamma)}$ ), these transitions are triggered by the minority, otherwise they are triggered by members of the majority. Indeed, there exists a trade-off for the determination of the mutating group and of the switching group. On the one side, the payoff of the switching

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21. Indeed, the number of mutations from group  $A$  necessary to make group  $B$  prefer  $H_{A>B}$  over  $H_{A=B}$  is the smallest  $M_A$  such that :

$$\xi \frac{N_A - M_A}{N_A + N_B} \theta \leq \xi \frac{M_A}{N_A + N_B} (\theta - \gamma) \quad (1.2)$$

Similarly, the number of mutations from group  $B$  necessary to make group  $A$  prefer  $H_{A>B}$  over  $H_{A=B}$  is the smallest  $M_B$  such that :

$$\xi \frac{N_B - M_B}{N_A + N_B} \theta \leq \xi \frac{M_B}{N_A + N_B} (\theta + \gamma) \quad (1.3)$$



group in the initial equilibrium has to be small<sup>22</sup> (i.e. the numerator of each fraction in the above expression of  $C_{E_{A>B} \rightarrow E_{A=B}}$ ), so that fewer mutations are necessary to make the switching group indifferent between the initial and the final equilibrium. This means that the size of the mutating group and the status of the switching group in the initial equilibrium have to be small. On the other side, the effect of the mutation of one member of the mutating group on the gap between the payoffs of the switching group in the initial and final equilibria has to be large (i.e. the denominator of each fraction in the above expression of  $C_{E_{A>B} \rightarrow E_{A=B}}$ ). This means that the switching group has to enjoy a high status in the initial and final equilibrium. If the minority is small enough, then the first criterium dominates. If the minority is large enough, the second one dominates. Note that the transition cost from the egalitarian equilibrium to the inegalitarian one,  $C_{E_{A=B} \rightarrow E_{A>B}}$ , decreases with  $\gamma$ , as fewer mutations become necessary for the majority to prefer the final equilibrium. In contrast, the transition cost from the inegalitarian to the egalitarian equilibrium,  $C_{E_{A>B} \rightarrow E_{A=B}}$ , decreases with  $\gamma$  if the minority is large enough (because the switching group is the minority and the larger  $\gamma$  is the less the minority appreciates  $H_{A>B}$ ) and increases with it if the minority is small enough (because the switching group is the majority and the larger  $\gamma$  is the more the majority appreciates  $H_{A=B}$ ). Comparing the expressions of the two transition costs,  $C_{E_{A=B} \rightarrow E_{A>B}}$  and  $C_{E_{A>B} \rightarrow E_{A=B}}$  leads to the following Proposition :

**Proposition 3.2 :** *The above presented  $2 \times 2$  evolutionary coordination game admits the following stochastically stable state, depending on the relative sizes of the two ethno-cultural groups :*

- If  $\frac{N_B}{N_A} > \frac{(\theta-\gamma)(2\theta+\gamma)}{\theta(2\theta-\gamma)}$ , then  $E_{A=B}$  is the unique stochastically stable state.
- If  $\frac{N_B}{N_A} < \frac{(\theta-\gamma)(2\theta+\gamma)}{\theta(2\theta-\gamma)}$ , then  $E_{A>B}$  is the unique stochastically stable state.

**Proof of Proposition 3.2 :** *It is a direct consequence of the equivalence  $\frac{N_B}{N_A} > \frac{(\theta-\gamma)(2\theta+\gamma)}{\theta(2\theta-\gamma)} \Leftrightarrow C_{E_{A=B} \rightarrow E_{A>B}} > C_{E_{A>B} \rightarrow E_{A=B}}$  (Young, 1993).*

Proposition 3.2 implies that, if the minority group  $B$  is large enough, egalitarian hierarchy views are going to spread in the society in the long term. On the contrary, if the minority group is small, inegalitarian hierarchy views are going to persist. In the sociological literature, the link between minority size and anti-minority attitudes has been the subject of much research in the recent years. Indeed, on the one hand, "intergroup contact theory", according to which the majority interacts more with a larger minority thus decreasing the majority's level

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22. As remarked earlier, adding a constant  $C$  to the payoff of a group, both in case of coordination and of miscoordination does not affect the model's results. Therefore, the criterium according to which the initial payoff of the switching group has to be small is equivalent to requiring the initial payoff of this group to have a small variable component (i.e. a small component that depends on the coordination with the other groups).



of prejudice, would predict a negative correlation between the minority's size and the level of prejudice against this minority. On the other hand, "group-threat theory", whereby the majority is assumed to feel threatened by a larger minority, would suggest the opposite prediction (Schlueter and Scheepers, 2010). The present model provides another mechanism in favor of the first prediction : a larger size of the minority makes it more costly for majority members to deviate from an egalitarian norm (as it will lead to miscoordination with a larger number of persons) and less costly for minority members to deviate from an inegalitarian one (as they will interact proportionately less with majority members with whom miscoordination will arise in case of deviation to the inegalitarian norm). Therefore, an increase in the size of the minority allows this group to better spread its preferred egalitarian hierarchy view. Empirical studies aimed at identifying which mechanism dominates have hitherto brought only mixed evidence. One group of studies documents a negative relation between minority size and its status, a second group fails to find such evidence, and a third group obtains a positive relation (see the corresponding references in Schlueter and Scheepers, 2010). The three-group model presented hereafter provides a possible explanation for these differing results by showing that, when more than two ethno-cultural groups are present, an increase in the size of a minority may, depending on the other ethno-cultural groups present in the society, improve or hurt its social status.

Back to the two-group model, in the inegalitarian equilibrium  $E_{A>B}$ , the minority group adopts the inegalitarian hierarchy view  $H_{A>B}$ , in which it holds a dominated status. We are therefore in a case of "internalized domination" that has been largely documented in the literature,<sup>23</sup> for example in the case of African Americans in the United States, Maori children in New Zealand, Black children in the Caribbean and Ethiopian Jews in Israel. The sociology literature provides two main explanations for the persistence of "internalized domination". First, inegalitarian hierarchy views can be sustained because of the effectiveness of consensual ideologies (Sidanius and Pratto, 2001).<sup>24</sup> Another explanation may stem from the general tendency for the emergence of negative stereotypes against low-status groups (Duckitt, 1992). Indeed, stereotypes are useful, both to high status groups, as they justify their dominance, and to low status groups, whom they provide with an efficient way to differentiate themselves from other low status groups (Tajfel, 1981). Eventually, evolutionary game theory provides a third explanation to this phenomenon : the need for coordination on common social norms for individual interactions to be productive.

The diffusion of a same hierarchy view in the whole population in the long term appears to

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23. See Fang, Sidanius and Pratto (1998); Sachdev and Bourhis (1987); Sidanius and Pratto (2001).

24. For example, a major survey on US public opinion released in 1997 asked a large number of Whites and Blacks about the degree to which they believe that "Blacks in your community have as good a chance as Whites" to get (a) "any kind of job", (b) "education", (c) "housing". The results showed that Whites and Blacks hold very similar views on all of these questions : there is a higher degree of agreement between them than of disagreement (Sidanius and Pratto, 2001) (page 106).

be quite realistic. Indeed, as noted in the literature review, a large strand of empirical literature, both in the economics and sociology fields, have shown that there exists a high level of consensus, within and across ethno-cultural groups, with respect to ethno-cultural hierarchy views, in the numerous Western countries investigated. For example, Hagendoorn (1995) conclude from their analysis of several studies on discrimination in the Netherlands, France, USA and the former Soviet Union that respondents belonging to the same ethnic group largely concur on their preferences regarding other ethnic groups. They adopt very homogeneous rankings of outgroups, even though they may differ in their overall level of prejudice.

Note that the threshold  $\frac{(\theta-\gamma)(2\theta+\gamma)}{\theta(2\theta-\gamma)}$  separating the two equilibria decreases with  $\frac{\gamma}{\theta}$ . Indeed, when  $\frac{\gamma}{\theta}$  increases, transitions from  $E_{A=B}$  to  $E_{A>B}$  and in the opposite direction both become less costly. However, the cost of the transition from  $E_{A>B}$  to  $E_{A=B}$  decreases quicker : much fewer mutations from the majority group become necessary to make the minority indifferent between  $H_{A>B}$  and  $H_{A=B}$ . Therefore, the minority does not need to be as large as before for the long-term hierarchy to be egalitarian. The threshold increasing with  $\frac{\gamma}{\theta}$  means that the more inegalitarian the inegalitarian hierarchy is (i.e. the larger  $\gamma$  is with respect to  $\theta$ ), the less likely it is to persist in the long term. However, if the inegalitarian hierarchy is only slightly inegalitarian, it will nearly always persist in the long term (i.e. for nearly all sizes of the minority). This feature may contribute to explaining why inegalitarian hierarchies are so pervasive in human societies (Quillian et al., 2019).

## 1.4 Three-group model

Having analyzed a simple two-group version of the model, we can now turn to the main contribution of the present paper, the generalization of the model to a society composed of one majority ethno-cultural group and two minorities. The presence of two minorities enriches the model a lot by allowing for the discussion of reciprocal impacts that minorities may have on each other's social statuses and the expected effects of a new minority's arrival or a minority split.

In the three-group model, the society is now composed of one majority group  $A$  of size  $N_A$  and two minorities  $B$  and  $C$  of sizes  $N_B$  and  $N_C$  such that  $N_A > N_B > N_C$ . Each individual may adopt one of four distinct hierarchy views : (1) a *majority-dominated* inegalitarian hierarchy view  $H_1 = H_{A>B=C}$  in which group  $A$  dominates groups  $B$  and  $C$  and these two minorities are equal, (2) a *minority-differentiating* hierarchy view  $H_2 = H_{A=B>C}$  in which group  $A$  and  $B$  are equal and dominate group  $C$ , (3) a “*stepwise*” inegalitarian hierarchy view  $H_3 = H_{A>B>C}$  in which group  $A$  dominates group  $B$  which dominates group  $C$ , (4) an *egalitarian* hierarchy view  $H_4 = H_{A=B=C}$  in which all groups are considered equal.<sup>25</sup> The status of a group in a given

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25. The *majority-dominated* inegalitarian hierarchy view  $H_1$  may be exemplified by the perceived hierarchy

hierarchy view  $H$  corresponds to its ranking with respect to the other groups. In particular, when comparing two hierarchy views, it will be considered that a group holds a higher status in a specific hierarchy view if, in this hierarchy view, it is the sole dominant group, while, in the other, it dominates with another group (to which it is equal).<sup>26</sup>

As in the two-group model, at each period of time  $t$ , each individual in the population interacts with  $\xi$  other individuals belonging to the three groups in proportions that correspond to the share of the different groups in the overall population. This assumption is relaxed in one of the extensions (see paragraph 1.10.1 in Appendix D). The payoffs extracted from each bilateral interaction are the same as in the two-group model. The average payoff of an individual belonging to group  $i$  and holding hierarchy view  $h$  during a period of time  $t$  is therefore :

$$U_i(h) = \xi \frac{N_j}{N_i + N_j + N_k} p_{j,h} V_{i,j}(h) + \xi \frac{N_k}{N_i + N_j + N_k} p_{k,h} V_{i,k}(h) \quad (1.6)$$

where  $j$  and  $k$  index the two other ethno-cultural groups (i.e.  $i \neq j \neq k$ ). Note that an interesting feature of this three-group coordination model is that it is one of the few in which an agent's strategy must be used with more than one type of agents (Neary, 2011), i.e. the members of the two other ethno-cultural groups, which interests must both be taken into account.

The newly defined static coordination game is a  $3 \times 4$  game. We have the following lemma :

**Lemma 4.1 :** *The above presented  $3 \times 4$  static coordination game admits four pure Nash equilibria :*

- *A majority-dominated inegalitarian equilibrium,  $E_1$ , in which all individuals adopt the majority-dominated inegalitarian hierarchy view.*
- *A minority-differentiating inegalitarian equilibrium,  $E_2$ , in which all individuals adopt the minority-differentiating hierarchy view.*
- *A “stepwise” inegalitarian equilibrium,  $E_3$ , in which all individuals adopt the “stepwise” inegalitarian hierarchy view.*
- *An egalitarian equilibrium,  $E_4$ , in which all individuals adopt the egalitarian hierarchy view.*

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between the majority group and the African and German minorities in Ireland (see McGinnity and Lunn, 2011). The *minority-differentiating* inegalitarian hierarchy  $H_2$  may correspond to the hierarchy between the dominant White Brazilian majority and Japanese minority, and the colored (Brown and Black) Brazilians who have been shown to be discriminated against (see Tsuda, 2000; Arcand and D’hombres, 2004). The *stepwise inegalitarian* hierarchy may be exemplified by the cumulative hierarchy between the White majority group in Portugal, the Brazilian minority (which is associated with an intermediary status) and the African Black minority (see de Renó Machado, 2004). Eventually,  $H_4$  could be illustrated by the hierarchy between the Swiss-German-, the French-, and the Italian-speaking minorities in Switzerland (see Minority Rights Group International, 2020).

26. Note that, in all of the four hierarchy views considered, group A dominates. This assumption allows to limit the number of possible hierarchy views. It has been checked that alleviating this assumption does not substantially alter the qualitative insights provided by the model.

**Proof of Lemma 4.1 :** *This directly results from the structure of the coordination game in which zero payoff is associated to interactions in case of miscoordination.*

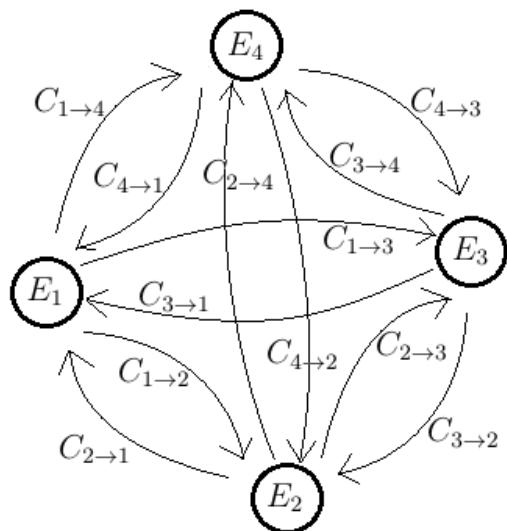
Note that these four pure Nash equilibria are valued differently by the three ethno-cultural groups. The majority group  $A$  prefers above all to dominate both minorities (i.e. equilibria  $E_1$  and  $E_3$ ) and, then, it prefers to dominate at least one minority (i.e.  $E_2$ ). Thus, denoting by  $\succ_i$  the order of preferences of group  $i$  over the different pure Nash equilibria, we have  $E_1 =_A E_3 \succ_A E_2 \succ_A E_4$ . Minority  $B$  ranks the four pure Nash equilibria differently. It prefers above all to be granted an equal status to majority  $A$  and dominate minority  $C$  (i.e.  $E_2$ ) and, then, it prefers to be granted an equal status to both other groups (i.e.  $E_4$ ). When dominated by majority  $A$ , it prefers to dominate minority  $C$  (i.e.  $E_3$ ) over being equal to it (i.e.  $E_1$ ). Its preferences over the different pure Nash equilibria are therefore  $E_2 \succ_B E_4 \succ_B E_3 \succ_B E_1$ . Eventually, minority  $C$  prefers above all the *egalitarian* equilibrium (i.e.  $E_4$ ). Then, it prefers the *majority-dominated* inegalitarian equilibrium (i.e.  $E_1$ ) and it values similarly the two last equilibria (i.e.  $E_2$  and  $E_3$ ). Its preferences can be summarized by  $E_4 \succ_C E_1 \succ_C E_2 =_C E_3$ . We can observe that the three groups rank the four pure Nash equilibria differently, so that no two groups have aligned interests. For example, group  $C$  appreciates equilibrium  $E_1$  (as compared to  $E_3$  and  $E_2$ ) because, despite having the lowest status in this equilibrium, it shares this low status with group  $B$ . Thus, group  $C$  will sometimes encourage transitions towards equilibrium  $E_1$  (by being the first group to switch to it through best-response adjustments), often at the expense of group  $B$ 's interests. On the opposite, group  $B$  will encourage transitions from  $E_1$  to  $E_3$  or  $E_2$  (and from  $E_3$  to  $E_2$ ), as it prefers to dominate minority  $C$ .

As in the two-group model, at the beginning of each period of time, one individual is randomly drawn and has the possibility to change his hierarchy view. With probability  $1 - \varepsilon$ , he chooses his best response to the distribution of hierarchy views in the population at  $t - 1$  and, with probability  $\varepsilon$ , he adopts a random hierarchy view. This assumption of random mutations is partially relaxed in one of the extensions (see paragraph 1.10.2 in Appendix D).

Similarly to the two-group model, this dynamic defines a Markov chain with a finite state space, which is both irreducible and aperiodic and therefore admits a unique stationary distribution. Its stochastically stable state (or states), defined as in the two-group model, is the one associated with the lowest cost minimum spanning tree (see Young (1993) for the justification) in the complete oriented graph which nodes correspond to the four pure Nash equilibria and which oriented edges are weighted by the transition cost between each pair of pure Nash equilibria (see Figure 1.1 for a depiction of this graph and of an example of spanning tree

associated with equilibrium  $E_2$ ).<sup>27 28</sup>

Graph corresponding to the  $3 \times 4$  model



One spanning tree associated with equilibrium  $E_2$

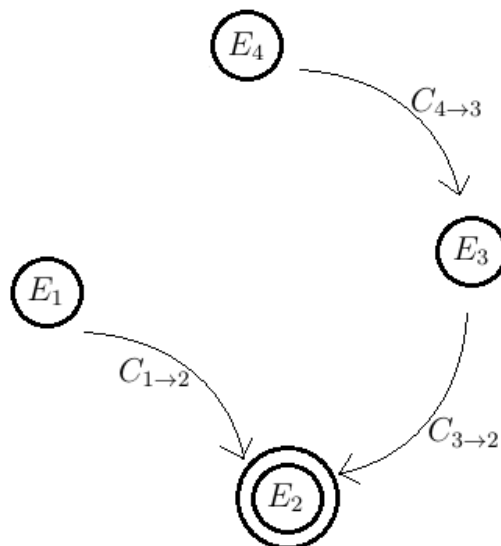


FIGURE 1.1

In order to determine the stochastically stable equilibrium, the following procedure proposed by Young (1993) is implemented :

1. Determination of the transition cost (i.e. the number of  $\varepsilon$ -mutations) necessary to go from each pure Nash equilibrium to each other Nash equilibrium.
2. Building of the oriented graph corresponding to the evolutionary game, as described above.
3. Identification of the minimum spanning tree leading to each pure Nash equilibrium.
4. Identification of the lowest cost minimum spanning tree (or trees) and its (or their) corresponding pure Nash equilibrium (or equilibria). This (or these) pure Nash equilibrium (or equilibria) is (or are) the stochastically stable state (or states), i.e. the equilibrium (or equilibria) that persists (or persist) in the long run.

Before implementing the procedure, it is important to note that multiplying all group sizes by a same constant does not affect the model, so that the size of the majority group  $A$  can be normalized to 1 without any loss of generality. Similarly, multiplying both  $\theta$  and  $\gamma$  by a same constant leaves the model unchanged. Therefore,  $\theta$  can be normalized to 1. Additionally, in

27. The minimum spanning tree associated with a specific pure Nash equilibrium is the oriented tree which spans over all pure Nash equilibria, which root is this specific pure Nash equilibrium and which edges are chosen so as to minimize the total cost of the tree (i.e. the sum of its edges' weights).

28. Note that, comparably to the two-group model, the three-group model admits some mixed Nash equilibria but those are not evolutionarily stable in a coordination game.

order to make the model more tractable, it is assumed that  $\gamma$  is close to  $\frac{1}{2}$ .<sup>29</sup> The free parameters of the model are thus the two minorities' sizes,  $N_B$  and  $N_C$  and, to a lesser extent,  $\gamma$ .

Even after those normalizations and simplification, the implementation of the procedure's steps would be extremely burdensome if done manually, as transition costs are piecewise functions of the two minorities' sizes and of  $\gamma$ , so that the minimum spanning trees leading to each equilibrium and the lowest cost minimum spanning tree or trees) are also defined piecewise. The procedure is therefore implemented in a computer program using Mathematica. The computer code is provided in Appendices E and F.

For the computation of transition costs between each pair of pure Nash equilibria, it is important to first prove the following Lemma :

**Lemma 4.2 :** *To transit from an initial pure Nash equilibrium  $E^{(i)}$  to a final pure Nash equilibrium  $E^{(f)}$ , the minimum transition cost (i.e. minimum number of  $\varepsilon$ -mutations necessary for the transition) can only be reached if all  $\varepsilon$ -mutations are “direct” (i.e. from the initial to the final equilibrium, as opposed to “indirect” mutations from the initial to another equilibrium different from the final one).*

**Proof of Lemma 4.2 :** *To show this, the following steps are followed : (1) “direct” transition costs between each possible initial and final equilibria are computed, using only “direct”  $\varepsilon$ -mutations (if possible, mutations from only one group are used and, if it is not sufficient, mutations from a second group may be added), (2) a lower bound on the “indirect” transition cost between each possible initial and final equilibria when using some “indirect”  $\varepsilon$ -mutations to make at least one group switch (through best-response adjustments) towards another equilibrium, different from the initial and final ones, is computed, (3) it is shown that, for each pair of initial and final equilibria, the “direct transition cost” computed in the first step is lower than the lower bound on the “indirect transition cost” computed in the second step. Therefore,  $\varepsilon$ -mutations from the initial to the final equilibrium lead to the lowest transition costs. See Appendix B for a full version of this proof.*

Lemma 4.2 implies that, to transit from equilibrium  $E^{(i)}$  to equilibrium  $E^{(f)}$ , it is inefficient to resort to  $\varepsilon$ -mutations toward another equilibrium (different from the initial and final ones) because it would be more costly (i.e. it would necessitate more mutations). This result is not evident, as we could have expected that, if one group can easily (i.e. through few mutations) be made to prefer an intermediary equilibrium different from the initial and final ones, it would allow to reduce the level of coordination on the initial equilibrium and therefore favor an easy

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29. More precisely, transition costs are computed assuming  $\gamma \approx 1/2$  but the comparisons necessary to determine the minimum cost spanning trees are done assuming  $\gamma = 1/2$  to limit the number of cases and improve the readability of tables and graphs.



transition toward the final equilibrium. We can further note that, in the three-group model, mutations from members of more than one group may be necessary to trigger a transition. Indeed, having one whole group mutate towards the final equilibrium may not suffice to make the other two groups prefer the final equilibrium. In order to find the transition cost from  $E^{(i)}$  to  $E^{(f)}$  using only  $\varepsilon$ -mutations towards the final equilibrium, it is necessary to compare the cost of having each of the three groups become indifferent between the initial and the final equilibrium and, thereafter, if both remaining groups still prefer the initial equilibrium, of having a second group become indifferent too (the first group to become indifferent is called “first switching group”, the second group to become indifferent is called “second switching group”, and the group or groups experiencing  $\varepsilon$ -mutations are called “mutating groups”). When two whole groups have switched to the final equilibrium, the third one follows through best response adjustments (because the final equilibrium is a Nash equilibrium). However, having only one group switch to the final equilibrium may not be sufficient to make the other two groups prefer the final equilibrium. The choice of the first switching group (and, if necessary, of the second switching group) depends on the parameters  $N_B \in [0, 1[$  and  $N_C \in [0, 1[$  (with  $N_B > N_C$ ). Thus, the transition costs are defined piecewise on the set  $\mathcal{P} \equiv \{(N_B, N_C, \gamma) \in [0, 1]^3 \text{ s.t. } N_B > N_C\}$ . Using the Proof of Lemma 4.2,<sup>30</sup> it can easily be shown that the matrix of transition costs in the vicinity of  $\gamma = \frac{1}{2}$  is the one represented in Table 1.1.<sup>31</sup> As in the two-group model, transition costs increase with the sizes of the different groups,  $N_B$  and  $N_C$ . As in the two-group model also, transition costs may increase or decrease with  $\gamma$ . Indeed  $\gamma$  impacts both the initial payoff of the first switching group and the marginal impact of an  $\varepsilon$ -mutation on the gap between this group’s payoff in the final and in the initial equilibrium. Typically, when the first switching group is better off in the initial than in the final equilibrium, the transition cost increases with  $\gamma$ <sup>32</sup> while, in the opposite case, it decreases with  $\gamma$ .<sup>33</sup>

In order to better understand which transitions are triggered by which mutating ethno-cultural groups, Figure 1.2 represents, for each pair of pure Nash equilibria, the unique or the two mutating groups that are at the origin of the transition of the society from the initial to the final equilibrium, depending on the sizes of the two minorities.<sup>34</sup> Figure 1.3 complements Figure 1.2 by presenting, for each pair of pure Nash equilibria, the first switching group.<sup>35</sup> The same trade-off as in the two-group model is at play for the choice of the mutating and switching

30. i.e. more precisely, the algorithm *TransitionCostsMatrix*.

31. The Mathematica program used for the computation of the matrix is presented in Appendix E.

32. For example, the transition cost from  $E_1$  to  $E_2$  when  $9N_B + 6N_C \leq 5$ ,  $\frac{(1+\gamma)N_B+N_C}{2+\gamma}$ , corresponding to a case where the first switching group is A (which prefers  $E_1$  over  $E_2$ ), increases with  $\gamma$ .

33. For example, the transition cost from  $E_1$  to  $E_2$  when  $3N_C \geq 1$ ,  $-1 + \frac{3+N_C}{2+\gamma}$ , corresponding to a case where B is the first switching group, decreases with  $\gamma$ .

34. The same algorithm *TransitionCostsMatrix* in conjunction with the function *Analysismutatinggroup* allow to obtain these figures. Both are produced in the Appendix (E and F respectively).

35. This figure is obtained using the algorithm *TransitionCostsMatrix* in conjunction with the function *Analysisfirstswitchinggroup*. Both are produced in the Appendix (E and F respectively).

groups : on the one hand the payoff of the switching group in the initial equilibrium must be as low as possible while, on the other hand, the effect of the mutation of one member of the mutating group on the gap between the payoffs of the first switching group in the initial and final equilibria must be as large as possible. As an illustration, the top-left graphs in Figure 1.2 and Figure 1.3 shows that, when both minorities are small enough, the transition from equilibrium  $E_1$  to equilibrium  $E_2$  is triggered by mutations of members of both minorities while the first switching group is the majority. In this case, the two criteria in the trade-off are optimized when choosing the majority  $A$  as the switching group. Indeed, the majority is the group that has the lowest initial payoff (as it only interacts with two very small groups) and is also the group that benefits the most from mutations of members of the other groups (the gap between the initial and final payoff of the majority is reduced by  $2\theta + 2\gamma$  at each mutation of group  $C$  members). Note that the mutation of all members of group  $C$  towards  $E_2$  is not sufficient to trigger a transition to the final equilibrium in this case, so that mutations of group  $B$  members are also necessary. When minority  $B$  is large and minority  $C$  is small, the two criteria in the trade-off contradict each other : while minority  $B$  has the lowest initial payoff, majority  $A$  is still the group for which the gap between the initial and the final payoff is reduced the most by mutations of the other groups' members. The first criterium dominates, so that group  $B$  is the first switching group, while group  $C$  and  $A$  are mutating groups.

Note that, in this model, transitions from one hierarchy view to another in a society are triggered by a conjunction of deviant behaviors from a sizable number of anonymous individuals who (randomly) start disagreeing with the prevailing view. This differs from Acemoglu and Jackson (2015)'s overlapping generation model, in which some "prominent" individuals play a key role in the triggering of transitions from one (historical) norm to a new one, as their behavior is recorded and taken into account, not just by the individual belonging to the next generation, but by all future generations.

We can further notice that mutations of hierarchy views towards a same new hierarchy happen independently. This may be seen as a "decentralized social movement", which does not require any attempt at coordination between group members nor any leader but simply arises randomly. Additionally, transitions are sometimes triggered by independent mutations from members of more than one group. This also happens in the absence of any coordination effort between the members of the two groups. Therefore, it may be interpreted as a "decentralized" alliance between ethno-cultural groups. Illustrations of "decentralized" alliances between minorities have been observed by many commentators,<sup>36</sup> for example during the early stages of anti-colonial movements in Africa, South America and South East Asia, with the Luo-Kikuyu alliance in Kenya, the cooperation between Africans and East Indians in Guyana, and the

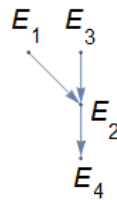
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36. See Rabushka and Shepsle (1972); Horowitz (2000); Young (2016).



Sinhalese-Tamil unity in Ceylon.<sup>37 38 39</sup>

Before deriving the minimum spanning tree associated with each equilibrium, it is important to understand why minimum spanning trees matter in the present context where multiple pure Nash equilibria are possible. The idea is that it allows to evaluate the minimum cost necessary to make all individuals in the society adopt the final hierarchy view, whatever the initial distribution of hierarchy views (distribution in which the four hierarchy views may be represented). Indeed, starting from an arbitrary initial distribution and aiming for a specific final equilibrium, it may be unnecessarily costly to try and make each individual directly adopt the final hierarchy view. The efficient way to reach this final equilibrium would be, on the contrary, to follow the minimum spanning tree. For example, let us consider the following minimum spanning tree :



According to this minimum spanning tree, it is most efficient, in order to reach an overall agreement on hierarchy view  $H_4$ , to first make individuals who hold hierarchy view  $H_1$  or  $H_3$  in the initial society adopt hierarchy view  $H_2$ , and to have all individuals who hold hierarchy view  $H_2$  adopt the final hierarchy  $H_4$ . This feature of the model is interesting as it suggests that the most efficient way to reach a given equilibrium hierarchy view is not by directly convincing individuals to adopt it, but by making them transit through intermediary hierarchy views progressively leading to the final one. For instance, if the final hierarchy view is the *egalitarian* one, it may be more efficient to make the population transit through increasingly egalitarian hierarchy views, to eventually reach the *egalitarian* one. This feature of the model appears to faithfully mirror the progressive integration of minority groups in societies, with an increasing share of the population granting them an intermediary status and then an equal status to the majority (see, for example, the progressive recognition of the Irish minority, which used to be strongly discriminated against during the nineteenth century in the United States and progressively gained an equal footing to the White majority, Ignatiev, 2012).

37. Alliances between minorities for the improvement of their status are often called “rainbow coalitions” (Kalin and Berry, 1996).

38. Germane (2015) also describes the flourishing of minority coalition-building in Central and Eastern Europe during the inter-war years. She underlines that Germans and Jews were especially proactive in forming informal alliances and spearheading movements for minority rights in the nation-states. Furthermore, in the United States, American Jewish minorities have been particularly involved in the battle against racial segregation (Germane, 2015; Aronsfeld, 1970; Salzman, Back and Sorin, 1992; Adams and Bracey, 1999; Bauman and Kalin, 1997).

39. The “decentralized” character of alliances between ethno-cultural groups in the present model contrasts with the two game theory models of alliances between militant groups proposed by (Bapat and Bond, 2012), in which alliances are decided at the group level.

Mutating group(s) depending on group sizes for each type of transition

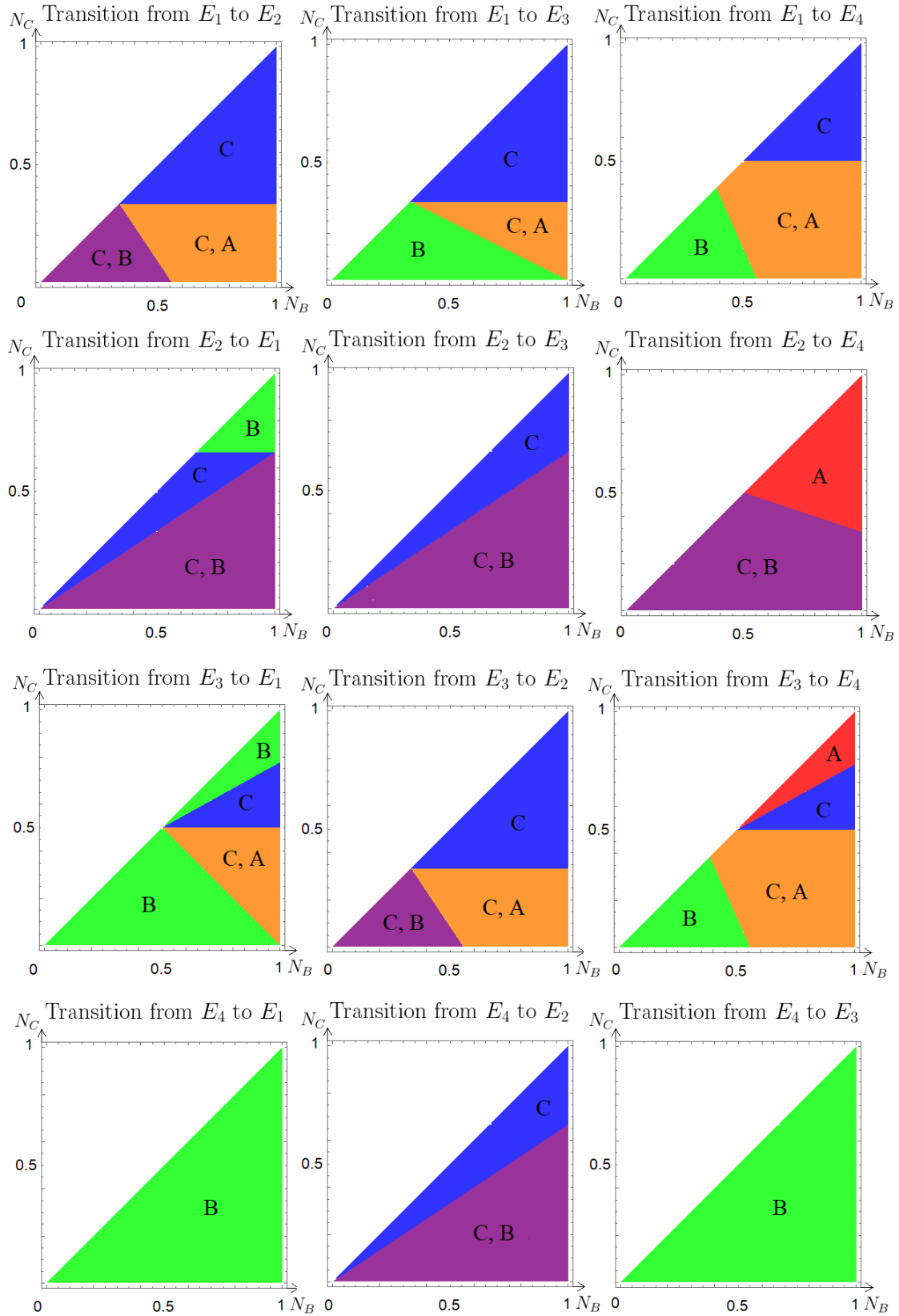


FIGURE 1.2 – Mutating group depending on the size of the two minorities for each transition type

First switching group depending on group sizes for each type of transition

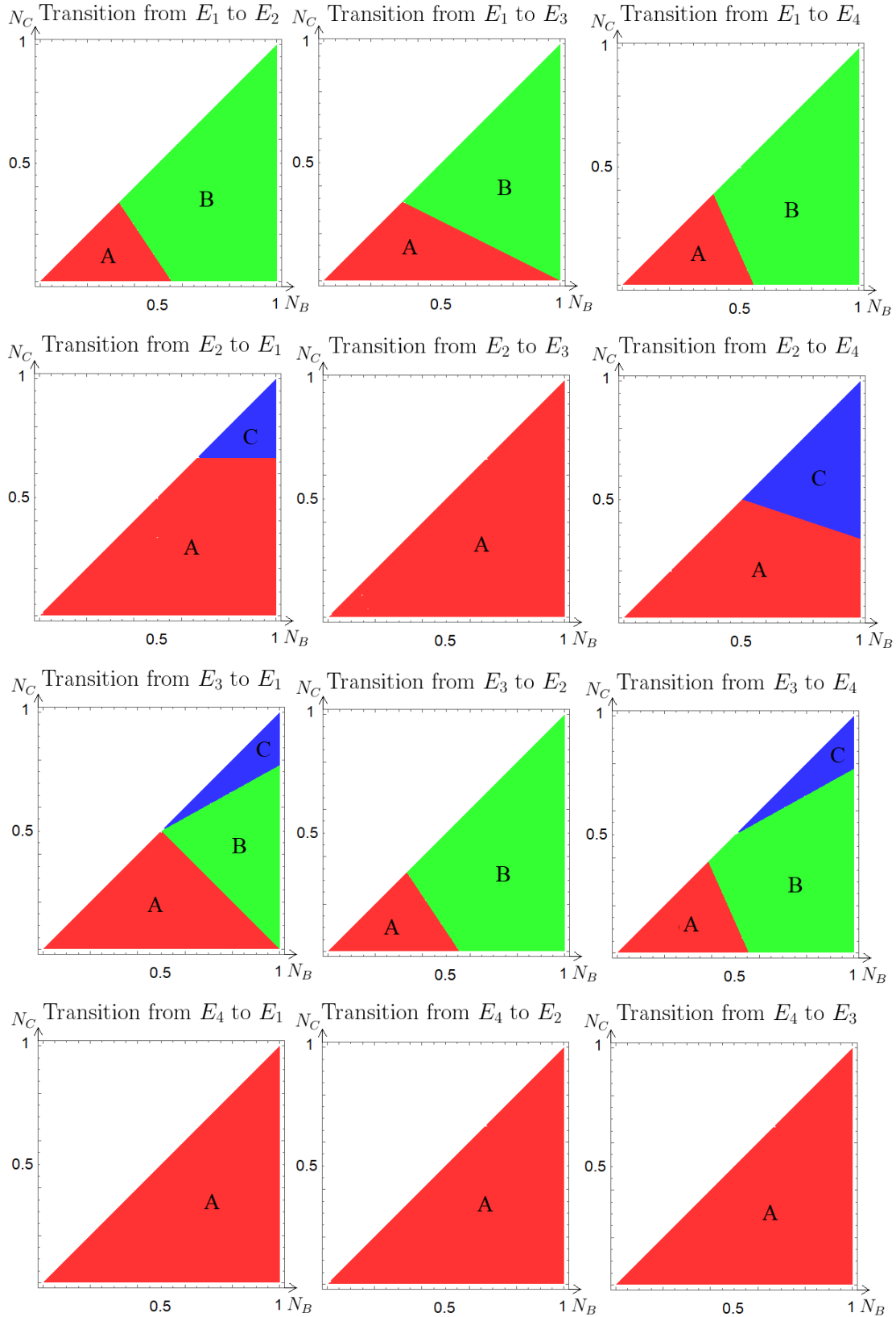


FIGURE 1.3 – First switching group depending on the size of the two minorities for each transition type

The key role of minimum spanning trees in this model also implies that, for a specific equilibrium to persist in the long term, this equilibrium must be both easy to reach from any other equilibrium (possibly through transitions involving intermediary equilibria) and difficult to upset in any direction (i.e. whatever the equilibrium towards which the  $\varepsilon$ -mutations take place). In practice, it means that a given hierarchy view persists in the population in the long term, if it is both easy to convince people with all other hierarchy views to adopt it and difficult to convince people with this given hierarchy view to adopt any other. Figure 1.8 provides an illustration of this double requirement.<sup>40</sup> It depicts a few examples of oriented graphs corresponding to the model's transition costs between the four pure Nash equilibria for different minority sizes. The colors of the edges represent the transition cost to go from the initial equilibrium of the edge to the final one. A red color means that the transition is the least costly one in the graph, while a blue color means that the transition is the most costly one in the graph. Intermediary costs have various colors represented in the color scale at the bottom of the figure. In the highest graph of transitions at the top of this figure, it can be observed that equilibria  $E_2$  and  $E_3$  are easy to reach from at least one equilibrium (a red arrow leads to each of them), but  $E_3$  is also easy to upset (there is an orange arrow from  $E_3$  to  $E_2$ ), so that equilibrium  $E_2$  can be expected to be the one that persists in the long term. Note that the whole minimum spanning tree matters, as the equilibrium that can be reached from another one at the lowest cost is not necessarily the one that has the lowest overall minimum spanning tree : in the graph of transitions at the right of the previous one,  $E_3$  and  $E_2$  are the easiest equilibria to reach from another equilibrium (red arrows lead to each of them), but, at the same time,  $E_4$  is hard to upset in all directions (only blue arrows lead away from it) so that it will be hard to reach  $E_3$  and  $E_2$  when starting at  $E_4$ . Therefore, minimum spanning trees leading to  $E_3$  and  $E_2$  will be quite costly and, in the end,  $E_4$  may be the equilibrium that persists in the long term. In this case, *egalitarian* hierarchy views persist in the long term, not because they are easy to reach, but because they are hard to undermine once adopted by all.

As the matrix of transition costs is defined piecewise on the set  $\mathcal{P}$ , the oriented graph corresponding to the model is also defined piecewise on this set. To compute the minimum spanning tree associated with each equilibrium, Edmond's algorithm is applied (Edmonds, 1967; Chu and Liu, 1965) on each subdivision of  $\mathcal{P}$  that arises in the computation of the matrix of transition costs. This algorithm proceeds as follows. Starting from the complete oriented graph, a sub-graph is built, in which only the lowest cost edge leading to each equilibrium is kept. If this sub-graph contains a cycle, a new version of the initial oriented graph is built, in which the nodes belonging to the cycle are merged into one unique node and some edges are given new weights. Then, by recurrence, the algorithm builds, once more, the sub-graph

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40. This figure is obtained using the function `PlotTransitioncostsmatrix` produced in Appendix F.

of this sub-graph, keeping only the lowest cost edge leading to each node. It repeats the same steps until reaching a sub-graph without any cycle. It then reconstitutes the minimum spanning tree associated with the equilibrium of interest in the initial oriented graph... (see Appendix C for a more detailed description of the algorithm). This algorithm relies on the comparison of the weight of all edges leading to the equilibrium of interest, which may require (for the comparison to be unambiguous) to further subdivide set  $\mathcal{P}$ . The computer program used for the implementation of Edmond's algorithm is provided in Appendix E.

Once the minimum spanning tree associated with each equilibrium has been found on each subdivision of set  $\mathcal{P}$ , the four minimum spanning trees are compared on each of these subdivisions. This comparison may require even further subdivisions of set  $\mathcal{P}$ . In the end, on each of these further subdivisions, the stochastically stable equilibrium or equilibria are the ones associated with the lowest cost minimum spanning trees. Merging the subdivisions where each equilibrium is stochastically stable leads to Proposition 4.3 :

**Proposition 4.3 :** *The above presented  $3 \times 4$  evolutionary coordination game admits the following stochastically stable states, depending on the sizes of the two minority ethno-cultural groups :*

- *If  $N_B + 6N_C \geq 5$ , then  $E_4$  is the unique stochastically stable state.*
- *If  $N_B + 6N_C \leq 5$  and  $2N_B \geq 1$  and  $N_B + N_C \geq 5/6$ , then  $E_2$  is unique stochastically stable state.*
- *If  $N_B + N_C \leq 5/6$  and  $3N_C \leq 1$ , then  $E_1$  and  $E_3$  are the two stochastically stable states.*
- *If  $3N_C \geq 1$  and  $2N_B \leq 1$ , then  $E_3$  is the unique stochastically stable state.*

**Proof of Proposition 4.3 :** *The above described procedure for the derivation of the stochastically stable states is implemented. The corresponding functions (Edmond algorithm, DeterminationLongTermEquilibriumForSpecificConstraints and DeterminationAllLongTermEquilibria) are produced and explained in Appendices B, C and E.*

The stochastically stable equilibria are represented in Figure 1.4, depending on the sizes of the two minorities (also see Figure 1.7 in Appendix A for the minimum spanning trees corresponding to each stochastically stable equilibrium, depending on the sizes of the two minorities).<sup>41</sup> As can be seen in Figure 1.4, the *egalitarian* hierarchy  $H_4$  only persists when both minorities are large enough (it corresponds to the red zone in Figure 1.4). Indeed, as already discussed, the *egalitarian* equilibrium  $E_4$ , although not particularly easy to reach from the other equilibria in this case, is very hard to upset (blue arrows leaving it in Figure 1.8). The

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41. Figure 1.7 is obtained using functions *FindingAllMinimumSpanningTrees*, *AnalyzingResultFindingAllMinimumSpanningTrees* and *PlotAnalyzingResultFindingAllMinimumSpanningTrees* produced in Appendix F.

*minority-differentiating* inegalitarian hierarchy  $H_2$  only persists if minority  $B$  is large enough and minority  $C$  is small enough (green zone in Figure 1.4). In this case, transitions from  $E_1$  or  $E_3$  to  $E_2$  indeed require very few mutations, as minority  $B$  can easily be convinced to switch (i.e. through very few  $\varepsilon$ -mutations). The *stepwise inegalitarian* hierarchy  $H_3$  is the only one to persist if the two minorities have intermediary and quite comparable sizes (around 1/2 for a discrimination coefficient  $\gamma \approx 1/2$ , this corresponds to the orange zone in Figure 1.4). In this case, equilibrium  $E_3$  is hard to upset in any direction (blue arrows leaving it in Figure 1.8) and easy to reach from both the *egalitarian* equilibrium  $E_4$  and the *minority-differentiating* inegalitarian one  $E_2$ .  $E_1$  and  $E_3$  both persist in the long term if the two minorities are small enough (the blue zone in Figure 1.4). They are both easy to reach from  $E_2$  and  $E_4$  through mutations of the small minorities. In order to know the probability associated with each of these two equilibria in the long term, the number of minimum spanning trees leading to each of them must be compared (see Young, 1993, for the justification). As can be seen in Figure 1.7, whenever  $E_1$  and  $E_3$  are both stochastically stable, they are associated with the same number of minimum spanning trees. Therefore, they are both associated with a probability of 1/2 in the long term.<sup>42</sup>

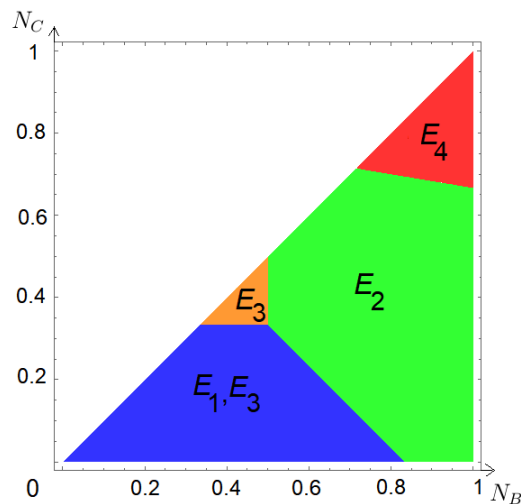


FIGURE 1.4 – Long-term equilibrium (or equilibria) depending on the two minorities' sizes,  $N_B$  and  $N_C$ .

The model's prediction that, in the presence of small minority groups, *majority-dominated*

42. Note that, another way to look at the results of Proposition 4.3 is through the lenses of fractionalization and polarization indices, as defined in Bazzi et al. (2019). In the model's setup, fractionalization is maximized when both minorities are as large as the majority. Polarization, on the other hand, is maximized when one minority is as large as the majority and the other is very small. Both indices reach their minimum, 0, when the two minorities have a zero size. Thus, it is clear that, when fractionalization is large enough, an *egalitarian* hierarchy view spreads in the population, whereas when polarization is large enough, a *minority-differentiating* inegalitarian hierarchy view is adopted by all. When both fractionalization and polarization are small enough, a *majority-dominated* inegalitarian hierarchy view or a *stepwise inegalitarian* hierarchy view is adopted. Eventually, for intermediary values of both indices, the *stepwise inegalitarian* hierarchy may persist.

inegalitarian hierarchy views of type  $H_1$  or *stepwise inegalitarian* hierarchy views of type  $H_3$  spread in the population seems to be largely corroborated by the literature. Indeed, as underlined in the literature review, numerous studies led in Western countries, in which a large majority group lives alongside several small minorities, show the existence of a “pattern of cumulative intergroup biases on which majority and minority groups appear to agree” (Hagendoorn, 1995). Additionally, to appreciate the role played by the *minority-differentiating* inegalitarian hierarchy view  $H_2$  and the *stepwise inegalitarian* hierarchy view  $H_3$ , the model’s long-term equilibria can be compared to the ones that would have been obtained if the only possible hierarchy views were  $H_1$  and  $H_4$  or if they were only  $H_1$ ,  $H_2$  and  $H_4$ . In these cases, using the same resolution method, the long-term equilibria can be shown to be the ones displayed in Figure 1.5 (where the left graph corresponds to the case where only  $H_1$  and  $H_4$  are possible hierarchy views and the right graph corresponds to the case where only  $H_1$ ,  $H_2$  and  $H_4$  are possible). Comparing the two graphs on this figure, it is clear that allowing for  $H_2$  hierarchy views reduces a lot the set of minority sizes for which the *egalitarian* equilibrium  $E_4$  persists in the long term<sup>43</sup> but it also reduces the set for which the *majority-dominated* inegalitarian equilibrium  $E_1$  persists.<sup>44</sup> Comparing the right graph with Figure 1.7, it can be observed that the introduction of  $H_3$  hierarchy views has a milder effect : *stepwise hierarchy* views replace, in some instances, *majority-dominated* hierarchy views  $H_1$ , either partially or totally.

Further analyzing Proposition 4.3 and Figure 1.4, note that the status of a group does not necessarily increase when its size increases. Indeed, if we consider the limit between the blue and the orange zone, we can remark that the status of group  $C$  just below the limit (i.e. in the blue zone where  $E_1$  and  $E_3$  both persist) is clearly larger than this group’s status just above the limit (i.e. in the orange zone where only  $E_3$  persists in the long term). Indeed, group  $C$  prefers equilibrium  $E_1$  over equilibrium  $E_3$  because, in the former equilibrium, it enjoys an equal status to minority  $B$ . A marginal increase in the size of minority  $C$  leading the society from the blue to the orange zone is therefore detrimental to minority  $C$  (but it benefits minority  $B$ ). The reason for this is that, just below the limit, the transition costs to go from  $E_1$  to  $E_2$  and from  $E_3$  to  $E_2$  are equal (these transitions both require the whole minority  $C$  to mutate, as well as part of the majority<sup>45</sup>). Just above the limit, mutations from only some members of minority  $C$  become necessary, which introduces an asymmetry : the transition cost from  $E_1$  to  $E_2$  becomes smaller than the transition cost from  $E_3$  to  $E_2$  and, as the former belongs to the

43. On the set of  $(N_B, N_C)$  for which  $E_4$  in the left graph is replaced by  $E_2$  in the right graph, the possibility of  $H_2$  hierarchy views benefits the majority and one minority while hurting the other. This situation may be interpreted as a “decentralized” “divide-and-rule” situation, in the sense that the possibility of  $H_2$  hierarchy views divides minorities and benefits the majority. The “divide-and-rule” situation is “decentralized” because it is not the product of a voluntary strategy implemented by the majority but, instead, of independent interactions between individuals.

44. In this case, the possibility of  $H_2$  hierarchy views benefits one minority,  $B$ , but hurts both the majority and minority  $C$ .

45. See Figure 1.2.



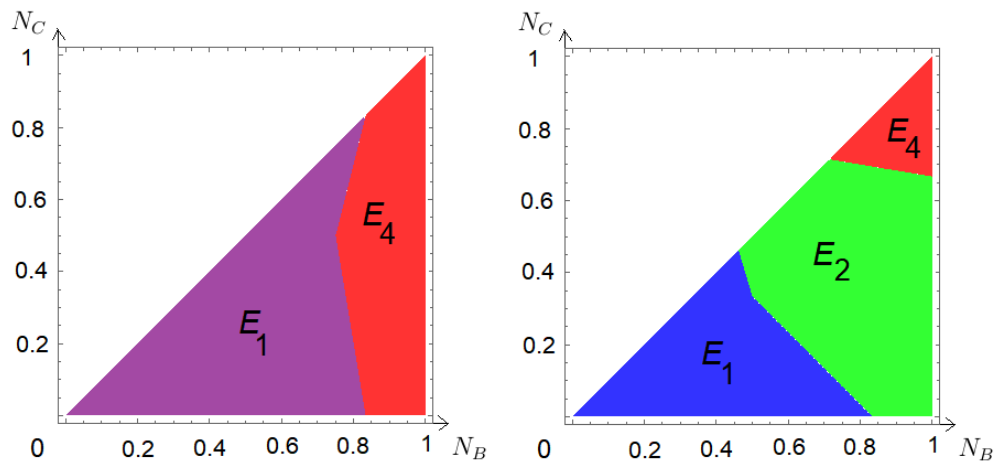


FIGURE 1.5 – Long-term equilibrium depending on the two minorities' sizes,  $N_B$  and  $N_C$  in two simplified versions of the three-group model with, in the left graph, only 2 possible hierarchy views ( $H_1$  and  $H_4$ ) and with, in the right graph, only 3 possible hierarchy views ( $H_1$ ,  $H_2$  and  $H_4$ )

minimum spanning trees leading to  $E_3$ <sup>46</sup> and the latter to the minimum spanning trees leading to  $E_1$ , the equilibrium  $E_3$  becomes easier to reach than  $E_1$  and therefore persists in the long term. Similarly, a marginal increase in the size of minority  $C$  leading the society from the blue to the green zone is also detrimental to minority  $C$  but beneficial to minority  $B$ . However, a marginal increase in the size of minority  $C$ , if it leads from the green to the red zone, benefits minority  $C$  at the expense of minority  $B$ . Focusing on minority  $B$  instead, we can observe that its status increases when its size marginally increases around the border between the blue and green zones and around the border between the orange and green zones, but not at the border between the green and red zones. Indeed, minority  $B$  prefers equilibrium  $E_2$  (where it dominates minority  $C$ ) over equilibrium  $E_4$ , so that an increase in minority  $B$ 's size reduces its status.

The model therefore predicts that an increase in a minority's size, in some instances, improves its status while reducing the other minority's,<sup>47</sup> in some instances improves its status without affecting the other minority's,<sup>48</sup> and in still other cases decreases the expanding minority's status while benefiting the other minority<sup>49</sup> (it never hurts both minorities). The first case, in which an increase in a minority's size improves its status while reducing the other minority's may be interpreted as an illustration of intergroup competition, which has been regularly documented by researchers in various countries. Meier et al. (2004), for example, show

46. This can be seen in Figure 1.7.

47. It is the case around the border between the green and red zones for minority  $C$  and between the blue and green zones for minority  $B$ .

48. It is the case around the border between the orange and green zones for minority  $B$ .

49. It is the case around the border between the blue and orange zones and between the blue and green zones for minority  $C$  and between the green and red zones for minority  $B$ .



how the Black and Latino minorities compete for some specific scarce resources in the United States, such as administrative and teaching positions, with improvements in the recognition of one minority in these domains directly translating into a reduction in the recognition of the other.<sup>50 51</sup> On the opposite, an example of situation in which an increase in a minority's size benefited another minority is provided by Fouka, Mazumder and Tabellini (2020), who empirically show that the Great Migration of African Americans from the South to the North of the US led to the better integration of Western and Northern Europeans. The variety of possible impacts of an increase in a minority's size predicted by the model may provide an explanation for the mixed results obtained in empirical studies regarding the link between minority size and level of prejudice against this minority, already evoked in this paper in the two-group model. These observations lead to the following Lemma :

**Lemma 4.4 :** *An increase in the size of a minority may improve or hurt the status of this minority, depending on the relative sizes of the different ethno-cultural groups in the society.*

**Proof of Lemma 4.4 :** *It is a direct consequence of Proposition 4.3.*

## 1.5 Further discussion of the results

### 1.5.1 Comparison of the two- and three-group models

Comparing the results yielded by the two- and three-group models, it is now possible to discuss the impact on hierarchy views of the arrival of a new minority in a country and of the splitting of one minority into two sub-minorities. The arrival of a new minority in a country, due to immigration or refugee movements, can indeed be proxied in the current setup by the addition of a new minority group in the society (i.e. fix the size of the majority and old minority  $B$  and compare the two- and three-group models, where minority  $C$  is the newly arrived minority). The splitting of one minority into two sub-categories due, for example, to a sudden increase in the salience of a certain ethno-cultural trait that differs between members of a same minority (e.g. religious characteristics after a religion-motivated terrorist attack, Oswald, 2005) or a cultural split (e.g. division of a religion into two new religious movements or division of a minority into one group that favors integration into the society and the other that

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50. However, this paper also shows that, when the resource is not scarce, as is the case for student performance, the relationship between the two minorities becomes complimentary.

51. Other examples of intergroup competition include the competition between German immigrants and African Americans in the mid- to late 19th century United States, between the different minorities in Belgium, between "old" and "new" Romas in Spain, and political competition between ethnic groups in African countries... See Strickland (2008), Teney et al. (2010), Magazzini and Piemontese (2016) and Eifert, Miguel and Posner (2010).

stands against it), can similarly be proxied by the division of a minority into two minorities, which sizes add up to the initial minority's size (i.e. fix the majority size and divide the initial minority  $B$  into two minorities,  $B$  and  $C$ , then compare the corresponding two- and three-group models).

### 1.5.1.1 Impact of the arrival of a new minority

In order to discuss the impact of the arrival of a new minority into a society,<sup>52</sup> the two- and three-group models have to be made comparable by applying the same normalizations and assumptions (i.e.  $\theta = 1$ ,  $N_A = 1$  and  $\gamma \approx 1/2$ ). With these normalizations and assumptions, the threshold of the two-group model between the egalitarian and inegalitarian equilibria becomes  $N_B = \frac{5}{6} \approx 0.83$ . Considering that minority  $B$  is the old minority (i.e. the minority that was already present at the arrival of the new minority  $C$ ), the society evolves from the long-term equilibrium of the two-group model with only groups  $A$  and  $B$  to the long-term equilibrium of the three-group models with group  $A$ , the old minority  $B$  and the new minority  $C$ . The comparison of the two models is depicted on the left graph in Figure 1.6 where the vertical black line corresponds to the threshold on  $N_B$  in the two-group model : to the right of this line, the egalitarian equilibrium persists in the long term in the two-group model and, to its left, the inegalitarian equilibrium persists.

From this Figure, it clearly appears that, if the old minority  $B$  and the majority  $A$  enjoyed an equal status before the arrival of the new minority (i.e.  $N_B > 0.83$ ), then the statuses of both majority  $A$  and minority  $B$  remain equal (in both equilibria  $E_2$  and  $E_4$ ), but, if the new minority is small enough, groups  $A$  and  $B$  now dominate the new minority (i.e. equilibrium  $E_2$  persists in the long term). If the old minority  $B$  instead used to be dominated by the majority before the arrival of the new minority (i.e.  $N_B < 0.83$ ), then this arrival improves minority  $B$ 's status : the minority  $B$  may become equal to the majority if equilibrium  $E_4$  or  $E_2$  persists in the long run, or obtain an intermediary status if equilibrium  $E_3$  or equilibria  $E_3$  and  $E_1$  persist. In contrast, the majority's status may be reduced by this arrival : if the total size of the two minorities is large enough, the majority is not the only dominant group anymore (i.e.  $E_2$  or  $E_4$  persists), if this total size is small enough, the majority remains the only dominant group. These results can be summarized in the following Proposition :

**Proposition 5.1 :** *In the present evolutionary game theory model, the arrival of a new minority :*

- *benefits or does not affect the status of the old minority*
- *dampens or does not affect the domination of the majority*

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52. For example, this new minority may be composed of Syrians or Iraqis fleeing their country during the recent wars.

**Proof of Proposition 5.1 :** *It is a direct consequence of Proposition 3.2 and Proposition 4.3.*

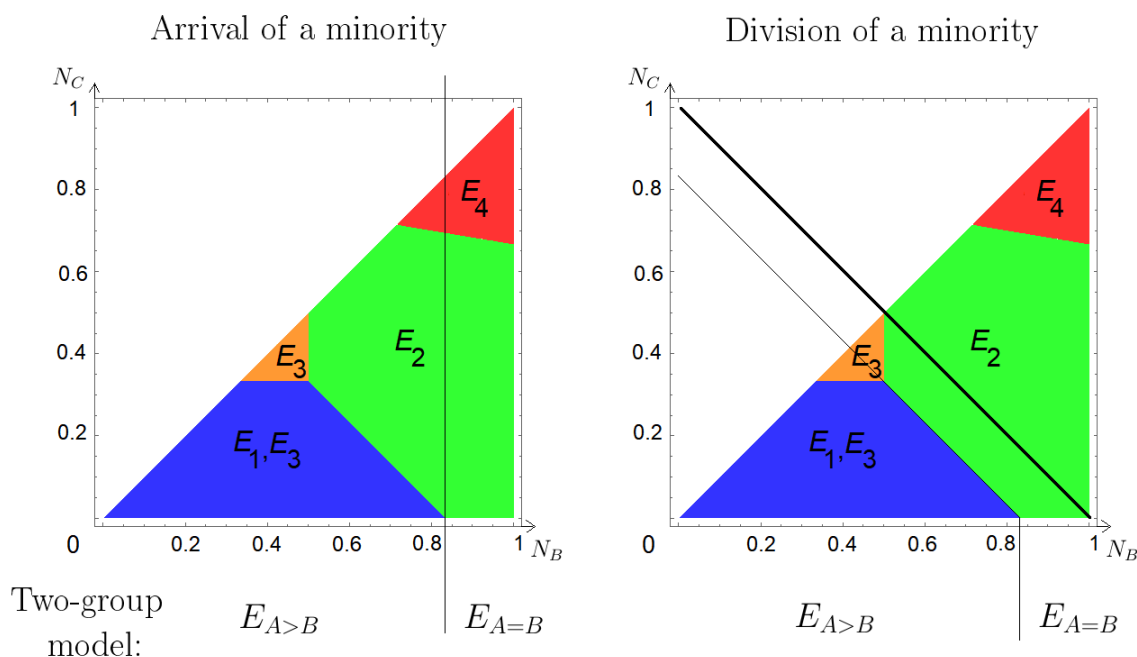


FIGURE 1.6 – Impact of the arrival of a new minority and of the division of a minority

### 1.5.1.2 Impact of the division of a minority

We can now discuss the impact of the schism of a minority into two smaller ones. A typical example for this corresponds to African-American elite clubs before the civil rights movement, which chose to divide the “black” category into “light” and “dark black” and discriminate against the latter (Graham, 2009). Another example is provided by London inhabitants of Pakistani origin, who resist being assimilated with Indians in the “South-Asian” category (Khan, 1976).<sup>53</sup>

To discuss the impact of the division of a minority, the results of the two- and three-group models must be compared, considering that minority  $B$  in the two-group model (hereafter denoted by  $B_i$  for “initial”) splits into minority  $B$  and  $C$  in the three-group model (hereafter denoted by  $B_f$  and  $C_f$  for “final”). Thus, the size of group  $B_i$  in the two-group model is equal to the sum of the sizes of groups  $B_f$  and  $C_f$  in the three-group model ( $N_{B_i} = N_{B_f} + N_{C_f}$ ). The comparison of the two models when a minority gets divided is depicted on the right graph in Figure 1.6. The thin oblique black line depicts the threshold between the two equilibria in

53. Other examples are provided by Horowitz (1977)).

the two-group model, translated in terms of  $N_{B_f}$  and  $N_{C_f}$  such that the total size of the new minority groups ( $N_{B_f} + N_{C_f}$ ) equals the threshold. Comparisons of the two-group and three-group models after the split will similarly have to be made along oblique lines parallel to this one to ensure that the sizes of the two new minority groups add up to the size of the old one. The zone above the thick oblique line cannot be reached after the division of the old minority, because this old minority's size was below the one of the majority (i.e.  $N_{B_i} < N_A = 1$ ) so that the sizes of the two new minorities can only add up to less than 1 (i.e.  $N_{B_f} + N_{C_f} < 1$ ). In this Figure, we can observe that, if the old minority  $B_i$  used to be equal in status to the majority (i.e.  $N_{B_i} > 0.83$ , corresponding to the zone between the two oblique lines), the split of the minority is always detrimental to the smallest new minority  $C_f$  (which becomes dominated both in equilibrium  $E_2$  and  $E_3$ ) and may either benefit (if  $E_2$  persists) or be detrimental (if  $E_3$  persists) to the largest new minority  $B_f$ . If the old minority  $B_i$  used to be dominated (i.e.  $N_{B_i} < 0.83$ , corresponding to the zone below the lowest oblique line), the split improves the status of the largest new minority  $B_f$  (both if  $E_3$  or  $E_3$  and  $E_1$  persist in the long term), which becomes intermediary, but hurts the smallest new minority  $C_f$ , which is now dominated both by the majority and the new minority  $B_f$ . These results can be summarized in the following Proposition :

**Proposition 5.2 :** *In the present evolutionary game model, the split of a minority :*

- *is always detrimental to the status of the smallest new subdivision of this minority.*
- *always improves the status of the largest new subdivision of this minority if it used to be dominated before the split.*
- *may hurt or improve the status of the largest new subdivision of this minority if it used to enjoy a status equal to the majority's before the split.*

**Proof of Proposition 5.2 :** *It is a direct consequence of Proposition 3.2 and Proposition 4.3.*

Proposition 5.2 implies that, in a society with several ethno-cultural groups, some incentives exist that favor the fragmentation of minorities instead of their fusion or union. Indeed, if some members of a minority decide to separate from the rest of the minority, for example by creating a new cultural or physical distinction within the minority (light vs dark Blacks for example), they can improve their social status at the expense of the rest of the minority. Note that the effect of the merge between two minorities is simply the exact opposite (positive impacts become negative impacts and vice versa).<sup>54</sup>

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54. Examples of merge between several minorities are the development of pan-ethnic identities among "Asians" or "Hispanics" in the United States (Padilla, 1986; Le Espiritu, 1992; Okamoto, 2003) and the development of the Bangala and Bakongo ethnic groups in Congo (Young, 2015a).

## 1.5.2 Discussing economic impacts

We can now turn to a brief discussion of the economic conclusions to be drawn from the model. So far, it has been assumed that egalitarian and inegalitarian interactions have the same level of overall productivity and all produce a total payoff of  $2\theta$  (i.e.  $\theta + \theta$  or  $\theta - \gamma + \theta + \gamma$ ). In this context, inegalitarian and egalitarian equilibria yield the same Benthamite social welfare (defined as the sum of payoffs of all individuals in the society) at each period of time, while the *egalitarian* equilibrium self-evidently brings a larger Rawlsian social welfare. Let us now assume that egalitarian interactions bring a payoff  $\theta'$  to each interacting individual, which only very slightly differs from  $\theta$ . This assumption modifies the model very marginally so that, in the long term, for  $\theta'$  sufficiently close to  $\theta$ , only the borders of the zones on which equilibria persist are shifted (the long-term equilibrium within each zone is preserved, as its minimum spanning tree is strictly less costly than the other Nash equilibria's).

It is not evident to theoretically anticipate whether, in reality, egalitarian or inegalitarian hierarchy views should yield the highest overall payoff. Indeed, one can expect that an inegalitarian hierarchy may allow for the easy designation of a leader in the interaction, which may improve its efficiency. But it may also lead to “stereotype threat” or a sentiment of injustice on the side of the dominated group, causing it to underperform, while the dominant group, subject to “stereotype lift”, may, on the contrary, overperform. Furthermore, an egalitarian hierarchy may allow for a better exchange of ideas than an inegalitarian hierarchy. The empirical literature on this subject, however, brings some insights on this question and suggests that inequality between individuals, when perceived as unfair, tends to reduce participation to public goods and increase sabotage (Waring and Bell, 2013; Anderson, Mellor and Milyo, 2008; Nishi et al., 2015; Fehr, 2018; Dickinson, Masclet and Peterle, 2018; Sadrieh and Verbon, 2006), thereby reducing aggregate welfare.<sup>55</sup>

In the model, considering that egalitarian interactions are marginally more productive than inegalitarian ones as suggested by the literature, i.e.  $\theta' > \theta$ , the egalitarian equilibrium  $E_4$  becomes the socially most desirable one in terms of aggregate welfare and the minority-differentiating inegalitarian equilibrium  $E_2$  the second-best. It implies that the society is the most productive when all groups are equally sized (leading to  $E_4$ ), and second most productive when at least one minority is large (leading to  $E_2$ ).<sup>56</sup> The prevalence of “stepwise” ethno-cultural hierarchies brought out by numerous studies led in Western countries is explained, in the model, by the relatively small sizes of the minorities present in these countries as compared

55. When not perceived as unfair, inequality may, however, favor collective action and increase participation to public goods (Simpson, Willer and Ridgeway, 2012).

56. If, instead, one assumes that inegalitarian interactions are marginally more productive, i.e.  $\theta > \theta'$ , then the society is the most productive when minorities have an intermediate size, leading to the persistence of a *stepwise inegalitarian* hierarchy view in the long term (i.e.  $E_3$ ). The second most productive equilibrium in this case is  $E_1$ , which is reached when the minorities are both small enough.

to the size of the majority group. This leads the evolutionary process to select an equilibrium of type  $E_3$  or  $E_1$ , even though the empirical literature suggests that these inegalitarian equilibria are inefficient.

The model with  $\theta' > \theta$  also implies that the impact of the arrival of a new minority as discussed in 1.5.1.1, by favoring the emergence of more egalitarian views (except when the old minority used to be equal to the majority before the arrival of the new minority and the new minority is small enough), is associated with a positive economic impact. On the opposite, the division of a minority, whilst benefiting some members of this minority, affects negatively the overall economic output.

## 1.6 Conclusion

The present paper proposes a three-group evolutionary game model of coordination between different ethno-cultural groups' members on common ethno-cultural hierarchy views. It allows to discuss, in the context of a multicultural society, how different ethno-cultural hierarchies may emerge from independent interactions between members of the various ethno-cultural groups, even in the absence of socio-economic and productivity differences between these groups (i.e. no statistical discrimination) or of prejudices, merely because status is defined at the level of heterogeneously sized ethno-cultural groups.

In this model, each individual in the society holds a specific hierarchy view and interacts with other individuals at each period of time. Interactions between individuals who agree on a same hierarchy view are more productive than interactions between disagreeing individuals. From time to time, individuals have the opportunity to alter their hierarchy views, taking into account the distribution of hierarchy views in the population and their corresponding best response. They may make mistakes and adopt hierarchy views that do not correspond to their best interests. Hierarchy views in the society thus evolve through time. At each period of time, the distribution of hierarchy views in the population consists in a mix of all possible hierarchy views. In the long-term, the whole society coordinates on a unique distribution of hierarchy views, consisting of hierarchy views that are the easiest to reach from all other hierarchy views (i.e. the ones that require the lowest number of mistakes to be reached). In order to determine this hierarchy view, it is necessary to build an oriented graph, in which nodes correspond to situations of overall coordination on each possible hierarchy view and in which oriented edges are weighted with the number of mistakes required for the transition of the society from the initial to the final node situation. The easiness to reach a given hierarchy view depends on the cost of the minimum spanning tree leading to its corresponding node. The role played by minimum spanning trees represents a key feature of this model and leads to interesting results.

First, the model stresses an indirect channel, distinct from the main channels discussed in

the literature, through which changes in the relative size of a minority may affect the status of this minority or of another : the altering of the transition costs between the different hierarchy views and therefore of the minimum spanning trees leading to each possible long-term equilibrium of hierarchy views, which may translate into a change in the hierarchy views that persist in the long-term in the society. This indirect channel sometimes allows a minority's status to be improved by an increase in its size. However, depending on the initial sizes of the different ethno-cultural groups, such an increase may sometimes instead lead to a reduction of the minority's status. This mechanism could explain why an increase in a minority's size has been empirically shown to lead, depending on the case, to an improvement or reduction of its social status.

The model also allows to understand how, depending on the relative sizes of the different groups, several groups' preferences over hierarchy views may diverge or coincide, leading to *de facto* "decentralized alliances" or competition between them. Comparing the two- and three-group versions of the model, the model predicts that the arrival of a new minority in a country benefits or does not impact the status of old minorities, while reducing the domination of the majority group. Additionally, the model shows that some members of a minority that is discriminated against may benefit from the division of this minority into smaller categories, some of which obtain a higher status after the division.

Eventually, a simple extension of the model introducing productivity differences between egalitarian and inegalitarian interactions shows how the evolutionary process leads, in societies with small minorities, to the emergence of economically inefficient inegalitarian hierarchy views. Additionally, the arrival of a new minority is shown to generally have a positive overall economic impact, by leading to more egalitarian hierarchy views, while the division of a minority reduces the overall output, by making inegalitarian interactions more frequent.

This model is, to the best of my knowledge, the first to propose a comprehensive mechanism for the emergence of ethno-cultural hierarchies, in which both majority's and minorities' incentives are taken into account. It also provides the first theorization of the reciprocal impacts that different minorities may have on each other's statuses in a multi-cultural society.

## 7 Appendix A - Figures related to the three-group model

	$E_1$	$E_2$	$E_3$	$E_4$
$E_1$	0	$-1 + \frac{3+N_C}{2+\gamma}$ if $3N_C \geq 1$ $1 + 2N_C - \frac{1+3N_C}{2-\gamma}$ if $3N_C \leq 1$ & $9N_B + 6N_C \geq 5$ $\frac{(1+\gamma)N_B+N_C}{2+\gamma}$ if $9N_B + 6N_C \leq 5$	$-1 + \frac{3+N_C}{2+\gamma}$ if $3N_C \geq 1$ $\frac{1}{2} + N_C \left( \frac{3}{2} - \frac{1}{1-\gamma} \right)$ if $3N_C \leq 1$ & $N_B + 2N_C \geq 1$	$\frac{1}{2}(1 + N_C - \gamma)$ if $2N_C \geq 1$ $(1 + N_C) \left( 1 - \frac{1}{2-\gamma} \right)$ if $9N_B + 4N_C \geq 5$ & $(2N_C \leq 1 \text{ \& } 2N_B \geq 1)$ $\parallel 2N_B \leq 1$
$E_2$	$(1 + N_B) \left( 1 - \frac{1}{2-\gamma} \right)$ if $3N_C \geq 2$ $\frac{N_B+N_C}{2+\gamma}$ if $3N_C \leq 2N_B$ $\frac{N_B+(1+\gamma)N_C}{2+2\gamma}$ if $3N_C \geq 2N_B$ & $(2N_B \leq 1$ $\parallel (2N_B \geq 1 \text{ \& } 3N_C \leq 2))$	0	$\frac{N_B+(1+\gamma)N_C}{2+2\gamma}$ if $3N_C \geq 2$ $\parallel (3N_C \geq 2N_B \text{ \& } 3N_C \leq 2$ & $(3N_B + 6N_C \geq 1 \parallel 2N_B \leq 3N_C))$ $\frac{N_B+N_C}{2+\gamma}$ if $(3N_C \leq 2N_B \text{ \& } 3N_B + 6N_C \geq 1)$ $\parallel (3N_C \leq 2N_B \text{ \& } 27N_B + 12N_C \geq 5)$ $\parallel (3N_C \leq 2N_B \text{ \& } 3N_B + 6N_C \leq 1$ & $27N_B + 12N_C \geq 5)$	$(1 + N_B) \left( 1 - \frac{1}{2-\gamma} \right)$ if $N_B + 3N_C \geq 2$ $\frac{N_B+N_C}{2}$ if $N_B + 3N_C \leq 2$
$E_3$	$(1 + N_B) \left( 1 - \frac{1}{2-\gamma} \right)$ if $9N_C \geq 2 + 5N_B$ $\frac{1}{2} + \frac{N_C}{2} \left( 2 - \frac{1}{1-\gamma} \right)$ if $2N_C \leq 1$ & $N_B + N_C \geq 1$ $\frac{1+N_C-(1-N_C)\gamma}{2+\gamma}$ if $2N_C \geq 1$ & $9N_C \leq 2 + 5N_B$ $\frac{N_B+N_C}{2}$ if $2N_B \leq 1$ $\parallel ((2N_B \geq 1 \text{ \& } N_B + N_C \leq 1))$	$-\frac{1}{2}(1 - N_C) + \frac{1}{1+\gamma}$ if $3N_C \geq 1$ $1 + 2N_C - \frac{1+3N_C}{2-\gamma}$ if $3N_C \leq 1$ & $9N_B + 6N_C \geq 5$ $\frac{N_B(1+\gamma)+N_C}{2+\gamma}$ if $9N_B + 6N_C \leq 5$	0	$(1 + N_B) \left( 1 - \frac{1}{2-\gamma} \right)$ if $9N_C \geq 2 + 5N_B$ $(1 + N_C) \left( 1 - \frac{1}{2-\gamma} \right)$ if $2N_C \leq 1$ & $9N_B + 4N_C \geq 5$ $\frac{1+N_C-(1-N_C)\gamma}{2+\gamma}$ if $2N_C \geq 1$ & $9N_C \leq 2 + 5N_B$ $\frac{(1+\gamma)(N_B+N_C)}{2+\gamma}$ if $9N_B + 4N_C \leq 5$
$E_4$	$\frac{N_B+N_C}{2+\gamma}$	$\frac{N_B+N_C}{2+\gamma}$ if $3N_C \geq 2$ $\parallel ((3N_C \geq 2N_B \text{ \& } 3N_C \leq 2)$ $\frac{N_B+N_C(1-\gamma)}{2}$ if $3N_C \leq 2N_B$	$\frac{N_B+N_C}{2+\gamma}$	0

TABLE 1.1 – Matrix of transition costs

Note : This table depicts the transition costs for each pair of initial and final equilibria in the vicinity of  $\gamma = \frac{1}{2}$ , depending on the relative sizes of minorities  $B$  and  $C$ . The cell in the  $i$ -th row and  $j$ -th column corresponds to the transition cost from the initial equilibrium  $E_i$  to the final one  $E_j$ . For the sake of readability, the conditions on minority sizes have been simplified by assuming  $\gamma = \frac{1}{2}$ .



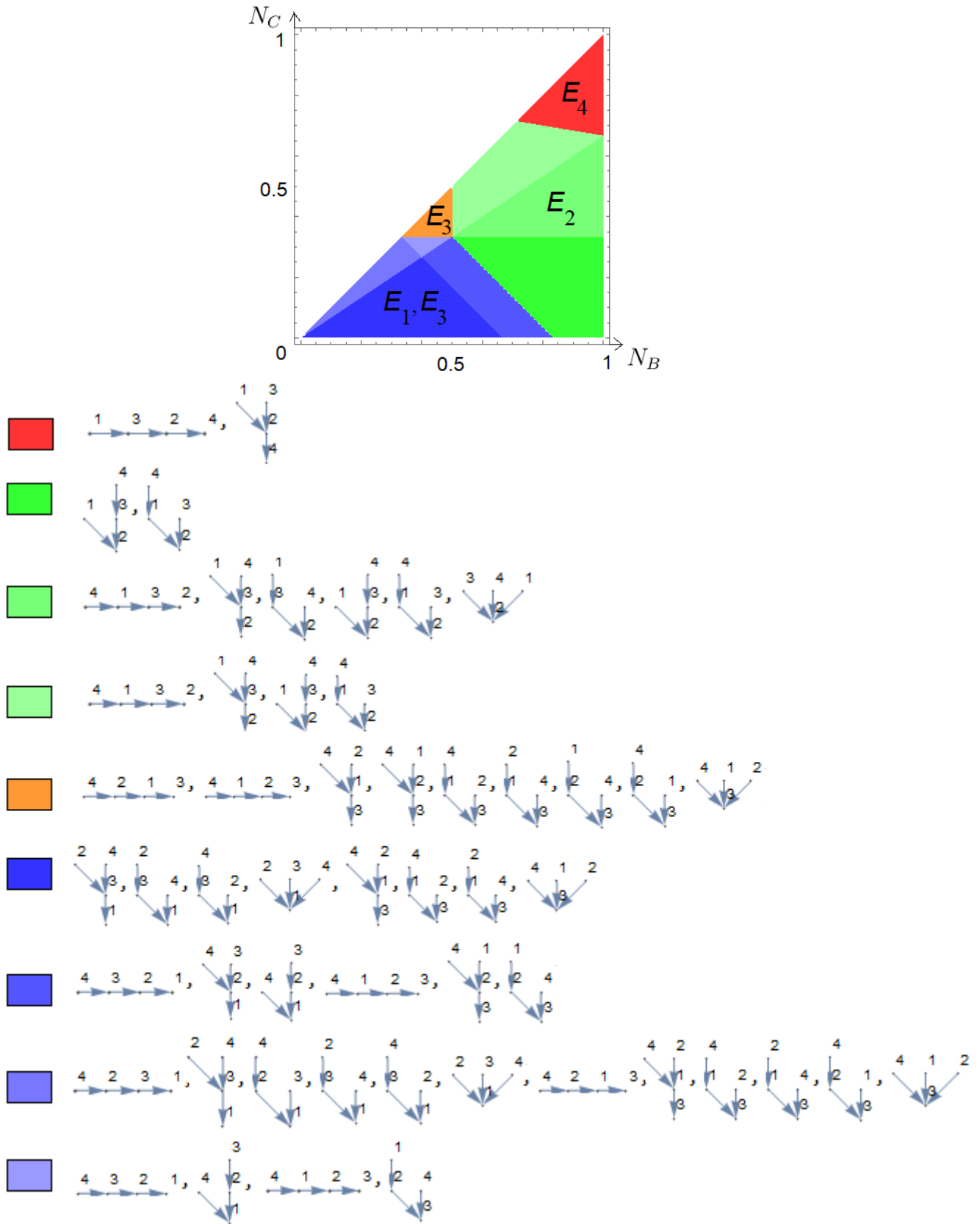


FIGURE 1.7 – All minimum spanning trees leading to each long-term equilibrium depending on the size of the two minorities

Note : For the sake of readability, equilibria  $E_1$ ,  $E_2$ ,  $E_3$  and  $E_4$  are simply denoted by 1, 2, 3 and 4 in the minimum spanning trees.

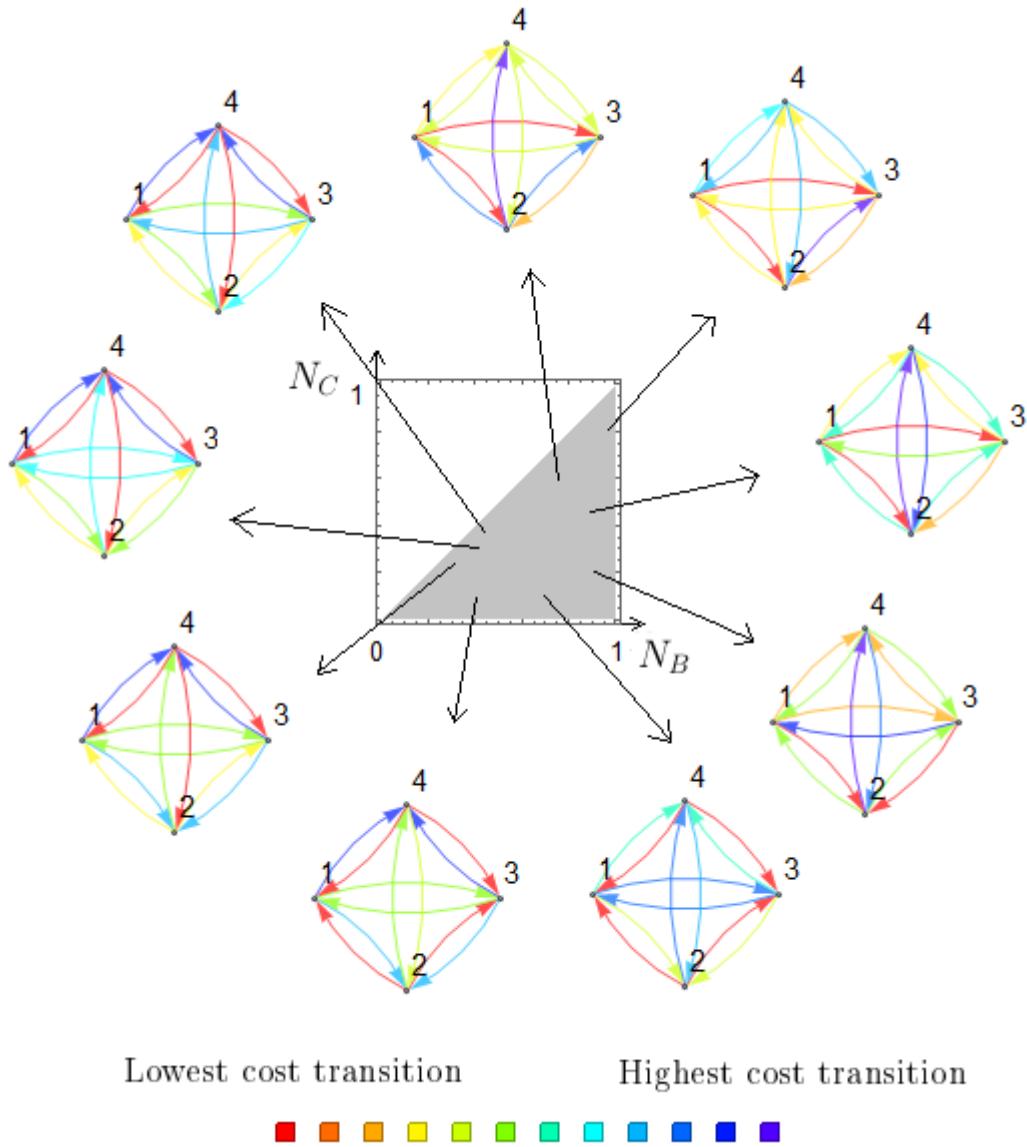


FIGURE 1.8 – Examples of mutation graphs for different sizes of the two minorities

Note : In each example of mutation graph, the red arrows correspond to the lowest cost transitions and the blue arrows to the highest cost transitions. For the sake of readability, long-term equilibria  $E_1$ ,  $E_2$ ,  $E_3$  and  $E_4$  are simply denoted by 1, 2, 3 and 4 in the oriented graphs.

## 1.8 Appendix B - Proofs of Lemmas and Propositions

### 1.8.1 Full Proof of Lemma 4.2

To prove Lemma 4.2, first note that, for a transition from one equilibrium to another to take place, two different scenarii are possible. In the first scenario, all switches between equilibria during the transition<sup>57</sup> happen between the initial and the final equilibrium. It will be called a “direct” transition. In the second scenario, some switches imply other equilibria than the initial and final one. It will be called an “indirect” transition.

In a “direct” transition, all switches happen between the initial and final equilibrium. In this case, to make one group want to switch between the initial and final equilibrium using the least number of  $\varepsilon$ -mutations, it is evident that  $\varepsilon$ -mutations should be directed from the initial to the final equilibrium too (indeed, it is clear that this type of mutations reduces the gap between the payoff of the first switching group in the initial and final equilibria the most, as it both decreases the initial payoff and increases the final one).  $\varepsilon$ -mutations from members of one group (or two groups if necessary<sup>58</sup>) are used to make a first group want to switch. Once it is done, it is clearly most efficient to have all members of the first-switching group switch to the final equilibrium through best-response adjustments at zero cost. Then, there are two possible cases. Either one of the two remaining groups prefers the final equilibrium over the initial one, in which case it also switches to it through best-response adjustments at zero cost, or both remaining groups prefer the initial equilibrium, in which case additional  $\varepsilon$ -mutations are required to make one of them prefer the final equilibrium.<sup>59</sup> Once the second group has switched to the final equilibrium, the third group necessarily also prefers the final equilibrium (as it is a Nash equilibrium and two groups already coordinated on it) and switches to it at no cost.

In an “indirect” transition, at least one switch implies another equilibrium than the initial and final ones. Intuitively, an “indirect” transition could be expected to require fewer

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57. The term “switch” from an initial to a final equilibrium is used when members of one group prefer the final equilibrium over the initial one, so that they adopt the final strategy through best-response adjustments with probability  $1 - \varepsilon \approx 1$  at each period at no cost.

58. Note that  $\varepsilon$ -mutations from two groups may be necessary to make one group prefer the final equilibrium, while  $\varepsilon$ -mutations from members of only one group were necessary in the two-group model.

59. In practice, the computation of “direct” transition costs shows that, for the optimal choice of first (and possibly second) mutating group and of first switching group, once the first switching group has switched, the other groups follow, so that no additional cost is required to have a second group switch.

$\varepsilon$ -mutations than a “direct” one if the switching of a group to an intermediary equilibrium (different from the initial and the final one) can be made at a lower cost than would have been necessary to make this group switch to the final equilibrium directly, and if this switch then makes it easier (i.e. fewer  $\varepsilon$ -mutations are required) to have another group prefer the final equilibrium over all others. The switch to an intermediary equilibrium is therefore only useful because it reduces the level of coordination on the initial equilibrium and thus also the final payoff necessary to make another group prefer the final equilibrium.<sup>60</sup>

To prove Lemma 4.2, the following steps are implemented (using Mathematica) : (1) “direct” transition costs between each possible initial and final equilibria are computed, using only “direct”  $\varepsilon$ -mutations from the initial to the final equilibrium, (2) a lower bound on the “indirect” transition cost between each possible initial and final equilibria when using “indirect”  $\varepsilon$ -mutations towards an intermediary equilibrium (different from the initial and final ones) to make at least one group switch towards this other equilibrium is computed, (3) it is shown that, for each pair of initial and final equilibria, the “direct transition cost” computed in the first step is lower than the lower bound on the “indirect transition cost” computed in the second step. Therefore,  $\varepsilon$ -mutations from the initial to the final equilibrium lead to the lowest transition costs.

### **1.8.1.1 Step (1) : Computation of the “direct” transition costs**

Before describing the algorithm used for the computation of “direct” transition costs for all possible initial and final equilibria and for all possible constraints on minority sizes, two auxiliary functions have to be defined.

The first auxiliary function, *DirectTransitionCostWithSpecificFirstSwitchingGroup*, computes, for given initial and final equilibria, a given first switching group and a given set of constraints on minority sizes, the “direct” transition cost. It implements the following steps :

- First, a first mutating group is selected among the two groups that are not the first switching group. To minimize the transition cost, this first mutating group must be

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60. Note that, if a first group has switched to the final equilibrium, it is inefficient to have “indirect” switches because, as already noted in footnote 59, the switching of a first group is sufficient to reach the final equilibrium.

the one whose mutations have the largest impact on the difference between the payoff of the first switching group in the initial and final equilibria (so that fewer mutations are needed to make the first switching group indifferent between the initial and final equilibria).

- The “naive” cost to make the first switching group switch is computed, using only mutations from the first mutating group.
- If this “naive” cost is larger than the size of the first mutating group, it means that having the whole first mutating group mutate to the final equilibrium is not sufficient to make the first switching group prefer the final equilibrium. In this case, the whole first mutating group needs to mutate, as well as part of the second mutating group. The corresponding transition cost is computed.
- If the “naive” cost is smaller than the size of the first mutating group, no mutations from another group are required.
- Once the cost to make the first switching group switch has been computed, it is necessary to check whether the switching of this group to the final equilibrium is sufficient to make the two other groups switch to the final equilibrium too. For this, it is sufficient that only one of the two other groups prefers the final equilibrium because, in this case, it can switch to it through best-response adjustments and, once two whole groups have reached the final equilibrium, the third one necessarily prefers the final equilibrium too (because it is a Nash equilibrium). Therefore, it is checked whether one of the two other groups is willing to switch to the final equilibrium.
- If it is the case, the function returns the cost to make the first switching group switch.
- If it is not, an additional cost is computed : i.e. the number of mutations from each of the two remaining groups to the final equilibrium necessary to make the other remaining group prefer the final equilibrium. The lowest of the two possible additional costs is retained. The function returns the sum of the cost to make the first switching group switch and the cost to make the second group switch.

If, at any step, the function stumbles upon a comparison that remains ambiguous under the set of constraints, it raises an error and returns the ambiguous inequality.

The second auxilliary function, *DirectTransitionCost*, computes, for given initial and final

equilibria and a given set of constraints on minority sizes, the “direct” transition cost. Its steps are the following :

- It calls, for each possible first switching group, the previous function *DirectTransitionCostWithSpecificFirstSwitchingGroup*.
- It compares the three “direct” transition costs obtained and returns the lowest one.

If the function stumbles upon a comparison that remains ambiguous under the set of constraints, it raises an error and returns the ambiguous inequality.

The algorithm to compute all “direct” transition costs, *TransitionCostsMatrix*, is as follows :

- For each possible pair of initial and final equilibria  $(E^{(i)}, E^{(f)})$  :
  - Try to compute the “direct” transition cost between them.
  - If an error is raised with a constraint on minority sizes, try to compute separately the “direct” transition cost when this constraint is met and when it is not.
  - If an error is raised with a new constraint on minority sizes, further subdivide the set  $\mathcal{P}$ , until the “direct” transition cost can be computed unambiguously on each subdivision.
- The algorithm returns the matrix of transition costs corresponding to each pair of initial and final equilibria. These transition costs are defined by part on  $\mathcal{P}$ .

### **1.8.1.2 Steps (2) and (3) : Computation of lower bounds on the “indirect” transition costs and comparison with the “direct” transition costs**

To compute a lower bound on the “indirect” transition costs, one auxilliary function is used : *AuxTestOptimalityDirectTransitionCosts*. This function computes, for given initial and final equilibria and constraints on minority sizes, a lower bound on the “indirect” transition cost and show that it is greater than the “direct” transition cost. It uses the following steps :

- First, it determines the two possible intermediary equilibria, different from the initial and the final one.
- Then, it computes, for each choice of intermediary equilibrium and first switching group, the minimum cost to have this group switch to the intermediary equilibrium, using function *DirectTransitionCostWithSpecificFirstSwitchingGroup*.

- After that, it assumes that the first switching group switches partially or totally to the intermediary equilibrium, possibly followed by other groups, so that all groups scatter between the initial and intermediary equilibria in some way. To reach the final equilibrium from this configuration, it is necessary, at some point, to make one group prefer the final equilibrium (or possibly, before, a second intermediary equilibrium) over the initial and intermediary equilibria. This will lead to what will be called, for the demonstration, the “second switch” (although other switches may have occurred since the first switch, but their cost is not taken into account). The final or second intermediary equilibrium towards which the “second switch” is directed is called “target equilibrium”.
- In order to show that direct transitions are more efficient than indirect ones, a lower bound on the cost of the “second switch” is computed for each choice of intermediary equilibrium, target equilibrium, first switching group and “second” switching group. It is shown, in each case, that the sum of the cost of the first switch and of the lower bound on the cost of the second switch is greater than the direct transition cost.

If, at any step, the function stumbles upon a comparison that remains ambiguous under the set of constraints, it raises an error and returns the ambiguous inequality.

More precisely, in function *AuxTestOptimalityDirectTransitionCosts*, the lower bound on the cost of the “second switch” is computed in the following way :

- First, it can be remarked that it will be easiest (i.e. optimal) to make the “second” switching group switch if the other groups’ members are initially distributed between the initial and intermediary equilibrium in such a way that, if enough  $\varepsilon$ -mutations take place between the initial (or, alternatively, intermediary) equilibrium and the target one, the “second” switching group will become indifferent at the same time between the initial, intermediary and target equilibria. Indeed, if the payoff in the initial equilibrium is different from the payoff in the intermediary equilibrium when the number of  $\varepsilon$ -mutations becomes sufficient for the payoff in the target equilibrium to become larger than the two former ones, there is an under-efficiency linked with the fact that fewer  $\varepsilon$ -mutations would have been needed if more individuals had been coordinated on the equilibrium (initial or intermediary) associated with the lowest payoff in the first place. Studying the “optimal” case therefore provides a lower bound on the cost of the “se-

cond" switch. We can denote by  $H_i$  the initial hierarchy view, by  $H_{int}$  the intermediary hierarchy view, by  $H_t$  the target hierarchy view. We also denote by  $N_{Ai}$ ,  $N_{Bi}$  and  $N_{Ci}$ , the number of members of group  $A$ ,  $B$  and  $C$  coordinated on the initial hierarchy in the "optimal" initial distribution before the second switch. Additionally, the payoff of the second switching group  $g$  when it adopts hierarchy  $H_e$  if  $N_{Ae}$  members of group  $A$ ,  $N_{Be}$  members of group  $B$  and  $N_{Ce}$  members of group  $C$  adopted it too, is denoted by  $P_g(H_e, N_{Ae}, N_{Be}, N_{Ce})$ . Starting from the initial configuration before the second switch, the number of  $\varepsilon$ -mutations of members of group  $g$  from the initial to the target equilibrium is denoted by  $n_g$  and the number of  $\varepsilon$ -mutations of members of group  $g$  from the intermediary to the target equilibrium is denoted by  $n'_g$ . With these notations, the condition that the "second" switching group becomes indifferent at the same time between the initial, intermediary and target equilibria (indexed by  $i$ ,  $int$  and  $t$  respectively) can be written, in the case where this "second" switching group is  $A$ , as follows :

$$\begin{aligned}
 & P_A(H_i, N_{Ai}, N_{Bi} - n_B, N_{Ci} - n_C) \\
 &= P_A(H_{int}, 1 - N_{Ai}, N_B - N_{Bi} - n'_B, N_C - N_{Ci} - n'_C) \quad (1.7) \\
 &= P_A(H_t, 0, n_B + n'_B, n_C + n'_C)
 \end{aligned}$$

- The minimization of  $n_B + n'_B + n_C + n'_C$  under the conditions (1.7),  $1 \geq n_{Ai} \geq 0$ ,  $N_B \geq N_{Bi} + n'_B$ ,  $n'_B \geq 0$ ,  $N_{Bi} \geq n_B \geq 0$ ,  $N_C \geq N_{Ci} + n'_C$ ,  $n'_C \geq 0$ , and  $N_{Ci} \geq n_C \geq 0$  using the parameters  $n_B$ ,  $n'_B$ ,  $n_C$ ,  $n'_C$ ,  $N_{Bi}$  and  $N_{Ci}$ <sup>61</sup> gives a lower bound on the cost to make the "second" switching group  $A$  switch toward the target equilibrium. The conditions will be referred to as "conditions (C)".
- To solve this minimization problem, we can first solve the system composed of the two equalities in (1.7) with respect to  $N_{Bi}$  and  $N_{Ci}$ . Denoting by  $\alpha_{kle}$  the payoff extracted from an interaction by a member of group  $k$  interacting with a member of group  $l$  when both are coordinated on hierarchy  $H_e$ ,<sup>62</sup> the following expressions for  $N_{Bi}$  and  $N_{Ci}$  are

---

61. Note that, as the number of members of group  $A$  adopting each hierarchy does not influence the payoff of group  $A$  members, it is not a relevant variable for the optimization of  $n_B + n'_B + n_C + n'_C$ .

62. i.e.  $\alpha_{kle} = V_{k,l}(H_e)$ .



obtained :

$$\begin{aligned}
 N_{Bi} = & (N_B \alpha_{ABint} \alpha_{ACi} + N_C \alpha_{ACint} \alpha_{ACi} \\
 & - (n_C + n'_C) (\alpha_{ACi} \alpha_{ACf} + \alpha_{ACf} \alpha_{ACint} + \alpha_{ACint} \alpha_{ACi}) \\
 & - n_B (\alpha_{ABf} \alpha_{ACi} + \alpha_{ACint} (\alpha_{ABf} + \alpha_{ABi})) \\
 & - n'_B (\alpha_{ACi} (\alpha_{ABf} + \alpha_{ABint}) + \alpha_{ABf} \alpha_{ACint})) \\
 & / (\alpha_{ABint} \alpha_{ACi} - \alpha_{ABi} \alpha_{ACint})
 \end{aligned} \tag{1.8}$$

$$\begin{aligned}
 N_{Ci} = & (n_C (\alpha_{ABi} \alpha_{ACf} + \alpha_{ABint} \alpha_{ACf} + \alpha_{ABint} \alpha_{ACi}) \\
 & + n'_C (\alpha_{ABi} \alpha_{ACf} + \alpha_{ABint} \alpha_{ACf} + \alpha_{ABi} \alpha_{ACint}) \\
 & + (n_B + n'_B) (\alpha_{ABf} \alpha_{ABi} + (\alpha_{ABf} + \alpha_{ABi}) \alpha_{ABint}) \\
 & - N_C \alpha_{ABi} \alpha_{ACint} - N_B \alpha_{ABi} \alpha_{ABint}) / (\alpha_{ABint} \alpha_{ACi} - \alpha_{ABi} \alpha_{ACint})
 \end{aligned}$$

— If  $\alpha_{ABint} \alpha_{ACi} > \alpha_{ABi} \alpha_{ACint}$ , then, when  $(n_B, n'_B, n_C, n'_C) = (0, 0, 0, 0)$ , we have  $N_{Bi} > N_B$  and  $N_{Ci} < 0$ . It is therefore necessary to add mutations of group B or group C members to bring  $N_{Bi}$  in the interval  $[n_B, N_B - n'_B]$  and  $N_{Ci}$  in the interval  $[n_C, N_C - n'_C]$  in order to verify conditions (C). As it can easily be verified that  $\frac{\partial N_{Ci} - n_C}{n'_C} = \frac{\partial N_{Ci} - n_C}{n_C} \geq \frac{\partial N_{Ci} - n_C}{n_B} = \frac{\partial N_{Ci} - n_C}{n'_B} > 0$  and  $\frac{\partial N_{Bi} + n'_B}{n'_C} = \frac{\partial N_{Bi} + n'_B}{n_C} \leq \frac{\partial N_{Bi} + n'_B}{n_B} = \frac{\partial N_{Bi} + n'_B}{n'_B} < 0$ , it is most efficient, in order to reduce the distance between  $N_{Bi}$  and the interval  $[n_B, N_B - n'_B]$  and reduce the distance between  $N_{Ci}$  and the interval  $[n_C, N_C - n'_C]$ , to increase  $n_C$  (or, equivalently,  $n'_C$ ):

- If  $N_B \alpha_{ABi} (\alpha_{ACf} + \alpha_{ACint}) < N_C \alpha_{ACf} \alpha_{ACint}$ , then, starting at  $(n_B, n'_B, n_C, n'_C) = (0, 0, 0, 0)$ , when  $n_C$  increases,  $N_{Ci}$  reaches  $[n_C, N_C]$  before  $N_{Bi}$  reaches  $[0, N_B]$ . In this case, the optimal number of mutations is the minimum  $n_C$  such that  $N_{Bi}$  reaches  $[0, N_B]$ . For this specific  $n_C$ , it can be verified that  $N_{Bi} \in [0, N_B]$  and  $N_{Ci} \in [n_C, N_C]$ .
- If  $N_B \alpha_{ABi} (\alpha_{ACf} + \alpha_{ACint}) \geq N_C \alpha_{ACf} \alpha_{ACint}$ , then, starting at  $(n_B, n'_B, n_C, n'_C) = (0, 0, 0, 0)$ , when  $n_C$  increases,  $N_{Bi}$  reaches  $[n_B, N_B]$  before  $N_{Ci}$  reaches  $[n_C, N_C]$ . In this case, for the minimum  $n_C$  such that  $N_{Ci}$  reaches  $[n_C, N_C]$ , it can be verified that  $N_{Bi} \in [n_B, N_B]$  and  $N_{Ci} \in [n_C, N_C]$  if the further condition  $N_C (\alpha_{ABi} + \alpha_{ABint}) \alpha_{ACf} \geq N_B \alpha_{ABi} \alpha_{ABint}$  is verified (which ensures that  $N_{Ci}$  reaches  $[n_C, N_C]$  before  $n_C$  becomes greater than  $N_C$ ). If, on the contrary,  $N_C (\alpha_{ABi} + \alpha_{ABint}) \alpha_{ACf} < N_B \alpha_{ABi} \alpha_{ABint}$ , then  $n_C$  reaches  $N_C$  before  $N_{Ci}$  reaches  $[n_C, N_C]$ . In this case, mutations of group C are

- not sufficient and further mutations from group  $B$  are required :  $n_C$  is kept equal to  $N_C$  and  $n_B$  is progressively increased to have  $N_{Ci}$  reach  $[n_C, N_C]$ . For the minimum value of  $n_B$  such that  $N_{Ci} \in [n_C, N_C]$ , it can easily be verified that  $N_{Bi} \in [n_B, N_B]$  too.
- Similarly, if  $\alpha_{ABint} \alpha_{ACi} < \alpha_{ABi} \alpha_{ACint}$ , then, when  $(n_B, n'_B, n_C, n'_C) = (0, 0, 0, 0)$ , we have  $N_{Bi} > N_B$  and  $N_{Ci} < 0$ . A very similar reasoning allows to show that mutations from only the initial equilibrium are sufficient and optimal to trigger a transition towards the target equilibrium.
  - Using the same reasoning when the second switching group is  $B$  or  $C$ , it can likewise be shown that mutations from only the initial equilibrium are sufficient and optimal to trigger a transition towards the target equilibrium.
  - A lower bound on the cost of the second switch for each choice of intermediary and target equilibria and for each choice of first and second switching group can therefore be computed in the following way :

$$\min n_B + n_C \text{ s.t. } N_{Ci} \in [n_C, N_C] \text{ and } N_{Bi} \in [n_B, N_B] \quad (1.9)$$

The algorithm to compute all lower bounds on “indirect” transition costs and show that they are greater than “direct” transition costs, *TestOptimalityDirectTransitionCosts*, proceeds as follows :

- For each possible initial and final equilibria and for each expression of the “direct” transition cost between them (as the “direct” transition costs are defined by parts on  $\mathcal{P}$  and thus each admit several expressions depending on parameters  $N_B$  and  $N_C$ ), the auxilliary function *AuxTestOptimalityDirectTransitionCosts* is called. If it raises an error with a new constraint on minority sizes, the function is applied separately on the case where the new constraint is met and on the case where it is not. If new errors are raised, the set  $\mathcal{P}$  is further subdivided until *AuxTestOptimalityDirectTransitionCosts* returns “True” or “False”.

## 1.8.2 Full proof of Proposition 4.3

To determine the model's long-term equilibria using the matrix of transition costs returned by *TransitionCostsMatrix*, the following functions are implemented.

A first function, *Edmondalgorithm*, corresponds to Edmond's algorithm, implemented recursively. It takes as arguments : a matrix of transition costs, a list of nodes (these nodes correspond to equilibria at the first step and then to cycles containing several equilibria), a table of correspondences between edges (which allows to reconstitute, at the end of the procedure, the initial graph), a root (a node that will be the root of the minimum spanning tree) and constraints on minority sizes. It returns the minimum spanning tree leading to the "root" equilibrium. The function exactly follows the steps described in 1.9. If, at any step, the function stumbles upon a comparison that remains ambiguous under the set of constraints, it raises an error and returns the ambiguous inequality.

A second function, *DeterminationLongTermEquilibriumForSpecificConstraints*, returns, for a given subset of  $\mathcal{P}$  defined by some constraints on minority sizes (*constraints\_*), the long-term equilibrium as well as the matrix of transition costs, the costs of the four minimum spanning trees (leading to each equilibrium) and the four minimum spanning trees. It proceeds as follows :

- First, a matrix of transition costs under the *constraints\_* is computed. It corresponds to the values of the overall transition costs matrix on a specific subset of  $\mathcal{P}$  where all coefficients of the matrix have a unique expression instead of being defined by parts. At the same time, the table of correspondences between edges is initialized.
- Then, for each equilibrium :
  - Apply Edmond's algorithm.
  - Compute the cost of the minimum spanning tree returned by Edmond's algorithm.
- Compare the costs of the four minimum spanning trees and return the equilibrium (or equilibria) associated with the lowest cost minimum spanning tree.

If, at any step, the function stumbles upon a comparison that remains ambiguous under the set of constraints, it raises an error and returns the ambiguous inequality.

A third function, *DeterminationAllLongTermEquilibria*, is used to decompose the set  $\mathcal{P}$  into subsets on which the long-term equilibrium can be determined unambiguously without raising any error. It returns the list of these subsets and the list of corresponding long-term equilibria.

A fourth function, *AnalysisResultsLongTermEquilibria*, is used to simplify the results returned by the preceding function, by merging zones on which a same long-term equilibrium persists.

A fifth function, *FigureAnalysisResultsLongTermEquilibria*, serves to depict the zones of  $\mathcal{P}$  on which each long-term equilibrium persists.

## 1.9 Appendix C - Chu-Liu/Edmond's algorithm

Chu–Liu/Edmonds' algorithm (Edmonds, 1967; Chu and Liu, 1965) is an algorithm from graph theory for finding a spanning arborescence (i.e. a directed graph in which, for a vertex (i.e. for a node)  $u$  called the root and any other vertex  $v$ , there is exactly one directed path from  $u$  to  $v$ ) of minimum weight. I reproduce hereafter the description of the algorithm, as presented in Wikipedia (2019), for the reader's information.

The algorithm takes as input a directed graph  $D = \langle V, E \rangle$  where  $V$  is the set of nodes and  $E$  is the set of directed edges, a distinguished vertex  $r \in V$  called the root, and a real-valued weight  $w(e)$  for each edge  $e \in E$ . It returns a spanning arborescence  $A$  rooted at  $r$  of minimum weight, where the weight of an arborescence is defined to be the sum of its edge weights,  $w(A) = \sum_{e \in A} w(e)$ .

The algorithm has a recursive description. Let  $f(D, r, w)$  denote the function which returns a spanning arborescence rooted at  $r$  of minimum weight. We first remove any edge from  $E$  whose destination is  $r$ . We may also replace any set of parallel edges (edges between the same pair of vertices in the same direction) by a single edge with weight equal to the minimum of the weights of these parallel edges.

Now, for each node  $v$  other than the root, find the edge incoming to  $v$  of lowest weight (with ties broken arbitrarily). Denote the source of this edge by  $\pi(v)$ . If the set of edges  $P = \{(\pi(v), v) \mid v \in V \setminus \{r\}\}$  does not contain any cycles, then  $f(D, r, w) = P$ .

Otherwise,  $P$  contains at least one cycle. Arbitrarily choose one of these cycles and call it  $C$ . We now define a new weighted directed graph  $D' = \langle V', E' \rangle$  in which the cycle  $C$  is "contracted" into one node as follows :

The nodes of  $V'$  are the nodes of  $V$  not in  $C$  plus a new node denoted  $v_C$ .

- If  $(u, v)$  is an edge in  $E$  with  $u \notin C$  and  $v \in C$  (an edge coming into the cycle), then include in  $E'$  a new edge  $e = (u, v_C)$ , and define  $w'(e) = w(u, v) - w(\pi(v), v)$ .
- If  $(u, v)$  is an edge in  $E$  with  $u \in C$  and  $v \notin C$  (an edge going away from the cycle), then include in  $E'$  a new edge  $e = (v_C, v)$ , and define  $w'(e) = w(u, v)$ .
- If  $(u, v)$  is an edge in  $E$  with  $u \notin C$  and  $v \notin C$  (an edge unrelated to the cycle), then include in  $E'$  a new edge  $e = (u, v)$ , and define  $w'(e) = w(u, v)$ .

For each edge in  $E'$ , we remember which edge in  $E$  it corresponds to.

Now find a minimum spanning arborescence  $A'$  of  $D'$  using a call to  $f(D', r, w')$ . Since  $A'$  is a spanning arborescence, each vertex has exactly one incoming edge. Let  $(u, v_C)$  be the unique incoming edge to  $v_C$  in  $A'$ . This edge corresponds to an edge  $(u, v) \in E$  with  $v \in C$ . Remove the edge  $(\pi(v), v)$  from  $C$ , breaking the cycle. Mark each remaining edge in  $C$ . For each edge in  $A'$ , mark its corresponding edge in  $E$ . Now we define  $f(D, r, w)$  to be the set of marked edges, which form a minimum spanning arborescence.

Observe that  $f(D, r, w)$  is defined in terms of  $f(D', r, w')$ , with  $D'$  having strictly fewer vertices than  $D$ . Finding  $f(D, r, w)$  for a single-vertex graph is trivial (it is just  $D$  itself), so the recursive algorithm is guaranteed to terminate.

## 1.10 Appendix D - Extensions to the three-group model

### 1.10.1 Introducing homophily

An important assumption in the model analyzed in this paper is that the number of interactions of each individual with the other groups perfectly reflects the relative sizes of these groups. This hypothesis is not very realistic as it is well known that individuals tend to prefer interacting with people who are similar to them (i.e. they exhibit homophily, see McPherson, Smith-Lovin and Cook (2001) for a review). Luckily, the model can easily be amended to allow for an exogenous homophily, if all groups have the same degree of homophily. Indeed, using the same definition of homophily as in Bazzi et al. (2019), it suffices to multiply the number of interactions with members of other groups by  $\sigma \in ]0, 1[$  and to add  $(1 - \sigma)$  times the total size of these other groups to the number of interactions with members of one's own group. For example, a member of group  $A$  will now interact, at each period of time, with  $\xi \sigma \frac{N_B}{N_A + N_B + N_C}$  members of group  $B$ ,  $\xi \sigma \frac{N_C}{N_A + N_B + N_C}$  members of group  $C$  and  $\xi \frac{N_A + (1 - \sigma)(N_B + N_C)}{N_A + N_B + N_C}$  members of his own group  $A$ , so that the total number of interactions per individual remains unchanged. The larger the homophily parameter  $\sigma$  is (while remaining below 1), the less biased individuals are in their choices of partners for interactions. These modifications of the model imply that all transition costs are multiplied by  $\sigma$ . Therefore, comparisons between them remain unchanged and all of the model's predictions remain valid in the presence of homophily. The only difference with the baseline model is that transitions from one equilibrium to the other are slower, so that convergence to the long term equilibrium requires more time.

### 1.10.2 Introducing intentional mutations

Another extension consists in introducing the possibility of having intentional mutations. In the baseline model presented in this paper, it is assumed that non-best response mutations happen randomly with a probability  $\varepsilon$ , which is standard in evolutionary game theory. However, Bowles (2009) argues that random mutations may not be the most realistic, as mutating groups trigger transitions that are not necessarily in their interest. In order to assess the impact of introducing the possibility for one ethno-cultural group to mutate more often towards hierarchy views that it prefers, the baseline model can be amended so that members of one minority have a probability  $\varepsilon$  to mutate randomly toward a hierarchy view that would make them worse off at equilibrium, as compared to their current hierarchy views and a probability  $\varepsilon^\iota$  (with  $\iota < 1$ ) to mutate intentionally toward a hierarchy view that would make them better off in equilibrium.<sup>63</sup> In practice, such an intentional mutation could materialize under the

---

63. It has been shown in the experimental literature that individuals may be ready to reduce their own payoff in the short-term to reduce inequality for example (Zizzo, 2003).

form of one or several members of a dominated group suddenly refusing to perform acts of submission (such as Rosa Park refusing to seat in the back of the bus in Montgomery in 1955 or half a million Untouchables converting to Navayana Buddhism with the influential Indian leader Ambedkar in 1956, in an attempt to gain equality with the other Indian castes<sup>64</sup>) or, if the initial hierarchy is relatively egalitarian, under the form of an individual suddenly starting to adopt a dominating behavior towards a minority (e.g. racial “jokes” or bullying, Ku Klux Klan actions). Such a modification of the model leads to the following Lemma :

**Lemma 10.1 :** *The larger the probability of intentional mutations  $\varepsilon^l$  in a given ethno-cultural group, the more likely this group’s favorite hierarchy views are to persist in the long run.*

**Proof of Lemma 10.1 :** *Increasing  $\varepsilon^l$  indeed reduces the costs of transitions that benefit this group and leaves the costs of the other transitions unaltered. Thus, hierarchy views that benefit this group are more likely to persist in the long run.*

### 1.10.3 Role of the inequality parameter $\gamma$

As in the two-group model, it is easy to see that increasing  $\gamma$  widens the set of minority sizes for which egalitarian equilibria persist in the long run. Additionally, considering a simple extension of the model where one would allow  $\gamma$  to differ across pairs of groups so that there exist distinct  $\gamma_{AB}$ ,  $\gamma_{AC}$  and  $\gamma_{BC}$  corresponding to the interactions between groups  $A$  and  $B$ , groups  $A$  and  $C$  and groups  $B$  and  $C$ , it is also easy to show that, for two groups  $i$  and  $j$ , the larger  $\gamma_{ij}$  is, the more likely it is that, in the long run, group  $i$  and  $j$  hold equal statuses.

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64. See Buswell Jr and Lopez Jr (2013).

## 1.11 Appendix E - Mathematica functions for the resolution of the three-group model

```
(*****)
(**** Preamble ****)
(*****)

(* Size of each group *)
Size = {NA, NB, NC};

(* Payoff of group X in equilibrium Y *)
Payoff = {{(1 +  $\gamma$ ) (Size[[2]] + Size[[3]]), Size[[2]] + (1 +  $\gamma$ ) Size[[3]],
          (1 +  $\gamma$ ) (Size[[2]] + Size[[3]]), Size[[2]] + Size[[3]]},
         {(1 -  $\gamma$ ) Size[[1]] + Size[[3]], Size[[1]] + (1 +  $\gamma$ ) Size[[3]],
          (1 -  $\gamma$ ) Size[[1]] + (1 +  $\gamma$ ) Size[[3]], Size[[1]] + Size[[3]]},
         {(1 -  $\gamma$ ) Size[[1]] + Size[[2]], (1 -  $\gamma$ ) (Size[[1]] + Size[[2]]),
          (1 -  $\gamma$ ) (Size[[1]] + Size[[2]]), Size[[1]] + Size[[2]]}};

(* Baseline constraints on the parameters *)
baselineconstraints = NA  $\in$  Reals && NB  $\in$  Reals && NC  $\in$  Reals &&  $\gamma$   $\in$  Reals &&
[nombres réels] [nombres réels] [nombres réels] [nombres réels]
 $\gamma < 1$  &&  $\gamma > 0$  && NB > NC && 1 > NB && NC > 0;
(* Payoff of group X adopting hierarchy Y when nA, nB and nC members of group A,
B and C adopted the same hierarchy *)
Payoffhierarchy[{X_, Y_, nA_, nB_, nC_}] :=
Module[{},
[module]
  {{(1 +  $\gamma$ ) (nB + nC), nB + (1 +  $\gamma$ ) nC, (1 +  $\gamma$ ) (nB + nC), nB + nC},
   {(1 -  $\gamma$ ) nA + nC, nA + (1 +  $\gamma$ ) nC, (1 -  $\gamma$ ) nA + (1 +  $\gamma$ ) nC, nA + nC},
   {(1 -  $\gamma$ ) nA + nB, (1 -  $\gamma$ ) (nA + nB), (1 -  $\gamma$ ) (nA + nB), nA + nB}}][X, Y] /.  $\gamma \rightarrow 1/2$ 
]

(*****)
(**** Function to count the number of mutations necessary to transit from
equilibrium eqinitial_ to eqfinal_ when the first group to switch
(i.e. to start preferring eqfinal_) is firstswitchinggroup_ and when the
constraints constraints_ on group sizes are imposed. The function also returns
the mutating groups and the list of switching groups. ****)
(*****)

DirectTransitionCostWithSpecificFirstSwitchingGroup[
  {eqinitial_, eqfinal_, firstswitchinggroup_, constraints_}] :=
Module[{othergroup1, othergroup2, firstmutatinggroup, secondmutatinggroup,
[module]
  Costfirstswitch, possible, Intermediatepayoff, finished,
  Costtomakefirstmutatinggroupswitch, Costtomakesecondmutatinggroupswitch,
  TotalCost, aux, auxbool1, auxbool2, auxboolpossible, auxboolfinished,
  auxboolfinished2, listmutatinggroups, listswitchinggroups},

  listswitchinggroups = {firstswitchinggroup};
  othergroup1 = Mod[ firstswitchinggroup, 3] + 1;
[module mod]
```



```

othergroup2 = Mod[firstswitchinggroup + 1, 3] + 1;
(** Choice of the first mutating group: the one that has the highest impact,
when it mutates, on the difference between the payoff of firstswitchinggroup
in the initial and in the final equilibrium **)
auxbool =
D[Payoff[[firstswitchinggroup, eqinitial]] + Payoff[[firstswitchinggroup, eqfinal]],
Size[[othergroup1]]] >=
D[Payoff[[firstswitchinggroup, eqinitial]] + Payoff[[firstswitchinggroup, eqfinal]],
Size[[othergroup2]]];
auxbool2 = Assuming[constraints, FullSimplify[auxbool /. {NA -> 1, γ -> 1/2}]];
(* If the first mutating group cannot be determined,
raise an error with the undecided inequality. *)
If[ToString[auxbool2] ≠ "True" && ToString[auxbool2] ≠ "False",
Return[Print["Error 0: "]; Print[auxbool2];
{"Error 0", auxbool2}]];
(* If it can be determined,
memorize which group is the first mutating group and which is the second and
store in a list of mutating groups the first mutating group
(we do not know yet if the second one will be necessary). *)
firstmutatinggroup = If[auxbool2, othergroup1, othergroup2];
secondmutatinggroup = If[firstmutatinggroup = othergroup1, othergroup2, othergroup1];
listmutatinggroups = {firstmutatinggroup};
(** Naive cost to make the first switching group switch **)
Costfirstswitch =
FullSimplify[Payoff[[firstswitchinggroup, eqinitial]] /
D[Payoff[[firstswitchinggroup, eqinitial]] + Payoff[[firstswitchinggroup, eqfinal]],
Size[[firstmutatinggroup]]];
(** Test if this first switch is possible using only the first mutating group **)
auxboolpossible =
D[Payoff[[firstswitchinggroup, eqinitial]] + Payoff[[firstswitchinggroup, eqfinal]],
Size[[firstmutatinggroup]]] ==
D[Payoff[[firstswitchinggroup, eqinitial]] + Payoff[[firstswitchinggroup, eqfinal]],
Size[[secondmutatinggroup]]];
possible = Assuming[constraints,
FullSimplify[(Size[[firstmutatinggroup]] >= Costfirstswitch || auxboolpossible) /.
{NA -> 1, γ -> 1/2}]];
(* If it is not possible to decide if the boolean "possible" is True or False,
raise an error with the undecided inequality *)
If[ToString[possible] ≠ "True" && ToString[possible] ≠ "False", Return[Print["Error 1: "];
Print[possible]; {"Error 1", possible}]];

```

```

(* If the first mutating group is not sufficient to make the first switching
group switch, compute the additional cost due to the use of the second
mutating group **)
Intermediatepayoff =
D[Payoff[[firstswitchinggroup, eqinitial]], Size[[secondmutatinggroup]] *
|dérivée d
Size[[secondmutatinggroup]] -
D[Payoff[[firstswitchinggroup, eqfinal]], Size[[firstmutatinggroup]] *
|dérivée d
Size[[firstmutatinggroup]];

(* In this case, compute the new cost to make the first switching group switch *)
Costfirstswitch =
If[possible == False,
|faux
FullSimplify[Size[[firstmutatinggroup]] +
|simplifie complètement
Intermediatepayoff /
D[Payoff[[firstswitchinggroup, eqinitial]] + Payoff[[firstswitchinggroup, eqfinal]],
|dérivée d
Size[[secondmutatinggroup]]], Costfirstswitch];

(* In this case still, add the second mutating group to the list of mutating groups *)
If[possible == False,
|si |faux
listmutatinggroups = Append[listmutatinggroups, secondmutatinggroup];
|ajoute

(** Check if the switching of the first group is enough to launch a transition
to the final equilibrium,
i.e. will the other groups follow and switch to the final equilibrium too?:
For this to happen, one of the two other groups must be willing to switch. Once
it is done, the last group will switch,
as the final equilibrium is a Nash equilibrium. Note that if the first mutating
group had to mutate entirely to make the first switching group switch,
then two groups are already in the final equilibrium so that the final
equilibrium is sure to be reached **)
auxboolfinished =
(Size[[firstmutatinggroup]] - Costfirstswitch) *
D[Payoff[[secondmutatinggroup, eqinitial]], Size[[firstmutatinggroup]] <
|dérivée d
Costfirstswitch * D[Payoff[[secondmutatinggroup, eqfinal]],
|dérivée d
Size[[firstmutatinggroup]] +
Size[[firstswitchinggroup]] * D[Payoff[[secondmutatinggroup, eqfinal]],
|dérivée d
Size[[firstswitchinggroup]]];
auxboolfinished2 =
Size[[secondmutatinggroup]] * D[Payoff[[firstmutatinggroup, eqinitial]],
|dérivée d
Size[[secondmutatinggroup]] <
Size[[firstswitchinggroup]] * D[Payoff[[firstmutatinggroup, eqfinal]],
|dérivée d
Size[[firstswitchinggroup]]];
finished =
If[Assuming[constraints,
|si |supposant
FullSimplify[(possible == False || auxboolfinished || auxboolfinished2) /.
|simplifie complètement |faux

```

```

[imprime complètement] [aux]
{NA → 1, γ → 1/2}], True, False];
[ra] [faux]

(** If it cannot be decided if the other groups will switch,
raise an error with the unresolved inequality **)
If[ToString[finished] ≠ "False" && ToString[finished] ≠ "True", Return[Print["Error 2 : "];
[convertis en chaîne de caractères] [convertis en chaîne de caractères] [reviens] [imprime]
Print[finished];
[imprime]
{"Error 2", Assuming[constraints,
[supposant]
FullSimplify[(auxboolfinished || auxboolfinished2) /. {NA → 1, γ → 1/2}]]];
[simplifie complètement]

(** If it is not enough, compare the cost of having each of the two remaining
groups switch **)
If[ToString[finished] == "False",
[convertis en chaîne de caractères]
Costtomakefirstmutatinggroupswitch =
FullSimplify[
[simplifie complètement]
(Size[[secondmutatinggroup]] * D[Payoff[[firstmutatinggroup, eqinitial]],
[dérivée d]
Size[[secondmutatinggroup]] - Size[[firstswitchinggroup]] *
D[Payoff[[firstmutatinggroup, eqfinal]], Size[[firstswitchinggroup]]]) /
[dérivée d]
(D[Payoff[[firstmutatinggroup, eqinitial]], Size[[secondmutatinggroup]] +
[dérivée d]
D[Payoff[[firstmutatinggroup, eqfinal]], Size[[secondmutatinggroup]]])];
[dérivée d]
Costtomakesecondmutatinggroupswitch =
FullSimplify[
[simplifie complètement]
((Size[[firstmutatinggroup]] - Costfirstswitch) *
D[Payoff[[secondmutatinggroup, eqinitial]], Size[[firstmutatinggroup]] -
[dérivée d]
(Costfirstswitch * D[Payoff[[secondmutatinggroup, eqfinal]],
[dérivée d]
Size[[firstmutatinggroup]] + Size[[firstswitchinggroup]] *
D[Payoff[[secondmutatinggroup, eqfinal]], Size[[firstswitchinggroup]]])) /
[dérivée d]
(D[Payoff[[secondmutatinggroup, eqinitial]], Size[[firstmutatinggroup]] +
[dérivée d]
D[Payoff[[secondmutatinggroup, eqfinal]], Size[[firstmutatinggroup]]])];
[dérivée d]
aux = Assuming[constraints,
[supposant]
FullSimplify[
[simplifie complètement]
(Costtomakefirstmutatinggroupswitch < Costtomakesecondmutatinggroupswitch) /.
{NA → 1, γ → 1/2}]];

(* If the comparison of the cost to make each of the two remaining groups
switch cannot be decided, raise an error with the undecided inequality *)
If[ToString[aux] ≠ "False" && ToString[aux] ≠ "True", Return[Print["Error 3: "];
[convertis en chaîne de caractères] [convertis en chaîne de caractères] [reviens] [imprime]
Print[aux];
[imprime]
{"Error 3", aux}]];

```

```

(** Wrap up the costs **)
If[aux, TotalCost = FullSimplify[Costfirstswitch + Costtomakefirstmutatinggroupswitch];
      |simplifie complètement
listmutatinggroups = Append[listmutatinggroups, secondmutatinggroup];
      |ajoute
listswitchinggroups = Append[listswitchinggroups, firstmutatinggroup],
      |ajoute
TotalCost = FullSimplify[Costfirstswitch + Costtomakesecondmutatinggroupswitch];
      |simplifie complètement
listswitchinggroups = Append[listswitchinggroups, secondmutatinggroup]
      |ajoute
, TotalCost = Costfirstswitch ];

FullSimplify[{TotalCost, listmutatinggroups, listswitchinggroups} /. {NA → 1, γ → 1/2}]
|simplifie complètement

```

```

(*****
**** Function to compute the number of mutations necessary to transit from
equilibrium eqinitial_ to eqfinal_ under the constraints constraints_. It
also returns the list of mutating groups and the list of switching groups. ****
*****)

```

```

DirectTransitionCost[{eqinitial_, eqfinal_, constraints_}] := Module[{a, b, c, aux},
      |module
(** Using the previous function,
compute the number of mutations necessary for each possible first switching group **)
a = Block[{Print}, DirectTransitionCostWithSpecificFirstSwitchingGroup[
      |bloc |imprime
      {eqinitial, eqfinal, 1, constraints}]];
If[StringContainsQ[ToString[a], "Error"], Return[a]];
      |contient chaîne de car... |convertis en chaîne de caractères |reviens
b = Block[{Print}, DirectTransitionCostWithSpecificFirstSwitchingGroup[
      |bloc |imprime
      {eqinitial, eqfinal, 2, constraints}]];
If[StringContainsQ[ToString[b], "Error"], Return[b]];
      |contient chaîne de car... |convertis en chaîne de caractères |reviens
c = Block[{Print}, DirectTransitionCostWithSpecificFirstSwitchingGroup[
      |bloc |imprime
      {eqinitial, eqfinal, 3, constraints}]];
If[StringContainsQ[ToString[c], "Error"], Return[c]];
      |contient chaîne de car... |convertis en chaîne de caractères |reviens

(** Compare these costs and return the cost,
list of mutating groups and first switching group associated with the lowest one **)
If[Assuming[constraints,
      |supposant
      FullSimplify[(a[[1]] >= b[[1]] && b[[1]] <= c[[1]]) /. {NA → 1, γ → 1/2}], Return[b]];
      |simplifie complètement |reviens
If[Assuming[constraints,
      |supposant
      FullSimplify[(a[[1]] >= c[[1]] && b[[1]] >= c[[1]]) /. {NA → 1, γ → 1/2}], Return[c]];
      |simplifie complètement |reviens

```

```

[simplifie complètement]
If[Assuming[constraints,
[supposant]
  FullSimplify[(a[[1]] <= c[[1]] && b[[1]] >= a[[1]]) /. {NA -> 1, γ -> 1/2}], Return[a]];
[simplifie complètement] [reviens]

(** If one inequality cannot be decided,
raise an error with the undecided inequality **)
aux = Assuming[constraints, FullSimplify[(a[[1]] >= b[[1]]) /. {NA -> 1, γ -> 1/2}]];
[supposant] [simplifie complètement]
If[ToString[aux] ≠ "True" && ToString[aux] ≠ "False", Return[Print["Error 4:"];
[convertis en chaîne de caractères] [convertis en chaîne de caractères] [reviens] [imprime]
  Print[aux];
[imprime]
  {"Error 4", aux}]];
aux = Assuming[constraints, FullSimplify[(a[[1]] >= c[[1]]) /. {NA -> 1, γ -> 1/2}]];
[supposant] [simplifie complètement]
If[ToString[aux] ≠ "True" && ToString[aux] ≠ "False", Return[Print["Error 5:"];
[convertis en chaîne de caractères] [convertis en chaîne de caractères] [reviens] [imprime]
  Print[aux];
[imprime]
  {"Error 5", aux}]];
aux = Assuming[constraints, FullSimplify[(b[[1]] >= c[[1]]) /. {NA -> 1, γ -> 1/2}]];
[supposant] [simplifie complètement]
If[ToString[aux] ≠ "True" && ToString[aux] ≠ "False", Return[Print["Error 6:"];
[convertis en chaîne de caractères] [convertis en chaîne de caractères] [reviens] [imprime]
  Print[aux];
[imprime]
  {"Error 6", aux}]];
]

```

```

(*****
**** Function to build the simplified matrix of transition
costs: for each pair of initial and final equilibrium, (k,l),
build a list of all the possible expressions for the transition cost between
them (i.e. TransitionCostsMatrixeachsubzone,) and a list of the corresponding
constraints on minority sizes (i.e. Tableadditionalconstraints). ****
*****)

```

```

TransitionCostsMatrix[{constraints_}] :=
Module[{Tableadditionalconstraints, counterpos, counterposmax,
[module]
  TransitionCostsMatrixeachsubzone, countersuccessivepb, k, l, res, aux1, aux2,
  FirstSwitchingGroupMatrix, MutatingGroupsMatrix},

Tableadditionalconstraints = Table[-99, {k, 4}, {l, 4}, {i, 1, 200}];
[table]

(** At the beginning, each table Tableadditionalconstraints[[k,l]] only
contains one first cell equal to True **)
For[k = 1, k ≤ 4, k++,
[pour chaque]
  For[l = 1, l ≤ 4, l++,
[pour chaque]
    Tableadditionalconstraints[[k, l, 1]] = True;
[est vrai]

```

```

]
];
counterpos = Table[1, {k, 4}, {l, 4}];
counterposmax = Table[1, {k, 4}, {l, 4}];
TransitionCostsMatrixeachsubzone = Table[-99, {k, 4}, {l, 4}, {i, 1, 200}];
FirstSwitchingGroupMatrix = Table[-99, {k, 4}, {l, 4}, {i, 1, 200}];
MutatingGroupsMatrix = Table[-99, {k, 4}, {l, 4}, {i, 1, 200}];
countersuccessivepb = 0;

For[k = 1, k ≤ 4, k++,
  For[l = 1, l ≤ 4, l++,
    If[k ≠ l,
      (** For each pair of initial and final equilibrium, (k,l),
        starting from the whole set P,
        DirectTransitionCost is called. If it returns an error
        (with a new constraint on NB and NC), then
        this constraint is added to the present cell and a new cell is added at
        the end of the list Tableadditionalconstraints[[k,l]] with the opposite
        constraint. Then, the function is called again on the same celle. If it
        raises an error, the same procedure as before applies. If a result is returned,
        it is stored in TransitionCostsMatrixeachsubzone[[k,l]] at the same
        position as the cell presently analyzed **)
      While[counterpos[[k, l]] ≤ Length[Tableadditionalconstraints[[k, l]]] &&
        ToString[Tableadditionalconstraints[[k, l, counterpos[[k, l]]]] ≠ "-99" &&
        countersuccessivepb ≤ 50,
        res =
        (Block[{Print}, DirectTransitionCost[
          {k, l, constraints && Tableadditionalconstraints[[k, l,
            counterpos[[k, l]]]}] /. {NA → 1, γ → 1/2};

        (* Case where there is an error *)
        If[StringContainsQ[ToString[res], "Error"],
          aux1 = Assuming[constraints,
            FullSimplify[Tableadditionalconstraints[[k, l, counterpos[[k, l]]] &&
              !(res[[2]])];
          If[!(StringContainsQ[ToString[aux1], "="]) && ToString[aux1] ≠ "False",
            Tableadditionalconstraints[[k, l, counterposmax[[k, l]] + 1] = aux1;
            counterposmax[[k, l]] = counterposmax[[k, l]] + 1;];
          aux2 = Assuming[constraints,
            FullSimplify[Tableadditionalconstraints[[k, l, counterpos[[k, l]]] &&
              res[[2]]];
          If[!(StringContainsQ[ToString[aux2], "="]) && ToString[aux2] ≠ "False",

```

```

Tableadditionalconstraints[[k, l, counterpos[[k, l]]] = aux2;,
Tableadditionalconstraints[[k, l, counterpos[[k, l]]] = False];
countersuccessivepb++,

(* Case where there is no error *)
TransitionCostsMatrixeachsubzone[[k, l, counterpos[[k, l]]] =
Assuming[constraints, FullSimplify[res[[1]]];
MutatingGroupsMatrix[[k, l, counterpos[[k, l]]] =
Assuming[constraints, FullSimplify[res[[2]]];
FirstSwitchingGroupMatrix[[k, l, counterpos[[k, l]]] =
Assuming[constraints, FullSimplify[res[[3]]];
counterpos[[k, l]] = counterpos[[k, l]] + 1;
countersuccessivepb = 0;
]
]
];
If[countersuccessivepb ≥ 50, Return[Print["Too many pbs"]];
{Tableadditionalconstraints[[All, All, 1 ;; Max[counterposmax]]],
TransitionCostsMatrixeachsubzone[[All, All, 1 ;; Max[counterposmax]]],
MutatingGroupsMatrix[[All, All, 1 ;; Max[counterposmax]]],
FirstSwitchingGroupMatrix[[All, All, 1 ;; Max[counterposmax]]]}
]

(*****
**** Auxilliary function to the next
one: it allows to verify that direct mutations are the most efficient for
specific initial equilibrium,
final equilibrium and constraints on minority sizes ****
*****)

AuxTestOptimalityDirectTransitionCosts[
{onemutationcost_, constraints_, eqinitial_, eqfinal_}] :=
Module[{eqinter, targeteq, bool, booltot, firstswitchinggroup, secondswitchinggroup,
numeroeqinter, numerotargeteq, costfirstswitch, lowerboundcostsecondswitch},

(* The two possible intermediary equilibria different from the initial and
the final one are computed *)
eqinter = Complement[{1, 2, 3, 4}, {eqinitial, eqfinal}];
booltot = True;

(** For each possible first switching group, second switching group,

```

```

intermediary equilibrium and target equilibrium
(i.e. the equilibrium towards which the second switching group
switches: the final equilibrium or the second intermediary equilibrium)
compute the cost of the first switch and a lower bound on the cost of the
second switch
(it is the minimum between lowerboundcostsecondswitch,
lowerboundcostsecondswitch2 and lowerboundcostsecondswitch3). Then,
compare the sum of the cost of the first switch and the lower bound on the
cost of the second switch with the direct transition cost and show that it
is always greater. **)
For[firstswitchinggroup = 1, firstswitchinggroup ≤ 3, firstswitchinggroup++,
|pour chaque
For[secondswitchinggroup = 1, secondswitchinggroup ≤ 3, secondswitchinggroup++,
|pour chaque
For[numeroeqinter = 1, numeroeqinter ≤ 2, numeroeqinter++,
|pour chaque
costfirstswitch = Block[{Print}, DirectTransitionCostWithSpecificFirstSwitchingGroup[
|bloc |imprime
{eqinitial, eqinter[[numeroeqinter]], firstswitchinggroup, constraints}]];

If[StringContainsQ[ToString[costfirstswitch], "Error"], Return[costfirstswitch]];
|si |contient chaîne de car... |convertis en chaîne de caractères |reviens
costfirstswitch = costfirstswitch[[1]];
targeteq = {eqfinal, eqinter[[numeroeqinter]]];

For[numerotargeteq = 1, numerotargeteq ≤ 2, numerotargeteq++,
|pour chaque
If[secondswitchinggroup == 1,
|si
lowerboundcostsecondswitch =
Assuming[constraints, FullSimplify[
|supposant |simplifie complètement
Minimize[{nB + nC, Payoffhierarchy[{1, eqinitial, 0, nBi - nB, nCi - nC}] ==
|minimise
Payoffhierarchy[{1, targeteq[[numerotargeteq]], 0, nB, nC}] ==
Payoffhierarchy[{1, eqinter[[numeroeqinter]], 0, NB - nBi, NC - nCi}] &&
constraints && NC ≥ nCi ≥ nC ≥ 0 && NB ≥ nBi ≥ nB ≥ 0}, {nBi, nCi, nB, nC}]]][[1]]
];

If[secondswitchinggroup == 2,
|si
lowerboundcostsecondswitch =
Assuming[constraints, FullSimplify[
|supposant |simplifie complètement
Minimize[{nA + nC, Payoffhierarchy[{2, eqinitial, nAi - nA, 0, nCi - nC}] ==
|minimise
Payoffhierarchy[{2, targeteq[[numerotargeteq]], nA, 0, nC}] ==
Payoffhierarchy[{2, eqinter[[numeroeqinter]], 1 - nAi, 0, NC - nCi}] &&
constraints && NC ≥ nCi ≥ nC ≥ 0 && 1 ≥ nAi ≥ nA ≥ 0}, {nAi, nCi, nA, nC}]]][[1]]
];

If[secondswitchinggroup == 3,
|si
lowerboundcostsecondswitch =
Assuming[constraints, FullSimplify[
|supposant |simplifie complètement
Minimize[{nA + nB, Payoffhierarchy[{3, eqinitial, nAi - nA, nBi - nB, 0}] ==
|minimise
Payoffhierarchy[{3, targeteq[[numerotargeteq]], nA, nB, 0}] ==
Payoffhierarchy[{3, eqinter[[numeroeqinter]], 1 - nAi, NB - nBi, 0}] &&

```



```

constraints && NB ≥ nBi ≥ nB ≥ 0 && 1 ≥ nAi ≥ nA ≥ 0}, {nAi, nBi, nA, nB}]]][[1]]
];

bool = Assuming[constraints,
  FullSimplify[Reduce[costfirstswitch + lowerboundcostsecondswitch ≥
    onemutationcost]]];
If[ToString[bool] ≠ "True" && ToString[bool] ≠ "False", Return[Print["Error Test1: "];
  Print[bool, ",", eqinitial, ",", eqfinal, ",", eqinter[[numeroeqinter]],
    ",", firstswitchinggroup, ",", secondswitchinggroup, ",", costfirstswitch,
    ",", lowerboundcostsecondswitch, ",", onemutationcost, ",", constraints];
  {"Error Test1", bool}]];

booltot = booltot && bool
];
]
]
];
booltot]

```

```
TRANSITIONMATRIX = TransitionCostsMatrix[{baselineconstraints}];
```

```

(*****
**** Function to verify that "direct" mutations from the initial to the final
equilibrium are always the most efficient way to transit from one equilibrium
to the other
(i.e. mutations towards other intermediary equilibria are underefficient) ****
*****)

```

```

TestOptimalityDirectTransitionCosts[{constraints_}] :=
Module[{matrixdirecttransitioncosts, eqinitial, eqfinal, nbcase, booltot,
  subzonestobetested, counterpos, counterposmax, auxtest, aux1, aux2},
  booltot = True;
  matrixdirecttransitioncosts = TRANSITIONMATRIX;

```

```

(** For each initial equilibrium, final equilibrium,
and expression of the direct mutation cost between these two equilibria
(indexed by nbcase), try to test the property that the
direct mutation cost is the lowest possible one,
using the auxiliary function AuxTestOptimalityDirectTransitionCosts. If this
function returns an error (and a constraint on minority sizes),
study the case where this new constraint is verified and the case where it
is not separately. Try again to test the property and sub-
divide cases further if necessary, until the property can be checked. **)

```

```

For[eqinitial = 1, eqinitial ≤ 4, eqinitial++,
|pour chaque
Print["eqinitial: ", eqinitial];
|imprime
For[eqfinal = 1, eqfinal ≤ 4, eqfinal++,
|pour chaque
Print["eqfinal: ", eqfinal];
|imprime
If[eqinitial ≠ eqfinal,
|si
For[nbcase = 1, nbcase ≤ Length[TRANSITIONMATRIX[[1, 1, 1]]], nbcase++,
|pour chaque |longueur
Print["nbcase: ", nbcase];
|imprime
If[ToString[TRANSITIONMATRIX[[2, eqinitial, eqfinal, nbcase]]] ≠ "-99",
|si |convertis en chaîne de caractères
subzonestobetested =
{FullSimplify[TRANSITIONMATRIX[[1, eqinitial, eqfinal, nbcase]] && constraints]];
|simplifie complètement
counterpos = 1;
counterposmax = 1;

While[counterpos ≤ counterposmax && counterposmax ≤ 40,
|tant que
If[ToString[subzonestobetested[[counterpos]]] == "False",
|si |convertis en chaîne de caractères
counterpos++,
auxtest = AuxTestOptimalityDirectTransitionCosts[
{TRANSITIONMATRIX[[2, eqinitial, eqfinal, nbcase]],
subzonestobetested[[counterpos]], eqinitial, eqfinal}];

If[StringContainsQ[ToString[auxtest], "Error"],
|si |contient chaîne de car... |convertis en chaîne de caractères
aux1 = FullSimplify[subzonestobetested[[counterpos]] && ! (auxtest[[2]])];
|simplifie complètement
aux2 = FullSimplify[subzonestobetested[[counterpos]] && auxtest[[2]]];
|simplifie complètement
subzonestobetested[[counterpos]] = aux1;
subzonestobetested = Append[subzonestobetested, aux2]; counterposmax++;
|appose
,
booltot = FullSimplify[booltot && auxtest];
|simplifie complètement
counterpos++;
]
]
]
]
];
Print["booltot: ", booltot];
|imprime
];
booltot]

```

```

(*****)
(*** Edmond algorithm function to determine, using a matrix of mutation costs,
the list of Nash equilibria,
a specific equilibrium root_ and under the constraints constraints_,
the minimum spanning tree which root is root_. This function is recursive
(a new graph is built at each call of Edmond algorithm,
if the initial graph contains a cycle). The InitialCorrespondingEdges_
variable allows to store,
at each step of the algorithm and for each edge of the new graph,
the edge to which it corresponded in the old graph ****)
(*****)

Edmondalgorithm[{InitialTransitionCostsMatrix_, initialListNE_, InitialCorrespondingEdges_,
root_, constraints_}]:=
Module[{FunctionPi, Minimumcostfound, ListPivV, counter, GraphPivV, Cycle,
|_module
VertexListCycle, Minimumspanningtree, AuxTransitionCostsMatrix, Correspondingedgesaux,
othernode, Nextminimumspanningtree, Nextcorrespondingedgesaux, NewTransitionCostsMatrix,
NewListOfVertices, nodetoexpand, incomingnodetonodetoexpand,
correspondingnodeinnodetoexpand, Cyclewithoutedge, outgoingnodetonodetoexpand,
listnewedgesfromnexttree, Newgraphaux, nodecorrespondingtonodetoexpand,
Graphcyclewithoutedge, listedgesinnextminimumspanningtree, i, j, bool, bool2,
bool3, a, resedmond},

(** Initialization of function pi and of the other variables **)
FunctionPi = Table[-99, Length[InitialTransitionCostsMatrix[[1]]];
|_table |longueur

AuxTransitionCostsMatrix = InitialTransitionCostsMatrix;
Correspondingedgesaux = InitialCorrespondingEdges;

(** Test if the number of Nash equilibria is equal to 2. If yes,
do nothing. If not, compute the lowest cost edge coming to each equilibrium
in initialListNE (except to the root) and save the initial equilibrium of
this edge in FunctionPi ***)
If[Length[initialListNE] == 2, Null,
|_si |longueur |expression nulle
For[i = 1, i ≤ Length[initialListNE], i++,
|_pour chaque |longueur
If[initialListNE[[i]] ≠ root,
|_si
Minimumcostfound = Infinity;
|_infini
For[j = 1, j ≤ Length[initialListNE], j++,
|_pour chaque |longueur
bool = Assuming[constraints,
|_supposant
Simplify[AuxTransitionCostsMatrix[[initialListNE[[i]], initialListNE[[j]]]] <
|_simplifie
Minimumcostfound]];

If[ToString[bool] ≠ "True" && ToString[bool] ≠ "False", Return[Print["Error 7: "];
|_si |convertis en chaîne de caractères |convertis en chaîne de caractères |reviens |imprime
Print[bool];
|_imprime
{"Error 7", bool}]];

If[j ≠ i && (bool),
|_si
Minimumcostfound = AuxTransitionCostsMatrix[[initialListNE[[i]],

```

```

    initialListNE[[j]]];
    FunctionPi[[initialListNE[[i]]] = initialListNE[[j]]; Null]], Null]];
|expression... |expression nulle

(* Define the list ListPivV,
which contains the minimum cost edge coming to each equilibrium except the
root (ListPivV[[i,1]] corresponds to the initial equilibrium of the minimum
cost edge going to ListPivV[[i,2]])*)
ListPivV = Table[-99, {x, Length[initialListNE] - 1}, {y, 2}];
|table |longueur

counter = 1;

For[i = initialListNE[[1]], i ≤ initialListNE[[Length[initialListNE]]], i++,
|pour chaque |longueur
  If[i ≠ root && MemberQ[initialListNE, i],
|si |est membre?
    ListPivV[[counter, 1]] = FunctionPi[[i]];
    ListPivV[[counter, 2]] = i;
    counter++, Null]];
|expression nulle

(* ListPivV is turned into a graph in order to test whether it contains cycles *)
GraphPivV = Graph[DirectedEdge @@@ ListPivV, VertexLabels → "Name"];
|graphe |bord dirigé |étiquettes des sommets

(* Test whether there are cycles and get the first one *)
Cycle = {};
If[FindCycle[GraphPivV] == {}, Minimumspanningtree = GraphPivV,
|si |trouve cycle
  Cycle = FindCycle[GraphPivV][[1]];
|trouve cycle
  VertexListCycle = VertexList[Cycle];
|liste des noeuds

(** Construct the new graph replacing this cycle with a unique new node
and reweighting edges properly. NewListOfVertices contains the nodes of
the new graph and NewTransitionCostsMatrix is the matrix containing the
new costs of transitions **)
(* Definition of the new list of nodes *)
NewListOfVertices = Table[-99, Length[initialListNE] - Length[VertexListCycle] + 1];
|table |longueur |longueur

counter = 1;
For[i = 1, i ≤ Length[initialListNE], i++,
|pour chaque |longueur
  If[MemberQ[VertexListCycle, initialListNE[[i]]] == False,
|si |est membre? |faux
    NewListOfVertices[[counter]] = initialListNE[[i]];
    counter++, Null]];
|expression nulle
  NewListOfVertices[[counter]] = Length[AuxTransitionCostsMatrix[[1]]] + 1;
|longueur
];

(** Definition of the new
matrix: all the nodes belonging to the cycle in the old graph are replaced
by one unique node in the new graph, vC,
(i.e. the node in position Length[AuxTransitionCostsMatrix[[1]]]+1 of the new matrix).
All edges in the old graph are studied one by one. When one node of the
edge belongs to the cycle, this edge is replaced by a new edge (in the new graph),
which weight is as described in Edmond's algorithm. When several edges link
the same two nodes in the new graph, the lowest cost one is kept. **)
NewTransitionCostsMatrix = Table[Infinity, {x, Length[AuxTransitionCostsMatrix[[1]]] + 1},
|table |infini |longueur

```

```

{y, Length[AuxTransitionCostsMatrix[[1]] + 1]];
  |longueur
For[i = 1, i ≤ Length[initialListNE], i++, For[j = 1, j ≤ Length[initialListNE], j++,
|pour chaque |longueur |pour chaque |longueur
  (* Case where the initial node of the edge belongs to the cycle *)
  If[(MemberQ[VertexListCycle, initialListNE[[i]]] == False) &&
  |si |est membre? |faux
    MemberQ[VertexListCycle, initialListNE[[j]]],
    |est membre?
    bool2 = Assuming[constraints,
    |supposant
      Simplify[AuxTransitionCostsMatrix[[initialListNE[[j]], initialListNE[[i]]] -
      |simplifie
        AuxTransitionCostsMatrix[[initialListNE[[j]],
        FunctionPi[[initialListNE[[j]]]]] <
        NewTransitionCostsMatrix[[Length[AuxTransitionCostsMatrix[[1]] + 1,
        |longueur
          initialListNE[[i]]]]];
      If[ToString[bool2] ≠ "True" && ToString[bool2] ≠ "False", Return[Print["Error 8: "];
      |si |convertis en chaîne de caractères |convertis en chaîne de caractères |reviens |imprime
        Print[bool2];
        |imprime
        {"Error 8", bool2}]];

      If[bool2,
      |si
        NewTransitionCostsMatrix[[Length[AuxTransitionCostsMatrix[[1]] + 1,
        |longueur
          initialListNE[[i]]] =
          AuxTransitionCostsMatrix[[initialListNE[[j]], initialListNE[[i]]] -
          AuxTransitionCostsMatrix[[initialListNE[[j]],
          FunctionPi[[initialListNE[[j]]]]];
        CorrespondingEdgesaux[[initialListNE[[i]],
        Length[AuxTransitionCostsMatrix[[1]] + 1, 1] = initialListNE[[i]];
        |longueur
        CorrespondingEdgesaux[[initialListNE[[i]],
        Length[AuxTransitionCostsMatrix[[1]] + 1, 2] = initialListNE[[j]];
        |longueur
        , Null], Null];
        |expres... |expression nulle
      (* Case where the final node of the edge belongs to the cycle *)
      If[MemberQ[VertexListCycle, initialListNE[[i]]] &&
      |si |est membre?
        (MemberQ[VertexListCycle, initialListNE[[j]]] == False),
        |est membre? |faux
        bool3 = Assuming[constraints,
        |supposant
          Simplify[AuxTransitionCostsMatrix[[initialListNE[[j]], initialListNE[[i]]] <
          |simplifie
            NewTransitionCostsMatrix[[initialListNE[[j]],
            Length[AuxTransitionCostsMatrix[[1]] + 1]]];
            |longueur
          If[ToString[bool3] ≠ "True" && ToString[bool3] ≠ "False", Return[Print["Error 9: "];
          |si |convertis en chaîne de caractères |convertis en chaîne de caractères |reviens |imprime
            Print[bool3];
            |imprime
            {"Error 9", bool3}]];

```

```

If[bool3,
  |si
  NewTransitionCostsMatrix[[initialListNE[[j]],
    Length[AuxTransitionCostsMatrix[[1]] + 1] =
    |longueur
  AuxTransitionCostsMatrix[[initialListNE[[j]], initialListNE[[i]]]];
  CorrespondingEdgesaux[[Length[AuxTransitionCostsMatrix[[1]] + 1,
    |longueur
    initialListNE[[j]], 1] = initialListNE[[i]];
  CorrespondingEdgesaux[[Length[AuxTransitionCostsMatrix[[1]] + 1,
    |longueur
    initialListNE[[j]], 2] = initialListNE[[j]];
  , Null];, Null];
  |expressi... |expression nulle
  (* Case where neither the initial nor the final node of the edge belongs
  to the cycle *)
  If[(MemberQ[VertexListCycle, initialListNE[[i]]] == False) &&
  |si |est membre? |faux
  (MemberQ[VertexListCycle, initialListNE[[j]]] == False) && i != j,
  |est membre? |faux
  NewTransitionCostsMatrix[[initialListNE[[j]], initialListNE[[i]]] =
  AuxTransitionCostsMatrix[[initialListNE[[j]], initialListNE[[i]]]];
  CorrespondingEdgesaux[[initialListNE[[i]], initialListNE[[j]], 1] =
  initialListNE[[i]];
  CorrespondingEdgesaux[[initialListNE[[i]], initialListNE[[j]], 2] =
  initialListNE[[j]];
  , Null];];];
  |expression nulle
];
  (* Treatment of the case when the graph studied contains only two nodes *)
  If[Length[initialListNE] == 2,
  |si |longueur
  othernode = If[initialListNE[[1]] == root, initialListNE[[2]], initialListNE[[1]]];
  |si
  MinimumSpanningtree = Graph[DirectedEdge@@@{{root, othernode}}, VertexLabels -> "Name"];
  |graphe |bord dirigé |étiquettes des sommets
  Null];
  |expression nulle
  (** Returning to the case where the graph contains more than two nodes,
  if the new graph built contains a cycle, by recurrence,
  apply Edmond's algorithm to the new graph to obtain its minimum spanning tree and then,
  using it, build the minimum spanning tree of the old graph. **)
  If[FindCycle[GraphPivV] != {} && Length[initialListNE] != 2,
  |si |trouve cycle |longueur
  resedmond = EdmondAlgorithm[NewTransitionCostsMatrix, NewListOfVertices,
  CorrespondingEdgesaux, root, constraints]];

  If[StringContainsQ[ToString[resedmond], "Error"], Return[resedmond]];
  |si |contient chaîne de car... |convertis en chaîne de caractères |reviens
  (* Using the minimum spanning tree computed with Edmond's algorithm for the new graph,
  build the minimum spanning tree corresponding to the old graph *)
  {Nextminimumspanningtree, Nextcorrespondingedgesaux, a} = resedmond;
  (* Find the node (i.e. nodetoexpand) of the new graph that corresponds to
  the cycle in the old graph. *)
  nodetoexpand = NewListOfVertices[[Length[NewListOfVertices]]];
  |longueur
  listedgesinnextminimumspanningtree = EdgeList[Nextminimumspanningtree];
  |liste de bord
  incomingnodetonodetoexpand = -99;
  (* Find the node that is at the origin of the minimum spanning tree's edge

```

```

    (in the new graph) that leads to nodetoexpand *)
For[i = 1, i ≤ Length[listedgesinnextminimumspanningtree], i++,
  pour chaque | longueur
  If[listedgesinnextminimumspanningtree[[i, 2]] == nodetoexpand,
    si
    incomingnodetonodetoexpand = listedgesinnextminimumspanningtree[[i, 1]]; Null
    | expression nulle
  ];
  (* If there is no such node, then it must be the root of the minimum spanning tree *)
  If[incomingnodetonodetoexpand == 999 999, incomingnodetonodetoexpand = root, Null];
  si | expression nulle
  (* Compute the node of the old graph orrespondingnodeinnodetoexpand so that
  the edge (incomingnodetonodetoexpand, correspondingnodeinnodetoexpand) of
  the old graph corresponds to the edge (incomingnodetonodetoexpand, nodetoexpand)
  in the new graph *)
  correspondingnodeinnodetoexpand =
  Correspondingedgesaux[[incomingnodetonodetoexpand, nodetoexpand, 2]];

  (* Suppress, in the cycle,
  the minimum cost edge leading to correspondingnodeinnodetoexpand *)
  Cyclewithoutedge =
  EdgeDelete[Cycle, DirectedEdge[FunctionPi[[correspondingnodeinnodetoexpand]],
  | élimine bord | bord dirigé
  correspondingnodeinnodetoexpand]];
  Graphcyclewithoutedge = Graph[Cyclewithoutedge, VertexLabels → "Name"];
  | graphe | étiquettes des sommets
  (* Build the new list of edges in the old graph's minimum spanning tree *)
  listnewedgesfromnexttree =
  Table[{-99, -99}, Length[listedgesinnextminimumspanningtree]];
  | table | longueur
  counter = 1;
  For[i = 1, i ≤ Length[listedgesinnextminimumspanningtree], i++,
  pour chaque | longueur
  If[listedgesinnextminimumspanningtree[[i, 1]] == nodetoexpand,
    si
    nodecorrespondingtonodetoexpand = Correspondingedgesaux[[nodetoexpand,
    listedgesinnextminimumspanningtree[[i, 2]], 1]];
    listnewedgesfromnexttree[[counter]] =
    {nodecorrespondingtonodetoexpand, listedgesinnextminimumspanningtree[[i, 2]]};
    counter ++, If[listedgesinnextminimumspanningtree[[i, 2]] == nodetoexpand,
    si
    listnewedgesfromnexttree[[counter]] =
    {incomingnodetonodetoexpand, correspondingnodeinnodetoexpand};
    counter ++, listnewedgesfromnexttree[[counter]] =
    {listedgesinnextminimumspanningtree[[i, 1]],
    listedgesinnextminimumspanningtree[[i, 2]]};
    counter ++];];];

  Newgraphaux = Graph[DirectedEdge @@@ listnewedgesfromnexttree, VertexLabels → "Name"];
  | graphe | bord dirigé | étiquettes des sommets
  (* Merge the minimum spanning tree of the new graph and the cycle of the
  old graph minus the suppressed edge to obtain the minimum spanning tree of
  the old graph *)
  Minimumspanningtree = GraphUnion[Graphcyclewithoutedge, Newgraphaux,
  | Union de graphes
  VertexLabels → "Name"];
  | étiquettes des sommets
  {Minimumspanningtree, Correspondingedgesaux, 0}]

```

```

(*****)
(*** Function to compute, for a given set of constraints on minority sizes,
NB and NC, the lng-term equilibrium or equilibria ***)
(*****)

DeterminationLongTermEquilibriumForSpecificConstraints[{{constraints_}}] :=
Module[{i, j, k, l, a, b, Transitioncostsmatrix, Correspondingedges, ListNE,
|_module
  Minimumspanningtrees, Listedgesinminimumspanningtrees, Costsminimumspanningtrees,
  Minimumcostminimumspanningtree, Longtermeq, auxboolean, Nblongtermeq, auxbooleanB,
  resedmond},

  Transitioncostsmatrix = Table[-99, {i, 1, 4}, {j, 1, 4}];
  |table

  Correspondingedges = Table[-99, {i, 1, 16}, {j, 1, 16}, {k, 1, 2}];
  |table

  Minimumspanningtrees = Table[-99, {i, 1, 4}];
  |table

  Costsminimumspanningtrees = Table[0, {i, 1, 4}];
  |table

  Listedgesinminimumspanningtrees = Table[Null, 4];
  |table |expression nulle

  Minimumcostminimumspanningtree = Infinity;
  |infini

  Longtermeq = Table[Null, {i, 1, 4}];
  |table |expression nulle

  Nblongtermeq = 0;

  (** Computation of the transition cost matrix **)
  For[i = 1, i ≤ 4, i++,
  |pour chaque
    For[j = 1, j ≤ 4, j++,
    |pour chaque
      If[j ≠ i,
      |si
        Transitioncostsmatrix[[i, j]] = DirectTransitionCost[{i, j, constraints}] /.
          {NA → 1, γ → 1/2};
        If[StringContainsQ[ToString[Transitioncostsmatrix[[i, j]]], "Error"],
        |si |contient chaîne de car... |convertis en chaîne de caractères
          Return[Transitioncostsmatrix[[i, j]]];
          |reviens
        Transitioncostsmatrix[[i, j]] = Transitioncostsmatrix[[i, j, 1]];
        Correspondingedges[[i, j, 1]] = i;
        Correspondingedges[[i, j, 2]] = j;
      ]
    ]
  ];

  (** Apply Edmond's algorithm to find the lowest cost minimum spanning tree
  corresponding to this matrix **)
  ListNE = {1, 2, 3, 4};

  (* For this, compute the minimum spanning tree for each equilibrium *)
  For[k = 1, k ≤ 4, k++,
  |pour chaque
    resedmond =

```



```

Block[{Print}, Edmondalgorithm[Transitioncostsmatrix, ListNE, Correspondingedges,
  |imprime
  k, constraints]]];
If[StringContainsQ[ToString[resedmond], "Error"], Return[resedmond]];
|contient chaîne de car... |convertis en chaîne de caractères |reviens
Minimumspanningtrees[[k]] = resedmond[[1]];
Listedgesinminimumspanningtrees[[k]] = EdgeList[Minimumspanningtrees[[k]]];
|liste de bord
(* Compute the cost of the minimum spanning tree (for each equilibrium) *)
For[l = 1, l ≤ Length[Listedgesinminimumspanningtrees[[k]], l++,
  |longueur
  a = Listedgesinminimumspanningtrees[[k]][[l, 1]];
  b = Listedgesinminimumspanningtrees[[k]][[l, 2]];
  Costsminimumspanningtrees[[k]] =
  Assuming[constraints,
  |supposant
  FullSimplify[(Costsminimumspanningtrees[[k]] + Transitioncostsmatrix[[b, a]]) /.
  |simplifie complètement
  {NA → 1, γ → 1/2}]];
];

(* Test if the cost of this equilibrium's minimum spanning tree is equal
the cost of the lowest cost minimum spanning tree obtained so far: if yes,
add this equilibrium in the list of long-term equilibria *)
auxbooleanNB = Assuming[constraints,
  |supposant
  FullSimplify[(Costsminimumspanningtrees[[k]] == Minimumcostminimumspanningtree) /.
  |simplifie complètement
  {NA → 1, γ → 1/2}]];
If[auxbooleanNB,
  |si
  Longtermeq[[Nblongtermeq + 1]] = k;
  Nblongtermeq++;
];

(* Test if the cost of this equilibrium's minimum spanning tree is strictly
below the cost of the lowest cost minimum spanning tree obtained so far: if yes,
save this equilibrium as the long-term equilibrium *)
auxboolean = Assuming[constraints,
  |supposant
  FullSimplify[(Costsminimumspanningtrees[[k]] < Minimumcostminimumspanningtree) /.
  |simplifie complètement
  {NA → 1, γ → 1/2}]];
If[ToString[auxboolean] ≠ "False" && ToString[auxboolean] ≠ "True",
  |convertis en chaîne de caractères |convertis en chaîne de caractères
  Return[Print["Error 10:"];
  |imprime
  Print[auxboolean];
  |imprime
  {"Error 10", auxboolean}]];
If[auxboolean,
  |si
  Minimumcostminimumspanningtree = Costsminimumspanningtrees[[k]];
  Longtermeq[[1]] = k;
  Nblongtermeq = 1;
];
];
{Transitioncostsmatrix, Costsminimumspanningtrees, Longtermeq, Minimumspanningtrees}

```

```
(*****
**** Function (1) to split the set  $P = \{(NB, NC) \in [0, 1] \times [0, 1], NB > NC\}$  into subsets
on which the long-term equilibrium (or equilibria) can be computed unambiguously
and (2) to compute the long-term equilibrium (or equilibria) on each subset ****
*****)
```

```
DeterminationAllLongTermEquilibria[{constraints_}] :=
Module[{Tableadditionalconstraints, counterpos, res, counterposmax,
|_module
  Tableresultsoneachsubzone, countersuccessivepb, aux1, aux2},
  Tableadditionalconstraints = Table[-99, {i, 1, 200}];
  |_table
  Tableadditionalconstraints[[1]] = True;
  |_vrai
  counterpos = 1;
  counterposmax = 1;
  Tableresultsoneachsubzone = Table[-99, {i, 1, 200}];
  |_table
  countersuccessivepb = 0;

  (** Progressively build the table Tableadditionalconstraints,
  in which each cell corresponds to a subset of P on which the long-
  term equilibrium can be
  determined: Start with a unique cell containing the value True and, then,
  if the function DeterminationLongTermEquilibriumForSpecificConstraints raises
  an error and returns a constraint,
  add this constraint to the present cell and build another cell at the end of
  the table with the opposite constraint. Then, by recurrence,
  try again to solve the present cell. If
  DeterminationLongTermEquilibriumForSpecificConstraints does not raises an error,
  save the long-term equilibrium obtained in table Tableresultsoneachsubzone,
  and start analyzing the next cell in the table **)
  While[counterpos ≤ Length[Tableadditionalconstraints] &&
  |_longueur
    ToString[Tableadditionalconstraints[[counterpos]]] ≠ "-99" && countersuccessivepb ≤ 50,
  |_convertis en chaîne de caractères
    If[ToString[FullSimplify[constraints && Tableadditionalconstraints[[counterpos]]]] ==
  |_si |_convertis e... |_simplifie complètement
      "False",
      counterpos++,
      (* Try to run DeterminationLongTermEquilibriumForSpecificConstraints *)
      res = Block[{Print}, DeterminationLongTermEquilibriumForSpecificConstraints[
  |_bloc |_imprime
        {constraints && Tableadditionalconstraints[[counterpos]]}]];

      (* If the function returns an error (and a new constraint),
      add the new constraint to the present cell and build a new cell at the end
      of the table with the opposite constraint *)
      If[StringContainsQ[ToString[res], "Error"],
  |_contient chaîne de car... |_convertis en chaîne de caractères
        aux1 = Assuming[constraints,
  |_supposant
          FullSimplify[Tableadditionalconstraints[[counterpos]] && ! (res[[2]])];
  |_simplifie complètement
```

```

]simplifie complètement
If[(! StringContainsQ[ToString[aux1], "=="] ||
  [contient chaîne de car... [convertis en chaîne de caractères
  StringContainsQ[ToString[aux1], ">="] || StringContainsQ[ToString[aux1], "<="] ||
  [convertis en chaîne de caractères [contient chaîne de car... [convertis en chaîne de caractères
  StringContainsQ[ToString[aux1], ">"] || StringContainsQ[ToString[aux1], "<"]],
  [convertis en chaîne de caractères [contient chaîne de car... [convertis en chaîne de caractères
Tableadditionalconstraints [[counterposmax + 1]] = aux1;
counterposmax ++];
aux2 = Assuming[constraints,
  [supposant
  FullSimplify[Tableadditionalconstraints [[counterpos]] && res [[2]]];
  [simplifie complètement
If[(! StringContainsQ[ToString[aux2], "=="] ||
[si [contient chaîne de car... [convertis en chaîne de caractères
  StringContainsQ[ToString[aux2], ">="] || StringContainsQ[ToString[aux2], "<="] ||
  [convertis en chaîne de caractères [contient chaîne de car... [convertis en chaîne de caractères
  StringContainsQ[ToString[aux2], ">"] || StringContainsQ[ToString[aux2], "<"]],
  [convertis en chaîne de caractères [contient chaîne de car... [convertis en chaîne de caractères
Tableadditionalconstraints [[counterpos]] = aux2;,
Tableadditionalconstraints [[counterpos]] = False];
  [faux
counterpossuccessivepb ++,
Tableresultsoneachsubzone [[counterpos]] = res;
counterpos ++;
counterpossuccessivepb = 0;
]
]
];
{Tableadditionalconstraints [[1 ;; counterposmax]],
  Tableresultsoneachsubzone [[1 ;; counterposmax]]}]

```

## 1.12 Appendix F - Mathematica functions for the analysis of the three-group model

```

RESULTSLONGTERMEQUILIBRIA = DeterminationAllLongTermEquilibria[{baselineconstraints}];
ANALYSISRESULTSLONGTERMEQUILIBRIA =
  AnalysisResultsLongTermEquilibria[{baselineconstraints}];
TRANSITIONMATRIX = TransitionCostsMatrix[{baselineconstraints}];

(*****
**** Computation of the zone of P corresponding to each long term equilibrium
(i.e. merging the subsets of P on which long-term equilibria have been computed) ****)
(*****)

AnalysisResultsLongTermEquilibria[{constraints_}] :=
Module[{result, counterposmax, possiblelongtermequilibria,
|module
  zonecorrespondingtoeachpossiblelongtermequilibrium, i, pos,
  counterpossiblelongtermequilibrium},

result = RESULTSLONGTERMEQUILIBRIA;
counterposmax = Length[result[[1]]];
|longueur
possiblelongtermequilibria = Table[-99, {i, 1, 20}];
|table
counterpossiblelongtermequilibria = 0;
zonecorrespondingtoeachpossiblelongtermequilibrium = Table[-99, {i, 1, 20}];
|table

(* Analyze each subset of P on which the long-
term equilibrium was computed. When a long-
term equilibrium is obtained for several subsets,
merge these subsets to find the total zone of P on which each long-
term equilibrium persists *)
For[i = 1, i <= counterposmax, i++,
|pour chaque
  If[ToString[FullSimplify[result[[1, i]]] != "False",
|si |convertis e... |simplifie complètement
  If[MemberQ[possiblelongtermequilibria, result[[2, i, 3]]],
|si |est membre?
  pos = Position[possiblelongtermequilibria, result[[2, i, 3]]][[1, 1]];
|position
  zonecorrespondingtoeachpossiblelongtermequilibrium[[pos]] =
  Assuming[constraints,
|supposant
  FullSimplify[zonecorrespondingtoeachpossiblelongtermequilibrium[[pos]] ||
|simplifie complètement
  (result[[1, i]] /. {Less -> LessEqual, Greater -> GreaterEqual})];,
|inférieur |inférieur ou é... |supérieur |supérieur ou égal
  counterpossiblelongtermequilibria++;
  possiblelongtermequilibria[[counterpossiblelongtermequilibria]] = result[[2, i, 3]];
  zonecorrespondingtoeachpossiblelongtermequilibrium[[
  counterpossiblelongtermequilibria]] =
  (result[[1, i]] /. {Less -> LessEqual, Greater -> GreaterEqual})
|inférieur |inférieur ou é... |supérieur |supérieur ou égal
  ]
]

```

```

];
{zonecorrespondingtoeachpossiblelongtermequilibrium[[
  1 ;; counterpossiblelongtermequilibria]],
  possiblelongtermequilibria[[1 ;; counterpossiblelongtermequilibria]]}]

(*****
**** Using the previous function's result: Depiction of the long-term equilibria ****
****)

FigureAnalysisResultsLongTermEquilibria[{constraints_}] :=
Module[{TableOfColors, Tobedepicted, nbpossiblelongtermequilibria, p, i, aux,
  module
  auxplot, zoneauxplot},
  TableOfColors = {Red, Green, Blue, Orange, Purple, Black};
  rouge |vert |bleu |orange |violet |noir
  Tobedepicted = ANALYSISRESULTSLONGTERMEQUILIBRIA;
  nbpossiblelongtermequilibria = Length[Tobedepicted[[1]]];
  longueur
  p = Table[-99, {x, nbpossiblelongtermequilibria}];
  table
  auxplot = Table[-99, {x, nbpossiblelongtermequilibria}];
  table
  (* zoneauxplot corresponds the most simple expression of the subset of P on
  which each long-term equilibrium persists *)
  zoneauxplot = {NB + 6 NC >= 5, NB + 6 NC <= 5 && 2 NB >= 1 && NB + NC >= 5/6, NB + NC <= 5/6 && 3 NC <= 1,
  3 NC >= 1 && 2 NB <= 1, False};
  faux
  (* For each possible long-term equilibrium,
  the corresponding subset of P is depicted *)
  For[i = 1, i <= nbpossiblelongtermequilibria, i++,
  pour chaque
  If[ToString[Tobedepicted[[1, i]]] != "False",
  convertis en chaîne de caractères
  aux = Tobedepicted[[1, i]] && NB > NC;
  p[[i]] = RegionPlot[aux, {NB, 0, 1}, {NC, 0, 1},
  tracé de région
  PlotStyle -> Directive[Opacity[.8], TableOfColors[[i]]], BoundaryStyle -> None,
  directive |opacité |style des frontières |aucun
  PlotPoints -> 100];
  nombre de points du tracé
  auxplot[[i]] = RegionPlot[NB > NC && zoneauxplot[[i]], {NB, 0, 1}, {NC, 0, 1},
  tracé de région
  PlotStyle -> Directive[Opacity[.5], Pink], BoundaryStyle -> None, PlotPoints -> 100];
  directive |opacité |rose |style des frontières |aucun |nombre de points du tracé
  Print[Show[{p[[i]], auxplot[[i]]}]]
  montre
  ]
  ]
];
Show[Cases[p, x_ /; ToString[x] != "-99"]]
cas |convertis en chaîne de caractères
]

```

```

(*****)
(**** Depiction of the first switching group for each transition between two
equilibria ****)
(*****)

Analysisfirstswitchinggroup[{}]:=
Module[{Tobedepticted, TableOfColors, p, i, aux, k, l, maxnbcases, nbcases, auxp},
|module
  TableOfColors = {Red, Green, Blue};
                    |rouge |vert |bleu

  (* In TRANSITIONMATRIX, the third table registers,
for each subset of P and each transition between two equilibria,
the corresponding mutating group or groups *)
  Tobedepticted = TRANSITIONMATRIX;
  maxnbcases = Length[Tobedepticted[[1, 1, 1]]];
                    |longueur

  nbcases = Table[maxnbcases, {i, 4}, {j, 4}];
                    |table

  p = Table[-99, {i, 4}, {j, 4}, {x, maxnbcases}];
                    |table

  (* For each transition and each subset of P,
depict the corresponding mutating group or groups *)
  For[k = 1, k ≤ 4, k++,
|pour chaque
    For[l = 1, l ≤ 4, l++,
|pour chaque
      If[k ≠ 1,
|si
        For[i = 1, i ≤ maxnbcases, i++,
|pour chaque
          If[ToString[Tobedepticted[[1, k, l, i]]] ≠ "-99",
|convertis en chaîne de caractères
            aux = Tobedepticted[[1, k, l, i]] && NB > NC;
            p[[k, l, i]] = RegionPlot[aux, {NB, 0, 1}, {NC, 0, 1},
|tracé de région
              PlotStyle → Directive[Opacity[.8],
|directive |opacité
                TableOfColors[[Tobedepticted[[4, k, l, i, 1]]]], BoundaryStyle → None,
|style des frontières |aucun

              PlotPoints → 100];
|nombre de points du tracé
            ,
            If[nbcases[[k, l]] > i - 1, nbcases[[k, l]] = i - 1];
|si
          ]
        ];
      Print["Analysis first switching group from ", k, " to ", l];
|imprime
      auxp = p[[k, l, 1];; nbcases[[k, l]]];
      Print[Show[Cases[auxp, x_ /; ToString[x] ≠ "-99"]]]
|mon... |cas |convertis en chaîne de caractères
    ]
  ]
]
]
]
]

```

```

(*****)
(**** Depiction of the mutation group or groups for each transition between
two equilibria ****)
(*****)

Analysismutatinggroup[{}]:=
Module[{Tobedepicted, TableOfColors, p, i, aux, k, l, maxncases, nbcases, auxp},
  TableOfColors = {Red, Green, Blue, Orange, Purple};
  (* In TRANSITIONMATRIX, the fourth table registers,
for each subset of P and each transition between two equilibria,
the corresponding first switching group *)
Tobedepicted = TRANSITIONMATRIX;
maxncases = Length[Tobedepicted[[1, 1, 1]]];
nbcases = Table[maxncases, {i, 4}, {j, 4}];
p = Table[-99, {i, 4}, {j, 4}, {x, maxncases}];
(* For each transition and each subset of P,
depict the corresponding first switching group *)
For[k = 1, k ≤ 4, k++,
  For[l = 1, l ≤ 4, l++,
    If[k ≠ 1,
      For[i = 1, i ≤ maxncases, i++,
        If[ToString[Tobedepicted[[1, k, l, i]]] ≠ "-99",
          aux = Tobedepicted[[1, k, l, i]] && NB > NC;
          p[[k, l, i]] = RegionPlot[aux, {NB, 0, 1}, {NC, 0, 1},
            PlotStyle → Directive[Opacity[.8],
              TableOfColors[[Tobedepicted[[3, k, l, i, 1]] +
                If[Length[Tobedepicted[[3, k, l, i]]] > 1, Tobedepicted[[3, k, l, i, 2]],
                0]]], BoundaryStyle → None, PlotPoints → 100];
          ,
          If[nbcases[[k, l]] > i - 1, nbcases[[k, l]] = i - 1];
        ]
      ];
    Print["Analysis mutating group from ", k, " to ", l];
    auxp = p[[k, l, 1]; nbcases[[k, l]]];
    Print[Show[Cases[auxp, x_ /; ToString[x] ≠ "-99"]]]
  ]
]
]
]
]

```

```
(*****)
(*** Function to find all the minimum spanning trees corresponding to each long-
term equilibrium ***)
(*****)
```

```
FindingAllMinimumSpanningTrees[{}]:=
Module[{result, nbofsubzones, Longtermq, i, j, costminimumspanningtree,
|_module
  Allpossiblespanningtreesperroot,
  counterminimumspanningtreescorrespondingtoeachlongtermq,
  listminimumspanningtreescorrespondingtoeachlongtermq, k, Cost},

  result = RESULTSLONGTERMEQUILIBRIA;
  nbofsubzones = Length[result[[1]]];
  |_longueur
  counterminimumspanningtreescorrespondingtoeachlongtermq =
  Table[-99, {i, nbofsubzones}];
  |_table
  listminimumspanningtreescorrespondingtoeachlongtermq = Table[-99, {i, nbofsubzones}];
  |_table

  (* Build the list of all possible spanning trees leading to each equilibrium
  (i.e. root) *)
  Allpossiblespanningtreesperroot =
  Table[
  |_table
    {Graph[{Mod[b + 2, 4] + 1 ↔ Mod[b + 1, 4] + 1, Mod[b + 1, 4] + 1 ↔ Mod[b, 4] + 1,
  |_graphe |_modulo mod |_modulo mod |_modulo mod |_modulo mod
      Mod[b, 4] + 1 ↔ b}, VertexLabels → "Name"],
  |_étiquettes des sommets
    Graph[{Mod[b + 1, 4] + 1 ↔ Mod[b + 2, 4] + 1, Mod[b + 2, 4] + 1 ↔ Mod[b, 4] + 1,
  |_modulo mod |_modulo mod |_modulo mod |_modulo mod
      Mod[b, 4] + 1 ↔ b}, VertexLabels → "Name"],
  |_étiquettes des sommets
    Graph[{Mod[b + 2, 4] + 1 ↔ Mod[b, 4] + 1, Mod[b, 4] + 1 ↔ Mod[b + 1, 4] + 1,
  |_modulo mod |_modulo mod |_modulo mod |_modulo mod
      Mod[b + 1, 4] + 1 ↔ b}, VertexLabels → "Name"],
  |_étiquettes des sommets
    Graph[{Mod[b, 4] + 1 ↔ Mod[b + 2, 4] + 1, Mod[b + 2, 4] + 1 ↔ Mod[b + 1, 4] + 1,
  |_modulo mod |_modulo mod |_modulo mod |_modulo mod
      Mod[b + 1, 4] + 1 ↔ b}, VertexLabels → "Name"],
  |_étiquettes des sommets
    Graph[{Mod[b + 1, 4] + 1 ↔ Mod[b, 4] + 1, Mod[b, 4] + 1 ↔ Mod[b + 2, 4] + 1,
  |_modulo mod |_modulo mod |_modulo mod |_modulo mod
      Mod[b + 2, 4] + 1 ↔ b}, VertexLabels → "Name"],
  |_étiquettes des sommets
    Graph[{Mod[b, 4] + 1 ↔ Mod[b + 1, 4] + 1, Mod[b + 1, 4] + 1 ↔ Mod[b + 2, 4] + 1,
  |_modulo mod |_modulo mod |_modulo mod |_modulo mod
      Mod[b + 2, 4] + 1 ↔ b}, VertexLabels → "Name"],
  |_étiquettes des sommets
    Graph[{Mod[b + 2, 4] + 1 ↔ Mod[b, 4] + 1, Mod[b + 1, 4] + 1 ↔ Mod[b, 4] + 1,
  |_modulo mod |_modulo mod |_modulo mod |_modulo mod
      Mod[b, 4] + 1 ↔ b}, VertexLabels → "Name"],
  |_étiquettes des sommets
    Graph[{Mod[b, 4] + 1 ↔ Mod[b + 1, 4] + 1, Mod[b + 2, 4] + 1 ↔ Mod[b + 1, 4] + 1,
  |_modulo mod |_modulo mod |_modulo mod |_modulo mod
      Mod[b + 1, 4] + 1 ↔ b}, VertexLabels → "Name"],
  |_étiquettes des sommets
```



```

Mod[b + 1, 4] + 1 ↔ b}, VertexLabels → "Name"],
  |étiquettes des sommets
Graph[{Mod[b, 4] + 1 ↔ Mod[b + 2, 4] + 1, Mod[b + 1, 4] + 1 ↔ Mod[b + 2, 4] + 1,
  |modulo mod |modulo mod |modulo mod |modulo mod
  Mod[b + 2, 4] + 1 ↔ b}, VertexLabels → "Name"],
  |étiquettes des sommets
Graph[{Mod[b + 2, 4] + 1 ↔ Mod[b, 4] + 1, Mod[b + 1, 4] + 1 ↔ b, Mod[b, 4] + 1 ↔ b},
  |graphe |modulo mod |modulo mod |modulo mod |modulo mod
  VertexLabels → "Name"],
  |étiquettes des sommets
Graph[{Mod[b + 2, 4] + 1 ↔ b, Mod[b + 1, 4] + 1 ↔ Mod[b, 4] + 1, Mod[b, 4] + 1 ↔ b},
  |graphe |modulo mod |modulo mod |modulo mod |modulo mod
  VertexLabels → "Name"],
  |étiquettes des sommets
Graph[{Mod[b, 4] + 1 ↔ Mod[b + 1, 4] + 1, Mod[b + 1, 4] + 1 ↔ b, Mod[b + 2, 4] + 1 ↔ b},
  |modulo mod |modulo mod |modulo mod |modulo mod
  VertexLabels → "Name"],
  |étiquettes des sommets
Graph[{Mod[b + 2, 4] + 1 ↔ Mod[b + 1, 4] + 1, Mod[b + 2, 4] + 1 ↔ b, Mod[b, 4] + 1 ↔ b},
  |modulo mod |modulo mod |modulo mod |modulo mod
  VertexLabels → "Name"],
  |étiquettes des sommets
Graph[{Mod[b, 4] + 1 ↔ Mod[b + 2, 4] + 1, Mod[b + 2, 4] + 1 ↔ b, Mod[b + 1, 4] + 1 ↔ b},
  |graphe |modulo mod |modulo mod |modulo mod |modulo mod
  VertexLabels → "Name"],
  |étiquettes des sommets
Graph[{Mod[b, 4] + 1 ↔ b, Mod[b + 1, 4] + 1 ↔ b, Mod[b + 2, 4] + 1 ↔ b},
  |graphe |modulo mod |modulo mod |modulo mod
  VertexLabels → "Name"}], {b, 1, 4}];
  |étiquettes des sommets

```

(\*\* On each subset of P, compute the cost of the minimum spanning tree and then find, in the table Allpossiblespanningtreesperroot, all the spanning trees that have this same cost. \*\*)

```

For[i = 1, i ≤ nbofsubzones, i++,
  |pour chaque
  Longtermeq = result[[2, i, 3]];
  counterminimumspanningtreescorrespondingtoeachlongtermq[[i]] =
  Table[0, {n, Position[Longtermeq, Null][[1, 1]] - 1}];
  |position |expression nulle
  listminimumspanningtreescorrespondingtoeachlongtermq[[i]] =
  Table[-99, {n, Position[Longtermeq, Null][[1, 1]] - 1}];
  |position |expression nulle
  For[j = 1, j ≤ Position[Longtermeq, Null][[1, 1]] - 1, j++,
  |pour chaque |position |expression nulle
  costminimumspanningtree = result[[2, i, 2, Longtermeq[[j]]]];
  For[k = 1, k ≤ Length[Allpossiblespanningtreesperroot[[Longtermeq[[j]]]], k++,
  |pour chaque |longueur
  Cost = Computecostspanningtree[{Allpossiblespanningtreesperroot[[Longtermeq[[j]], k]],
  result[[2, i, 1]]}];

  If[FullSimplify[Cost == costminimumspanningtree],
  |si |simplifie complètement
  counterminimumspanningtreescorrespondingtoeachlongtermq[[i, j]] =
  counterminimumspanningtreescorrespondingtoeachlongtermq[[i, j]] + 1;

```

```

If[ToString[listminimumspanningtreescorrespondingtoeachlongtermeq[[i, j]]] == "-99",
  |si |convertis en chaîne de caractères
  listminimumspanningtreescorrespondingtoeachlongtermeq[[i, j]] =
    {Allpossiblespanningtreesperroot[[Longtermeq[[j]], k]}},
  listminimumspanningtreescorrespondingtoeachlongtermeq[[i, j]] =
    Append[listminimumspanningtreescorrespondingtoeachlongtermeq[[i, j]],
    |appose
      Allpossiblespanningtreesperroot[[Longtermeq[[j]], k]]
    ]
]
];
{result[[2, All, 3]], counterminimumspanningtreescorrespondingtoeachlongtermeq,
  |tout
  listminimumspanningtreescorrespondingtoeachlongtermeq}}

(*****
*** Auxilliary function to compute the cost of a spanning tree *****)
(*****

ComputeCostSpanningTree[{Tree_, TransitionCostMatrix_}] := Module[{list, Cost, i},
  |module
  list = EdgeList[Tree];
  |liste de bord
  Cost = 0;

  For[i = 1, i ≤ Length[list], i++,
  |pour chaque |longueur
  Cost = FullSimplify[Cost + TransitionCostMatrix[[list[[i, 1]], list[[i, 2]]]]
  |simplifie complètement
  ];
  Cost]

(*****
*** Function to simplify the results of the function FindingAllMinimumSpanningTrees
(i.e. merge the subsets of P on which the minimum spanning trees are the same) *****)
(*****

AnalyzingResultFindingAllMinimumSpanningTrees[{}]:=
Module[{result, simplerversion, i, j, counter, found},
  |module
  result = FindingAllMinimumSpanningTrees[{}];
  simplerversion = Table[-99, {i, 4}, {j, Length[result[[1]]}];
  |table |longueur
  counter = 0;

  For[i = 1, i ≤ Length[result[[1]]], i++,
  |pour chaque |longueur
  found = 0;
  For[j = 1, j ≤ counter, j++,
  |pour chaque

```

```

Pour chaque
If[result[[1, i]] == simplerversion[[1, j]] && result[[2, i]] == simplerversion[[2, j]] &&
  Si
    SubsetQ[result[[3, i]], simplerversion[[3, j]]] &&
    Sous-ensemble?
    SubsetQ[simplerversion[[3, j]], result[[3, i]],
    Sous-ensemble?
    found = 1;
    simplerversion[[4, j]] =
    FullSimplify[simplerversion[[4, j]] || RESULTSLONGTERMEQUILIBRIA[[1, i]]];
    simplifie complètement
  ]
];
If[found == 0,
  Si
    counter++;
    simplerversion[[1, counter]] = result[[1, i]];
    simplerversion[[2, counter]] = result[[2, i]];
    simplerversion[[3, counter]] = result[[3, i]];
    simplerversion[[4, counter]] = RESULTSLONGTERMEQUILIBRIA[[1, i]]
  ]
];
simplerversion[[All, 1 ;; counter]]
  tout

```

```

(*****
**** Depiction of all the minimum spanning trees corresponding to each long-
term equilibrium ****
*****)

```

```

PlotAnalyzingResultFindingAllMinimumSpanningTrees[{}]:=
Module[{result, i, p, TableOfColors},
  Module
    result = AnalyzingResultFindingAllMinimumSpanningTrees[{}];
    Print["result: ", result];
    Imprime
    p = Table[-99, {i, Length[result[[1]]}];
    Table
      longueur
    TableOfColors = {Red, Green, Lighter[Green, 1/2], Lighter[Green], Blue,
      rouge vert plus clair vert plus clair vert bleu
      Lighter[Blue, 1/2], Orange, Lighter[Blue], Lighter[Blue, 1/6], White};
      bleu orange plus clair bleu plus clair bleu blanc
    For[i = 1, i <= Length[result[[1]], i++,
      longueur
      p[[i]] = RegionPlot[result[[4, i]] && NB > NC, {NB, 0, 1}, {NC, 0, 1},
      tracé de région
      PlotStyle -> Directive[Opacity[.8], TableOfColors[[i]], BoundaryStyle -> None,
      style de tracé directive opacité style des frontières aucun
      PlotPoints -> 100];
      nombre de points du tracé
    ];
    Show[p]
    montre
  ]
]

```

```

(*****)
(*** Depiction of the graph of transition costs corresponding to the case
     where minority B is of size NBex and minority C is of size NCex
     (with edges colored according to their weight ***)
(*****)

PlotTransitioncostsmatrix[{NBex_, NCex_}] :=
Module[{result, i, j, matrixtobedepicted, matrixtobedepictedwithcolors, k, aux,
  module
  TableOfColors, listedges, listcoloredges},
  result = TRANSITIONMATRIX;
  matrixtobedepicted = Table[-99, {i, 4}, {j, 4}];
  matrixtobedepictedwithcolors = Table[-99, {i, 4}, {j, 4}];
  TableOfColors =
  Map[Hue, {0, 0.07, 0.11, 0.16, 0.2, 0.25, 0.45, 0.5, 0.55, 0.6, 0.65, 0.72}];
  Print[TableOfColors];
  For[i = 1, i ≤ 4, i++,
  For[j = 1, j ≤ 4, j++,
  If[i ≠ j,
  For[k = 1, k ≤ Length[result[[1, i, j]]], k++,
  If[FullSimplify[result[[1, i, j, k]] /. {NB → NBex, NC → NCex}],
  matrixtobedepicted[[i, j]] =
  FullSimplify[result[[2, i, j, k]] /. {NB → NBex, NC → NCex}];
  ]
  ]
  ];
  aux = Sort[DeleteCases[Flatten[matrixtobedepicted], -99]];
  listedges = {-99};
  listcoloredges = {-99};
  For[i = 1, i ≤ 4, i++,
  For[j = 1, j ≤ 4, j++,
  If[i ≠ j,
  listedges = Append[listedges, i ↔ j];
  listcoloredges = Append[listcoloredges,
  i ↔ j → TableOfColors[Position[aux, matrixtobedepicted[[i, j]][[1, 1]]]];
  matrixtobedepictedwithcolors[[i, j]] =

```

```

TableOfColors[[Position[aux, matrixtobedepicted[[i, j]][[1, 1]]]]
]
]
];

Graph[Drop[listedges, 1], EdgeStyle → Drop[listcoloredges, 1], EdgeStyle → Thickness[0.1],
VertexLabels → "Name", VertexLabelStyle → Directive[15]]]

```



## Chapitre 2

# Trust or property rights ? Can trusted relationships substitute for costly land registration in West African cities ? \*

---

\*. This chapter corresponds to a joint work with Harris Selod, Senior Economist at the World Bank. We are grateful to Amadou Cissé for the many discussions about social structures in West Africa that initially motivated this paper, and to Pierre M. Picard, Jan Brueckner and Tony Yezer for suggestions and technical comments on the model. We are also grateful to Eliana la Ferrara and Karen Macours for useful insights on kinship and land markets in developing countries, as well as to Thierry Verdier and Miren Lafourcade and to the participants to the Labor and Public Economics Seminar at the Paris School of Economics for various comments and suggestions. We gratefully acknowledge the funding of the Paris School of Economics Mobility Grant, the ANR SOCOCITY project, the Labex OSE and the Labor and Public Economics Group at the Paris School of Economics.

**Abstract :**

Using an urban land use model, we study the market failures associated with land tenure insecurity and information asymmetry, and analyze households' responses to mitigate tenure insecurity. When buyers and sellers of land plots can pair along trusted kinship lines whereby deception (the non-disclosure of competing claims on a land plot to a buyer) is socially penalized, information asymmetry is attenuated but overall participation in the land market is reduced. Alternatively, when owners can make land plots secure by paying to register them in a cadaster, both information asymmetry and tenure insecurity are reduced, but the registration cost limits land market participation at the periphery of the city. We compare the overall surpluses under these trust and registration models and under a hybrid version of the model that reflects the context of today's West African cities where both registration and trusted relationships are simultaneously available to residents. The analysis highlights the substitutability of trusted relationships to costly registration and predicts the gradual evolution of economies towards the socially preferable registration system if registration costs can be sufficiently reduced.

**Keywords :** Land markets, property rights, information asymmetry, informal land use, land registration, ethnic kinship

**JEL classification :** P14, Q15, R14



## **2.1 Introduction**

In developing countries, informally holding land is more often the norm than the exception. In sub-Saharan African cities, in particular, a large fraction of landowners—in some cases up to 80 percent—do not hold a formal property right on their land. This high level of informality mirrors the deficiencies of land registration systems which, in sub-Saharan Africa, remain prohibitively costly and unaffordable to most households. It is all the more problematic as informal tenure can have large private and socioeconomic costs. A key reason is the risk of eviction associated with informal land, which reduces investment in land (Besley, 1995) or may reduce labor market participation due to the necessity of spending time guarding one's land plot (Field, 2007). Informal land tenure also hinders the tradability of land, possibly leading to land misallocation. Eventually, households residing on informal plots are exposed to a wide range of social ills, including crime, poor health from low housing quality, and negative human capital externalities (Galiani and Schargrotsky, 2010; Galiani et al., 2017; Nakamura, 2017).

To our knowledge, the theoretical model presented in this paper is the first to focus on the interaction between social norms and land markets, and how land transactions among trusted parties can address the information asymmetry that has come to characterize today's urban land markets in sub-Saharan Africa (Durand-Lasserve, Durand-Lasserve and Selod, 2015; Bank, 2019). In our model, purchasing informal land is risky for buyers, as plot ownership might be contested in the future. In an ideal world, competing land ownership claims could be extinguished through adjudication and registration of land ownership in a cadaster leading to the issuance of a property title. In practice, it can be very costly to do so and this solution is only chosen by a fraction of the population. The objective of our paper is thus to investigate how urban households who do not pay for land registration may rely on an alternative way to address tenure insecurity when transacting informal land. More specifically, we study a mechanism whereby buyers and sellers match in the informal market according to a trusted ethnic relationship that reduces the information asymmetry and the likelihood of purchasing an insecure plot. We formalize this idea in an urban land use model with tenure insecurity and information asymmetry, where we study equilibrium land market transactions and associated inefficiencies. In our framework, plots are of two types : risky plots, which ownership may be contested in the future, and risk-free plots, which ownership cannot be contested. In addition, buyers and sellers of land plots may have reciprocal duties based on trusted ethnic kinship. If a risky plot is exchanged between individuals linked by ethnic kinship without disclosure of the risk to the buyer, the seller will be considered to have violated his duty and a social penalty will be imposed on him. In that context, a buyer expects that a seller he is ethnically related with will be more likely to sell him a secure plot and the buyer will consequently be ready to pay a premium. Knowing this, sellers may decide whether to transact with kin or non-kin mem-

bers, depending on the intrinsic risk on their plot, the social penalty and the ethnic premium. An important prediction of the model is that although matching along ethnic lines reduces information asymmetry, it also lowers overall market participation. Alternatively, when owners are offered the possibility to make plots secure by paying to register them in a cadaster, both information asymmetry and tenure insecurity are reduced, but the cost of registration limits transactions at the periphery of the city. We compare the overall surplus under these two polar cases and under a hybrid version of the model, where both registration and trusted relationships are available options, as is the case in many sub-Saharan-African cities.

Our approach relates to two existing trends of literature from anthropology and economics. First, a well-established anthropological literature describes links among groups in a wide range of societies. Individuals from such groups are referred to as “allies”, “kins” or “cousins” and exhibit codified reciprocal duties along those links (Mauss, 1923). These duties may take various forms, including the requirement to treat one another fairly or to exchange gifts such as food or shelter. Such links are very commonly found in sub-Saharan Africa. We found published analyses in the context of Burkina Faso, Burundi, the Gambia, Guinea, Mali, Rwanda, Senegal, Tanzania and Zambia (Freedman, 1977; Raphaël, 1992; Fouéré, 2004; Smith, 2004, 2006; Diallo, 2006; Dunning and Harrison, 2010). In West Africa and central Africa, the social institution underpinning those links is referred to under the generic French term of “cousinage” (referring to the social links between groups of so-called “cousins”), a term that we will use throughout this paper.<sup>1</sup> These cousinage relationships often correspond to alliances between pairs of social groups defined by ethnicity, patronyms and/or the professions traditionally exerted by members of these groups.<sup>2</sup> Although cousinage relationships come from a very old tradition,<sup>3</sup> they are still widely used nowadays. In Senegal, it was found in a survey that 46 percent of Senegalese practice cousinage everyday and an additional 30 percent practice it sometimes (Smith, 2004). Although the anthropological literature has mostly focused on reciprocal social relationships, several authors mention the role of cousinage in markets, as revealed by price bargaining along ethnic lines (see Hagberg, 2006 for Burkina Faso, and Birkeland, 2007 and Jones, 2007 for Mali). In the economics literature, however, only a small number of papers have focused on kin relationships and land markets, with no specific focus on cousinage. Relevant studies include the work of Marx, Stoker and Suri (2019), who show how

---

1. An alternative term for cousinage is “joking relationships” (in French, “cousinage à plaisanterie”), which refers to the codified jokes that individuals exchange upon their first encounter. Joking according to ritualized mocking allows to identify the nature and intensity of bilateral relationships and stress reciprocal duties before engaging in social interactions.

2. For example, the Sérère and Poular are two “allied” ethnic groups in Senegal and the Gambia and the Ba and Diallo are two “allied” family names in Senegal. In Mali, groups that traditionally exerted the profession of blacksmith are linked with all other castes.

3. In Mali, for instance, cousinage is believed to have been ordained by the 13th century ruler Sundiata Keita, as part of the oral constitution of the Mali Empire.

ethnicity affects the bargaining power of slum dwellers in Kenya, and Macours, De Janvry and Sadoulet (2010) and Macours (2014), who study social and ethnic matching on informal rental markets in the Dominican Republic and Guatemala in response to insecure property rights.

The second trend of literature that we build on involves an emerging urban economics literature on land tenure insecurity in developing countries and its implications for land markets. This literature trend began with Jimenez (1985) seminal model of squatting in which informal dwellers coordinate land invasions to protect themselves from evictions. Brueckner and Selod (2009) further studied the emergence of a city's squatter settlements in a general equilibrium with inelastic land supply. In their model, squatting "squeezes" the formal land sector, explaining the high price of formal land in an equilibrium configuration where formal and informal settlements coexist.<sup>4</sup> Our paper, however, does not involve squatting, whereby land is occupied without being purchased or rented out from its rightful owner, but focuses on the larger context of tenure informality and insecurity, whereby the occupant of a land plot may be its legitimate owner but does not have a fully-fledged property right, leading to the possibility of competing claims and conflicts. A small number of recent models have extended the standard monocentric land use model of urban economics initially developed by Alonso (1964), Mills (1967) and Muth (1969), in order to account for these issues. In Selod and Tobin (2018), urban households compete for land and simultaneously decide the type of property right to purchase from a land administration among a menu of rights that provides various degrees of tenure security. The model leads to an equilibrium with formal and more secure property rights at the proximity of the city center, a prediction that also holds in our model. Cai, Selod and Steinbuchs (2018) extend the Selod and Tobin model to a calibrated dynamic stochastic model with internal migration that allows them study the long term trajectory of formal and informal land uses and the persistence of informal settlements over time. Picard and Selod (2020) extend the canonical model of urban economics to study the conversion of agricultural land into urban residences and the associated changes in land tenure. They introduce information asymmetry between buyers and sellers of risky plots—a feature that is also present in our model—and find that information asymmetry deters land market participation and hinders the land use conversion process at the periphery of the city. Other spatial papers model specific types of informal housing. This is the case of Brueckner, Rabe and Selod (2019), who develop a theory explaining the emergence of a rental market for backyard structures in South African cities, and Pfeiffer et al. (2019), who propose a dynamic land-use model with formal and informal housing, including traditional informal settlements as well as backyarding . Other recent studies have focused on the determinants of informal housing and urban slums, stressing the role of migration and the relative elasticities of formal and informal housing supply in determining the

---

4. Brueckner (2013) further extended the model with the introduction of a rent-seeking organizer. Shah (2014) modified the model to account for squatting on public land. Turnbull (2008) proposed a non-spatial but dynamic model of the landowner-squatter relationship that focuses on the timing of evictions.

amount of informal housing (Alves, 2017; Henderson, Regan and Venables, 2016; Cavalcanti, Da Mata and Santos, 2019).

Our model builds on the above urban economics literature, especially on Selod and Tobin (2018) and Picard and Selod (2020), as we introduce tenure insecurity and information asymmetry in a monocentric land use model. To our knowledge, however, our model is the first land use model with interpersonal transactions, an important feature that was largely missing in the theoretical literature on land markets in developing countries, in spite of its likely high prevalence.<sup>5</sup> The introduction of ethnic matching allows us to assess and compare the respective advantages of transactions sanctioned by property rights registration and of transactions under trusted relationships. It also allows us to study the coexistence of the two practices within a single city. Our framework generates novel predictions regarding the prevalence of ethnic matching in land markets in the presence of costly registration, and highlights the substitutability of trusted relationships to costly registration as well, as the gradual evolution of economies towards full cadastral coverage as registration costs are reduced.

The paper is organized as follows. We start by presenting a benchmark urban economics model with tenure insecurity in Section 2.2. In Section 2.3, we sequentially present two polar cases : a first extension where households have the possibility to establish a registered property right (see Subsection 2.3.1) and a second extension where land cannot be registered but where buyers and sellers may pair according to a trusted relationship (see Subsection 2.3.2). In Section 2.4, we then present a hybrid model—closest to capturing the reality of developing country cities—where both registration and reliance on trusted relationships for transactions of informal land are available options. The final section concludes.

## **2.2 An urban land-use model with tenure insecurity (benchmark model)**

We first present a benchmark model based on the standard land use model of urban economics, in which we introduce tenure insecurity. This allows us to derive city structure and surplus in the absence of a property right system that makes land tenure secure.

### **2.2.1 Main assumptions**

The urban space is represented by a line segment at the extremity of which lies a CBD where all jobs are located. Each location on this segment (denoted by its distance  $x$  to the city

---

5. For a model of impersonal transactions and a theory of cadasters, see Arruñada (2012). The idea of interpersonal transactions regarding land sales were only previously explored in a theoretical model by Lanjouw and Levy (2002) who contrasted land transaction conditions between family members and outside parties in a non-spatial setting.

center) has a unit mass of landowners, each endowed with one land plot.<sup>6</sup> Each landowner decides whether or not to sell his land plot to a potential migrant coming to the city, thereby extracting the migrant's willingness to pay for residence in that particular location. Because migrants will be working in the CBD, they value proximity to the city center. As migrant buyers are competing with one another, sellers sell their plots to the highest bidder. We consider an open-city model, in which buyers migrate to the city until the expected utility in the city (given by their expected disposable income) is equalized with the rural utility level  $u$ .<sup>7</sup>

In our model, land tenure is insecure for some plots in the sense that a buyer can lose his plot in the future with a non-zero probability. This probability may reflect the numerous conflicts over land ownership that are prevalent in many developing country cities, in particular those that result from unclear initial ownership of the land by the seller, which is ground for competing claims.<sup>8</sup> However, not all plots are insecure. There are two possible levels of tenure security  $Q \in \{q, 1\}$ , with  $q < 1$ . Insecure plots may be contested and have a probability  $q$  of remaining in the hands of their buyer in the future, whereas secure plots are uncontested and have a probability 1 of remaining in the hands of their buyer. When a buyer is evicted from his plot, the plot is simply grabbed by an absentee landowner and can be resold to another migrant. We denote  $\pi$  the exogenous proportion of secure plots before the city forms and assume it is uniform across all locations.

The key assumption in our model is the existence of an information asymmetry between sellers (i.e; initial landowners) and buyers. Whereas sellers know the tenure security level of their plots (i.e., they know if there is a competing claim), migrant buyers cannot observe this characteristic before the transaction takes place. In what follows, we will refer to the initial owners of secure plots as 1-owners and to the initial owners of insecure plots as  $q$ -owners. If landowners decide not to sell their plot to a migrant, they simply keep it for agriculture and obtain a fixed revenue equal to the agricultural land rent  $R_a$ . We assume that  $u \leq R_a$ , reflecting the fact that migrants are rural laborers who, by definition, cannot be paid above the agricultural land rent.

We present below the market behavior of buyers and sellers in each location and derive the resulting spatial extent of the urban land market.

---

6. Our assumption of a unit of land per location makes our framework akin to Alonso (1964).

7. We assume a linear utility function and a price of the composite good normalized to 1, so that the utility in the city defined as the consumption of the composite good is exactly equal to the expected disposable income.

8. Other conflicts may oppose heirs, customary owners and investors, private parties and public authorities. See Durand-Lasserve, Durand-Lasserve and Selod (2015) for a full typology of urban land conflicts.

## 2.2.2 Sellers and buyers' behavior

The sellers' decision to sell is modeled by a binary choice variable  $P \in \{0, 1\}$ , with  $P = 1$  if the seller transacts with a migrant, and  $P = 0$  if the seller does not participate in the land market. We denote  $\pi(x)$  the share of 1-sellers among sellers in location  $x$  who decide to sell.<sup>9</sup> We consider that buyers have rational expectations and can fully anticipate the value  $\pi(x)$ .

In location  $x$ , the buyer of a plot can expect to obtain a secure plot with probability  $\pi(x)$  and an insecure plot with probability  $1 - \pi(x)$ . If the plot is insecure, it is lost with probability  $1 - q$ . For the buyer, the expected probability of keeping the plot is thus  $\pi(x) + (1 - \pi(x))q$  and that of losing it is  $(1 - \pi(x))(1 - q)$ . Furthermore, the buyer knows that, if he is not evicted and can remain in the city, he will have utility  $y - tx - R(x)$ , corresponding to his urban income net of commuting costs and of the price paid for the plot (denoted  $R(x)$ ). If evicted and having to return to the rural area, the buyer is not reimbursed for the plot purchase and gets utility  $u - R(x)$ . It is then easy to see that the expected utility of a buyer purchasing a plot in  $x$  is :

$$(\pi(x) + (1 - \pi(x))q)(y - tx - R(x)) + (1 - \pi(x))(1 - q)(u - R(x)) \quad (2.1)$$

We are now ready to derive the bidding behavior of buyers. Equating (2.1) with the rural utility level  $u$  (given our open city assumption) and inverting the resulting equation in the land price, we obtain the bid-rent of a buyer of a plot located in  $x$  :

$$\psi(x, u) = \{\pi(x) + q(1 - \pi(x))\}(y - tx - u) \quad (2.2)$$

This bid-rent measures the buyer's willingness to pay for the plot to exactly attain equilibrium utility  $u$ . Note that the bid-rent function depends on the buyer's expectation regarding tenure insecurity, so that the buyer's willingness to pay increases with  $\pi(x)$ , the fraction of 1-sellers among sellers and with  $q$ , the level of tenure security of risky plots.

As for sellers, their market participation decision will depend on the plot's location  $x$ , its intrinsic tenure security level  $Q$  and the market price  $R(x)$ , which we capture with the generic notation  $P(x, Q, R)$ . In turn, because the benefit  $B$  of a landowner will depend on his market participation decision and on the market prevailing price  $R(x)$  in location  $x$ , we express it as  $B(P, x, Q, R) \equiv PR(x) + (1 - P)R_a$ . The formula expresses *gross* profit and simply states that landowners who do not participate in the land market ( $P = 0$ ) obtain a benefit of  $B = R_a$ , while landowners who participate in the market ( $P = 1$ ) obtain a benefit of  $B = R(x)$ .<sup>10</sup>

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9.  $\pi(x)$  may differ from  $\pi$  if the proportions of secure and insecure plots sold in  $x$  differ.

10. Considering that the seller gives up on agricultural production, the *net* profit from a sale is  $PR(x) + (1 - P)R_a - R_a$ .

### 2.2.3 Competitive Equilibrium

Having characterized the behaviors of both sellers and buyers, we can now define the spatial equilibrium. To do this, however, we need to introduce the additional notations  $L_q(x)$  and  $L_1(x)$  for the respective quantities of insecure land and secure land that are transacted in  $x$ . With these notations, the total quantity of land transacted in  $x$ , can be decomposed as  $L(x) = L_q(x) + L_1(x)$ .

The set of equilibrium conditions that define the equilibrium are as follows : First, the equilibrium quantity of land that is sold in each location  $x$  must be smaller than the initial unit land endowment in that location, which yields the following land use constraint :

$$L_q(x) + L_1(x) \leq 1 \quad \text{for any } x \quad (2.3)$$

Then, in equilibrium, the market participation decision of the seller for each plot location, tenure security level and price,  $P^*(x, Q, R)$ , maximizes his gross profit, which leads to the profit maximization condition :

$$P^*(x, Q, R) \in \text{ArgMax}_{P \in \{0,1\}} B(P, x, Q, R) \quad \text{for any } x \quad (2.4)$$

Additionally, due to the infinite potential pool of migrants to the city, sellers are able to perfectly extract buyers' willingness to pay so that the land price is equal to the bid-rent in each location  $x$ , taken at the rural utility level  $u$  :

$$R(x) = \psi(x, u) \quad \text{for any } x \text{ where } L(x) > 0 \quad (2.5)$$

Finally, we can directly express the city fringe or "boundary" denoted  $x_b$  as the location closest to the CBD such that the gross benefits of 1-sellers and  $q$ -sellers accounting for their optimal market participation decisions are equal to the agricultural land rent  $R_a$ . This can be written as :

$$x_b = \min x \text{ s.t. } B^*(x, 1, R) = B^*(x, q, R) = R_a \quad (2.6)$$

where  $B^*(x, Q, R) \equiv B(P^*(x, Q, R), x, Q, R)$  is the optimal payoff (i.e. the gross profit evaluated at the optimal participation decision) of a seller of a plot in location  $x$ , endowed with a plot of security level  $Q$ , and selling at price  $R$ . Since there is only one price for land irrespective of the tenure security level (given that buyer cannot distinguish between risky and secure plots), the condition boils down to  $R(x_b) = \psi(x_b, u) = R_a$ , which is the standard city fringe condition. We have the following equilibrium definition :

**Definition 1 :** *A competitive equilibrium is a set of market participation decisions ( $P^*$ ), prices in each location ( $R(x)$ ), and a city fringe ( $x_b$ ) that satisfies the system of equilibrium conditions (2.3), (2.4), (2.5) and (2.6).*



Note that our equilibrium is defined “ex-ante” in the sense that agents make choices depending on their expectation that a conflict may materialize, but before the existence of a conflict can be observed. It also relies on rational expectations, in the sense that buyers and sellers know the model of the economy and are able to correctly assess the equilibrium proportion of secure plots among transacted plots. The main difference with the standard adverse selection model (see Akerlof, 1978) is that, in our model, uncertainty only directly affects buyers who may lose their plot if facing a risk of eviction.

To solve the system, we identify all possible combinations of sellers’  $P$ -decisions that are Nash equilibria (i.e., the combinations in which no landowner would gain from revising his  $P$ -decision given the  $P$ -decisions of all other landowners). We show in Appendix A that a continuum of equilibria are possible. In other words, there is a continuum of  $P$ -decisions that are compatible with our equilibrium conditions (2.3)-(2.6). In these equilibria, all owners in the segment  $[0, x_a]$  participate in the market. These multiple equilibria only differ with respect to market participation decisions over the segment  $]x_a, x_a^*[$  with  $x_a^* \equiv \frac{1}{i}(y - R_a - u)$  (on this segment any transacted land plot is sold at exactly price  $R_a$ ). More specifically, we show in Appendix A that each equilibrium in this continuum of equilibria is characterized by the number of 1- and  $q$ -sellers in each location  $x \in ]x_a, x_a^*[$ , which must verify  $(L_q(x), L_1(x)) \in [0, 1 - \pi[ \times [0, \pi[$  and  $B(P, x, Q, R) = R_a$ . Let us denote by  $\mathcal{E}_{L_q, L_1}$  the equilibrium characterized by functions  $L_q$  and  $L_1$  over the interval  $]x_a, x_a^*[$ . We show in Appendix A that  $\mathcal{E}_{L_q, L_1}$  is unstable if there exists  $x \in ]x_a, x_a^*[$  such that either  $L_q(x) > 0$  or  $L_1(x) > 0$  and that any small deviation in  $P$ -decisions from that equilibrium will always trigger a transition towards  $\mathcal{E}_{0,0}$ . This equilibrium is therefore the unique stable equilibrium. In that equilibrium, no landowner participates in the land market beyond  $x_a$  so that the city fringe is in  $x_b = x_a$ . Our results can be summarized in the following proposition :

**Proposition 1 :** *There is a single stable equilibrium, in which all landowners between the city center and the city fringe  $x_a = \frac{1}{i} \left[ y - \frac{R_a}{\pi + q(1 - \pi)} - u \right]$  participate in the land market. The equilibrium price curve is  $R(x) = [\pi + q(1 - \pi)](y - tx - u)$ .<sup>11</sup>*

**Proof :** See Appendix A.

Observe that the land price curve is linear with slope  $-[\pi + q(1 - \pi)]t$ , where  $\pi + q(1 - \pi)$  is the probability for a buyer to keep a purchased plot. In equilibrium, when marginally moving outwards from the city center, the reduction in land price exactly compensates the increase

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11. Note that to avoid the degenerate case of an empty city, the model requires the exogenous parameters to verify  $y - \frac{R_a}{\pi + q(1 - \pi)} - u > 0$ . From now on, we assume that this condition is satisfied.



in *expected* transport costs (given the probability of keeping the plot and commuting to the city center rather than losing the plot and moving back to the rural area without the need to commute anymore). The equilibrium price slope becomes flatter if plots become more insecure (lower  $q$ ) or if sellers with secure plots are scarcer (lower  $\pi$ ). As expected, when there is no tenure insecurity in the model (either because  $q = 1$  or  $\pi = 1$ ), the slope is equal to the *certain* marginal transport cost as in the standard version of the urban economics model with unit land consumption.

Inspection of the equilibrium city fringe formula for  $x_a$  shows that the city size decreases with the proportion of insecure plots ( $1 - \pi$ ) and the level of tenure insecurity ( $1 - q$ ). It is easy to understand that, when either one of these values marginally increases, the “last” seller at the city fringe prefers to keep his plot under agricultural use, since buyers’ willingness to pay is reduced. As we will see in the following section, this reflects a market failure in the sense that some plots are not transacted, due to tenure insecurity and information asymmetry.<sup>12</sup> Figure 2.1 represents the equilibrium land price as a function of distance to the CBD (with the slope of the land price written in blue letters), as well as the equilibrium city structure.<sup>13</sup>

## 2.2.4 Suboptimality of the equilibrium

The market equilibrium involves an externality, insofar as agents do not internalize the effect of their market participation decision on the composition of transacted plots, which in turn affects other agents’ decisions. Following Fujita (1989), we define the surplus as the city production (sum of wages) minus the costs to organize the city (transport costs, composite good consumption, and foregone agricultural production).<sup>14</sup> Although our framework to solve the equilibrium does not require to specify what happens to the plot after the buyer is evicted (since choices are made ex-ante, i.e. before the realization of a potential conflict), we need to introduce assumptions regarding the use of the land after an eviction in order to be able to write the surplus formula. When the buyer of a land plot is evicted, we assume that the plot is

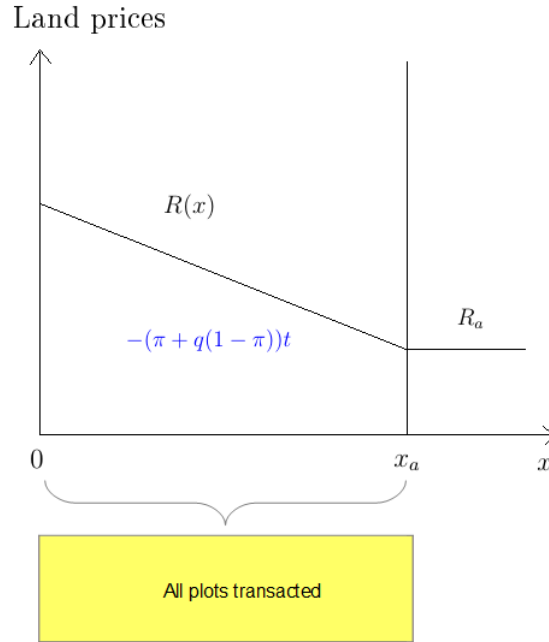
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12. Considering a variant of the model with risk aversion, it can be shown that the city size would also decrease with risk aversion. To see this, assume a Von-Neumann Morgenstern context with a CCRA Bernoulli function,  $z \rightarrow \frac{z^{1-\rho}-1}{1-\rho}$ , where  $\rho$  is risk aversion. The bid-rent  $\psi(x, u)$  is now implicitly defined by the equation  $u = (1 - q)(1 - \pi(x))\left(\frac{(u-R)^{1-\rho}-1}{1-\rho}\right) + (\pi(x) + q(1 - \pi(x)))\left(\frac{(y-lx-R)^{1-\rho}-1}{1-\rho}\right)$ . It is defined uniquely, as can easily be seen by deriving the LHS of the equality with respect to  $R$  and by observing that the LHS is only defined if  $u \geq R$ . Applying the implicit function theorem, we show that  $\frac{\partial \psi(x, u)}{\partial \rho} < 0$ , which further implies that  $\frac{\partial x_a}{\partial \rho} < 0$ . In other words, the greater the risk aversion, the smaller the city. Introducing risk aversion is, however, not necessary to derive the main results of our model and would make it much less tractable. We therefore abstract from modeling risk aversion in our model.

13. In Appendix A, we also present a figure that plots the payoffs of sellers underlying their participation decisions (see Figure 2.6).

14. This is mathematically equivalent to another definition of surplus that would consider the utility increment from migration to the city net of the opportunity cost of land use.

FIGURE 2.1 – City structure and land prices (benchmark model)



Note : This figure represents the equilibrium land price and market participation as a function of distance to the city center. The slope of the land price curve is indicated in blue.

grabbed by an absentee agent and resold at price  $R(x)$  to a new migrant worker. The process, however, may not be instantaneous. If there is some friction after the eviction, the plot will remain unoccupied for some time. We denote  $\theta \in [0, 1]$ , the fraction of time during which an evicted plot is occupied. If  $\theta = 0$ , the plot is immediately filled with a new occupant. If  $\theta = 1$ , the plot occupant is never replaced.  $\theta$  is assumed to be the same for all land plots. In the competitive equilibrium, recognizing that the composite good consumption is  $u$ , the surplus can be written as :

$$\begin{aligned} \Gamma_{\theta}(q, \pi, u) &= \int_0^{x_a} (\pi + (q + \theta(1 - q))(1 - \pi))(y - xt - u - R_a) dx \\ &= (\pi + (q + \theta(1 - q))(1 - \pi))(y - u - R_a - \frac{x_a}{2}t)x_a \end{aligned} \quad (2.7)$$

When  $\theta = 0$ , a plot whose occupant was evicted is lost to city production. The surplus is :

$$\Gamma_0(q, \pi, u) = (\pi + q(1 - \pi))(y - u - R_a - \frac{x_a}{2}t)x_a$$

When  $\theta = 1$ , evictions do not disrupt city production and the surplus is :

$$\Gamma_1(q, \pi, u) = (y - u - R_a - \frac{x_a}{2}t)x_a > \Gamma_0(q, \pi, u)$$

As regards the optimal city configuration, it is easy to see that it corresponds to a situa-

tion where plots are allocated to a migrant until an optimal city boundary denoted  $x_a^*(q, \pi, u)$ . Indeed, if a plot is not allocated, its contribution to the surplus is zero. If a secure plot is allocated, it contributes to the city surplus by an amount  $y - xt - u - R_a$ . If an insecure plot is allocated, it contributes to the city surplus by an amount  $(q + \theta(1 - q))(y - xt - u - R_a)$ .  $x_a^*$  is defined as the boundary beyond which no plots are allocated in the optimal city configuration. It is easy to see that  $x_a^* = \frac{1}{t}(y - R_a - u) > x_a$ , and no informal plot will be sold beyond. The optimal surplus associated with this configuration is thus :

$$\Gamma_\theta^*(q, \pi, u) = \int_0^{x_a^*} (\pi + (q + \theta(1 - q))(1 - \pi))(y - xt - u - R_a) dx \geq \Gamma_\theta(q, \pi, u)$$

The gap between the market equilibrium surplus  $\Gamma_\theta(q, \pi, u)$  and the optimal surplus  $\Gamma_\theta^*(q, \pi, u)$  is caused by tenure insecurity ( $q$  and  $\pi$ ), which decreases the size of the city to  $x_a < x_a^*$ . When tenure insecurity is removed from the model, the surplus rises and the city size  $x_a$  grows to become optimal.<sup>15</sup> In contrast, suppressing production disruption does not make the city size optimal, as land owners do not take this parameter into account in their decisions.

Focusing on the optimal surplus, note that it is a function of the model's parameters  $q, \pi$  and  $u$ , as well as  $\theta$ . Intuitively, a greater  $u$  reduces both the optimal city size and the incremental gain from city production (as migration to the city is reduced), while a greater  $\pi$  or  $q$  increases both city size and city production. When  $\theta$  increases, however, only city production increases. The optimal surplus is maximum when tenure insecurity or production disruption are removed (i.e.  $\pi = 1, q = 1$  or  $\theta = 1$ ). Indeed :

$$\Gamma_1^*(q, \pi, u) = \Gamma_\theta^*(1, \pi, u) = \Gamma_\theta^*(q, 1, u) = \max_{\pi, q, \theta} \Gamma_\theta^*(q, \pi, u) = \int_0^{x_a^*} y - xt - u - R_a dx$$

We denote this maximum optimal surplus  $\Gamma^{**}$  and will use it as an optimality benchmark in the rest of the paper. It is reached by the market equilibrium surplus when tenure insecurity is suppressed for any level of production disruption :

$$\Gamma_\theta(1, \pi, u) = \Gamma_\theta(q, 1, u) = \Gamma^{**}$$

## 2.3 Trust and registration as tenure security devices

The above section showed that land tenure insecurity and information asymmetry cause a market failure, whereby some landowners at the periphery of the city opt out of the market, leading to a sub-optimal urban equilibrium. Tenure insecurity and information asymmetry

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<sup>15</sup> It can easily be checked that  $\Gamma_\theta^*(1, \pi, u) = \Gamma_\theta(1, \pi, u) \geq \Gamma_\theta(q, \pi, u)$  and  $\Gamma_\theta^*(q, 1, u) = \Gamma_\theta(q, 1, u) \geq \Gamma_\theta(q, \pi, u)$  for any  $q \in [0, 1]$  and  $\pi \in [0, 1]$ . When either  $\pi = 1$  or  $q = 1$ , we see that  $x_a = x_a^*$ .

can be reduced through different institutional settings. In this section, we separately study the introduction in the benchmark model of two such institutional settings . The first is a cadaster/registry of property rights, thanks to which landowners have their registered rights recognized and enforced. The second setting relies on bilateral trusted relationships between buyers and sellers, based on group kinship. We present these institutional settings sequentially before comparing them.

### **2.3.1 A model of registration**

In the first extension, we add a property rights registration system to the benchmark model. Registration extinguishes competing claims on a land plot and makes it fully secure. Because it is observable by all, it allows buyers to identify a fraction of secure plots (i.e., those which are registered) with certainty. In this extension, sellers have the possibility to register their land before entering a transaction, anticipating that a registered plot will sell at a premium (that capitalizes both the increase in tenure security and the removal of information asymmetry). We assume that there is a registration cost,  $k$ , which is the same for all plots, irrespective of the initial tenure security level.

#### **2.3.1.1 Sellers and buyers' behavior**

An owner now has two choices. He chooses whether to participate in the market (decision  $P \in \{0, 1\}$ ) and, conditional on participating in the market, whether to register his plot (decision  $F \in \{0, 1\}$ ). If choosing  $F = 1$ , the tenure security level of the plot is reset at the value 1. There are thus two sale situations depending on sellers' decisions, each commanding a different price. Applying the same bid-rent approach as in the previous section, we see that the buyer of a registered plot will be willing to pay  $\psi(x, u|F = 1) = y - tx - u$  to reach utility level  $u$ . Similarly, the buyer of a non-registered plot will be willing to pay  $\psi(x, u|F = 0) = \{\pi(x) + q(1 - \pi(x))\}(y - tx - u)$ .

#### **2.3.1.2 Competitive equilibrium**

Given the additional features, of the model, the notations are slightly modified in comparison with the benchmark case. As before, we continue to use  $L_1(x)$  and  $L_q(x)$  to denote the quantities of secure and risky land that are transacted, while  $R(x)$  continues to denote the price of informally transacted land. However, we now introduce the notation  $L_f(x)$  to denote the quantity of registered (and transacted) land in each location  $x$ , and  $R_f(x)$  to denote the price of formally registered land. We now allow the market participation and the registration decisions to depend on location, the intrinsic tenure security level, and both formal and informal market prices, with the notations  $P(x, Q, R_f, R)$  and  $F(x, Q, R_f, R)$ . As for the seller's gross profit, it

is now also generically a function of the registration status of the land and of both formal and informal land prices, hence the notation  $B(P, F, x, Q, R_f, R)$ .

We can now adapt our definition of the competitive equilibrium as follows :

**Definition 2 :** *A competitive equilibrium is a set of market participation and registration decisions, prices in each location  $x$  and a city fringe that satisfies the following equilibrium conditions :*

$$\left\{ \begin{array}{l} L(x) = L_f(x) + L_q(x) + L_1(x) \leq 1 \quad \text{for any } x \quad (8) \\ (P^*(x, Q, R_f, R), F^*(x, Q, R_f, R)) \in \text{ArgMax}_{(P,F) \in \{0,1\}^2} B(P, F, x, Q, R_f, R) \quad \text{for any } x \quad (9) \\ R_f(x) = \psi(x, u | F = 1) \quad \text{for any } x \text{ where } L_f(x) > 0 \quad (10) \\ R(x) = \psi(x, u | F = 0) \quad \text{for any } x \text{ where } L(x) > 0 \quad (11) \\ x_b = \min x \text{ s.t. } B^*(x_b, 1, R_f, R) = B^*(x_b, q, R_f, R) = R_a \quad (12) \end{array} \right.$$

where  $B^*(x, Q, R_f, R) \equiv B(P^*(x, Q, R_f, R), F^*(x, Q, R_f, R), x, Q, R_f, R)$  is the optimized pay-off (i.e., taken at the optimal participation and formalization decisions) of a seller of a plot of security level  $Q$  in location  $x$  selling at price  $R$  if the plot is informal and  $R_f$  if it is formal.

The equilibrium conditions are very similar to (2.3)-(2.6), but they also account for the registration decision, registered land, and registered land prices. As in the benchmark version of the model, the city fringe condition allows for one of the two owner types (1- or  $q$ -owners) to not participate in the market and comes down to equating the bid rent of the last seller to the agricultural land rent. There is also an additional equation that determines the price of formal land as the upper envelope of formal bid-rents in places where land is registered by sellers. As previously, we solve for the competitive equilibrium by identifying stable Nash equilibria (see Appendix B).<sup>16</sup> The equilibrium structure of the city depends on the level of the registration cost as summarized in the following proposition :

**Proposition 2 :** *There exist two formalization cost thresholds,  $\underline{k} = R_a \frac{(1-q)(1-\pi)}{\pi(1-q)+q}$  and  $\bar{k} = (1-q)(1-\pi)(y-u)$ , such that :<sup>17</sup>*

- **If  $k \leq \underline{k}$  (Case 1) :** *The city is fully formal (all owners register and sell their plots). It extends until  $x_b = \hat{x}(k) = \frac{1}{t} [y - R_a - k - u]$ .*

16. In what follows, we only mention stable equilibria. All the stable and unstable equilibria are presented and discussed in the Appendix.

17. Throughout the rest of the paper, we assume that  $y-u > \max(\frac{k}{(1-q)(1-\pi)}, \frac{R_a}{\pi+q(1-\pi)})$  to ensure the existence of the city and the possibility of having unregistered plots. This implies that  $\underline{k} < \bar{k}$ . It is a stronger assumption than the one we had to justify the existence of the city under the benchmark model.

- **If  $k < \bar{k} \leq \bar{k}$  (Case 2) :** The city extends until  $x_b = x_a$  and is organized in two zones, one formal on  $[0, \check{x}(k)]$  (Zone 1) and one informal on  $]\check{x}(k), x_a]$  (Zone 2), where  $\check{x}(k) = \frac{1}{t} \left( y - \frac{k}{(1-q)(1-\pi)} - u \right)$ , with the border  $x_a$  being the same as in the benchmark case (see Section 2 above). The central residential zone  $[0, \check{x}(k)]$  is fully formal, with all owners registering their plot and participating in the market. The price on that segment is  $R_f(x) = y - xt - u$ . The peripheral residential zone  $]\check{x}(k), x_a]$  is fully informal, with all owners participating in the market without registering their plot. The informal price is  $R(x) = [\pi + q(1 - \pi)](y - xt - u)$ .
- **If  $k > \bar{k}$  (Case 3) :** The city extends until  $x_a$  and is fully informal (all owners participate in the land market without registering their plot).

**Proof :** See Appendix B.

Case 1 can be viewed as a developed country case where an affordable registration system is available and all land is registered. Case 2 is representative of a developing country context where registration is costly and where formal and informal land uses coexist. There is perfect spatial sorting between registered and non-registered plots, as landowners decide to register their land in the vicinity of the city center (zone  $[0, \check{x}(k)]$ ), but not further away. Case 3 corresponds to the unlikely case where the registration cost is so high that no one registers and the equilibrium configuration is exactly the same as in the benchmark model presented in the previous section (just as if registration were not an option). Graphs in Figure 2.2 represent the equilibrium city structure and land prices in Cases 1 and 2.<sup>18</sup>

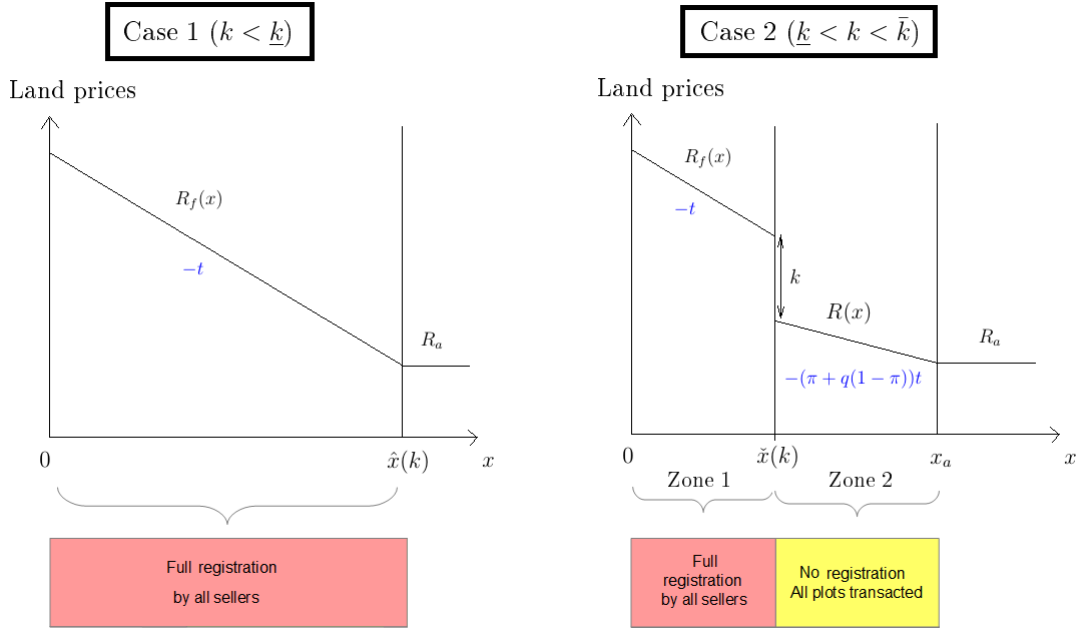
Note that the urban fringe in Case 1 ( $\hat{x}(k)$ ) is greater than in Case 2 ( $x_a$ ).<sup>19</sup> This property is consistent with the observation we previously made that tenure insecurity and information asymmetry reduce city size (see Section 2). Also observe that the formal zone boundaries  $\hat{x}(k)$  and  $\check{x}(k)$  are both decreasing functions of  $k$ , implying that the greater the registration cost, the smaller the formal zone in the city (which covers the whole city in Case 1). As regards Case 2 specifically, we see that, in the informal zone (in the periphery of the city) where all plots are transacted, buyers are unable to distinguish between risky and non-risky plots. Within that zone, there is thus a single land price function for non-registered plots ( $R(x)$ ). Additionally, because a fraction of transacted land is insecure, there is a slower capitalization of land prices when one moves towards the city center, leading to a flatter land price curve in the informal zone than in the formal zone. Finally, the discontinuity between formal and informal land prices in  $\check{x}(k)$  can be explained as follows : Since it is sellers who bear the formalization cost, they formalize in locations where they can extract a land price increment from buyers that is

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18. In Appendix B, we also present a figure that plots the payoffs of sellers underlying their participation and registration decisions (see Figure 2.7).

19. Indeed, observing that  $\hat{x}(k)$  is only defined for  $k \leq \bar{k}$ , we see that  $\hat{x}(k) - x_a = \frac{1}{t} [\bar{k} - k] > 0$ .

FIGURE 2.2 – City structure and land prices (registration model)



Note : This figure represents the equilibrium land price, market participation and registration as a function of distance to the city center when  $k < \bar{k}$  and when  $\bar{k} < k < \tilde{k}$ . The slopes of the land price curve are indicated in blue.

greater than the formalization cost. They stop formalizing in  $\check{x}(k)$ , where the buyers' utility gain from formalization (and willingness to pay a land price increment) is exactly equal to the formalization cost. The discontinuity in land prices ensures that there is continuity in buyers' utility and sellers' profits. Mathematically, we see that if there were no price discontinuity, the utility gain around  $\check{x}(k)$  would be :  $y - \check{x}(k)t - [(\pi + q(1 - \pi))(y - \check{x}(k)t) + (1 - \pi)(1 - q)u] = k$ .

### 2.3.1.3 Surplus gains from property rights

We can derive the surplus in the city under the registration system. Taking into account, as before, the possibility of productive disruption following an eviction, the surplus is given by :

$$\Lambda(k) = \begin{cases} \int_0^{\hat{x}(k)} (y - xt - k - u - R_a) dx & \text{in Case 1 } (k \leq \bar{k}) \\ \text{or } \int (y - xt - k - u - R_a) dx & \\ \quad + ((q + \theta(1 - q))(1 - \pi) + \pi) \int_{\check{x}(k)}^{x_a} (y - xt - u - R_a) dx & \text{in Case 2 } (\bar{k} < k \leq \tilde{k}) \end{cases} \quad (2.13)$$

Comparing the competitive surpluses with and without the land registration system ( $\Lambda$  and  $\Gamma$ ) yields the following property :

**Proposition 3 :** *The equilibrium surplus under the registration system is always strictly greater than in the benchmark model for  $k < \bar{k}$  and it is equal to the surplus in the benchmark model for  $k \geq \bar{k}$ .*

**Proof :** When  $k = 0$ ,  $\Lambda - \Gamma$  is strictly positive since  $1 > \pi + (q + \theta(1 - q))(1 - \pi)$  and  $\hat{x}(k) > x_a$ . On the interval  $[0, \underline{k}]$ , we have  $\Lambda - \Gamma = \int_0^{\hat{x}(k)} (y - xt - k - u - R_a) dx - \int_0^{x_a} (\pi + (q + \theta(1 - q))(1 - \pi))(y - xt - u - R_a) dx$ . The gap decreases with  $k$ , as  $\frac{\partial(\Lambda - \Gamma)}{\partial k} = -\frac{1}{t}(y - k - u - R_a) < 0$ . Next, let us consider  $\Lambda - \Gamma$  for  $k \in [\underline{k}, \bar{k}]$ . We have  $\Lambda - \Gamma = \int_0^{\hat{x}(k)} [y - xt - k - u - R_a - (\pi + (q + \theta(1 - q))(1 - \pi))(y - xt - u - R_a)] dx$ . Its derivative is  $\frac{\partial\Lambda - \Gamma}{\partial k} = -\frac{1}{t} \left[ y - u - (1 - \theta) \left( \frac{k}{(1 - q)(1 - \pi)} - R_a \right) \right]$ , which is negative until  $k$  reaches  $k_0 \equiv (1 - \pi)(1 - q) \left( \frac{y - u}{1 - \theta} + R_a \right)$  and positive after. As  $k_0 > \bar{k}$ ,  $\Lambda - \Gamma$  decreases with  $k$  on the interval  $[\underline{k}, \bar{k}]$  and reaches 0 in  $k = \bar{k}$ . Thus,  $\Lambda - \Gamma > 0$  for  $k < \bar{k}$  and  $\Lambda - \Gamma = 0$  for  $k \geq \bar{k}$ . This completes the proof of Proposition 3.

To understand Proposition 3, observe that  $k$  can be viewed as the extra cost to avoid eviction and the associated production loss. When  $k$  is sufficiently small, some degree of formalization occurs and increases the surplus. Interestingly, the dominance of the registration system does not necessarily require the city to be fully formal (as in Case 2, which is only partially formal). Note, however, that although the introduction of property rights is an improvement over the benchmark model if the registration cost is low enough, it does not completely remove the market failure. In fact, we show in Appendix B that the market equilibrium city structure and the optimal city structure only coincide when  $k = 0$ .<sup>20</sup> When the registration cost is low enough ( $0 < k \leq \underline{k}$ ), the equilibrium configuration is completely formal (which solves both the tenure insecurity and information asymmetry problems), and yet, market participation is still reduced at the periphery of the city because of the strictly positive registration cost.

It is also remarkable that the optimum city configuration for the registration model (see Appendix B) actually requires the presence of an informal zone, as long as  $k > 0$ . This is because registration of peripheral plots involves a registration cost that outweighs the incremental production gain net of commuting costs. In the competitive equilibrium, there is an informal zone (between  $\check{x}(k)$  and  $x_a$ ), but its size is sub-optimal. This is due to an externality associated with registration, as landowners choose to register based on the anticipation of buyers' willingness to pay for a secure plot rather than on buyers' contribution to production in the city.<sup>21</sup>

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20. In that case, not only is the market equilibrium optimal, but it reaches the maximum optimal surplus  $\Gamma^{**}$  of the benchmark model with no tenure insecurity (as property rights can be obtained for free).

21. The result that the optimal city structure may require some level of informality when formal property rights are costly to establish was first derived in Cai, Selod and Steinbuks (2018). Also note that in the presence of agglomeration effects, the externality might be attenuated if sellers anticipate an increase in their own labor income from migration to the city.



### 2.3.2 A model of trust

We now present a second extension of the benchmark model where landowners do not have the possibility to register their plot (i.e., they cannot remove the risk on their plot) but may instead choose whom they transact with in response to the information asymmetry. More precisely, each individual owner may decide whether to transact with a potential migrant with whom he has an ethnic relationship that involves some amount of trust. Borrowing the language of the anthropological literature on joking relationships, we refer to this behavior as transacting with a cousin (versus transacting with a non-cousin).<sup>22</sup> In our setting, there is no need to define groups and specify their numbers, as we just focus on whether landowners transact with a cousin or not (with an infinite pool of cousins potentially supplied by migration to the city). Cousinage relationships (the existence of a trusted relationship) are known and observable by all agents. Our only assumption is that tenure insecurity is location-specific but not group-specific, implying that, in each location, the proportions of risky and secure plots are the same among all groups.

We denote by  $C \in \{c, nc\}$  the landowner's decision to sell to a cousin ( $C = c$ ) or to a non-cousin ( $C = nc$ ). As in the benchmark model, buyers do not know the risk associated with the plot they are purchasing ( $Q \in \{q, 1\}$ ). Mirroring the literature on ethnic groups and social sanctions (Fearon and Laitin, 1996; Ferrara, 2003; Habyarimana et al., 2007), the key assumption in this setting is that selling a low-security plot to a cousin will always be punished with penalty  $J > 0$ . Therefore, sellers have an incentive to be more honest in their transactions with cousins than in their transactions with non-cousins.<sup>23</sup> The social penalty reflects the ostracism imposed on individuals who betray trust among cousins as codified in the cousinage institution. Given our assumption that tenure security is only location-specific, we denote  $\pi^c(x)$  the proportion of 1-sellers in  $x$ , as a fraction of all sellers who transact with a *cousin*. Similarly,  $\pi^{nc}(x)$  is the proportion of 1-sellers in  $x$ , as a fraction of all sellers who transact with a *non-cousin*.

Observe that land markets are now inter-personal (as opposed to the impersonal land markets presented in the benchmark and in the registration versions of the model). Also note that, because different levels of trust exist between cousins and between non-cousins, there are now two prices for plots, depending on whether the transaction involves cousins or non-cousins. We denote these inter-personal prices  $R^c(x)$  and  $R^{nc}(x)$  when the transaction involves cousins and non-cousins respectively.

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22. Although we refer to cousinage relationships, this version of our model encompasses the case of any society where trusted relationships exist within and across groups of individuals.

23. For simplicity,  $J$  is the same among all cousin groups.

### 2.3.2.1 Sellers and buyers' behavior

The expected utilities of a buyer buying from a cousin seller or from a non-cousin seller are respectively :

$$\begin{cases} u_c(x) = \{\pi^c(x) + q(1 - \pi^c(x))\}(y - tx) + (1 - \pi^c(x))(1 - q)u - R^c(x) & \text{and} \\ u_{nc}(x) = \{\pi^{nc}(x) + q(1 - \pi^{nc}(x))\}(y - tx) + (1 - \pi^{nc}(x))(1 - q)u - R^{nc}(x) \end{cases}$$

Because we have an open city, migration will occur until buyers obtain the same utility level as in the rural area (which we still denote  $u$ ). Inverting the above utility functions in the land price gives us the bid-rent functions in each location of the city, both for transactions among cousins and among non-cousins :

$$\begin{cases} \psi(x, u|C = c) = \{\pi^c(x) + q(1 - \pi^c(x))\}(y - tx - u) \\ \psi(x, u|C = nc) = \{\pi^{nc}(x) + q(1 - \pi^{nc}(x))\}(y - tx - u) \end{cases}$$

Anticipating buyers' willingness to pay (given by the above bid-rent functions), landowners choose whether to participate in the market (decision  $P \in \{0, 1\}$ ) and whom to sell to (decision  $C \in \{c, nc\}$ ).

Let us now detail the sellers' profit associated with each decision. If a seller decides not to participate in the land market, he receives the agricultural rent  $R_a$ . An owner of a secure plot selling to a cousin buyer ( $C = c, Q = 1$ ) receives a payment  $R^c(x)$ . An owner of an insecure plot selling to a cousin buyer ( $C = c, Q = q$ ) receives a payment  $R^c(x)$ , but faces the social penalty  $J$  that reduces his/her benefit to  $R^c(x) - J$ .<sup>24</sup> Finally, an owner selling to a non-cousin buyer receives a payment  $R^{nc}(x)$  and there is no social penalty if the transacted plot is insecure.

### 2.3.2.2 Competitive equilibrium

We can now adapt the equilibrium definition to the inter-personal market setting. The decision to participate in the market is now a function of the interpersonal prices. It can be denoted  $P(x, Q, R^c, R^{nc})$ . The decision to sell to a cousin or a non-cousin is also a function of the same arguments and is denoted  $C(x, Q, R^c, R^{nc})$ . The profit of a seller can now be generically expressed as  $B(P, C, x, Q, R^c, R^{nc})$ . In this version of the model, we decompose transacted land, not only according to its intrinsic tenure insecurity, but also according to the potential cousinage relationship between buyers and sellers. This requires the introduction of the notations  $L^c(x)$  and  $L^{nc}(x)$  for land transacted between cousins and non-cousins respectively. With these additional notations, we have the following equilibrium definition :

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24.  $J$  captures the disutility experienced by landowners when they are punished. Although it can be non-monetary in nature, landowners behave as if their monetary benefit were reduced by  $J$ .

**Definition 3 :** An equilibrium is a set of market participation decisions, “cousinage” decisions, prices in each location  $x$  and a city fringe that satisfies the following equilibrium conditions :

$$\left\{ \begin{array}{l} L(x) = L_q(x) + L_1(x) = L^c(x) + L^{nc}(x) \leq 1 \quad \text{for any } x \quad (14) \\ (P^*(x, Q, R^c, R^{nc}), C^*(x, Q, R^c, R^{nc})) \\ \in \text{ArgMax}_{(P,C) \in \{0,1\} \times \{c,nc\}} B(P, C, x, Q, R^c, R^{nc}) \quad \text{for any } x \quad (15) \\ R^c(x) = \psi(x, u | C = c) \quad \text{for any } x \text{ where } L^c(x) > 0 \quad (16) \\ R^{nc}(x) = \psi(x, u | C = nc) \quad \text{for any } x \text{ where } L^{nc}(x) > 0 \quad (17) \\ x_b = \min x \text{ s.t. } B^*(x_b, 1, R^c, R^{nc}) = B^*(x_b, q, R^c, R^{nc}) = R_a \quad (18) \end{array} \right.$$

where  $B^*(x, Q, R^c, R^{nc}) \equiv B(P^*(x, Q, R^c, R^{nc}), C^*(x, Q, R^c, R^{nc}), x, Q, R^c, R^{nc})$  is the optimized payoff (i.e., for the optimal participation and cousinage decisions) of a seller of a plot of security level  $Q$  in location  $x$  selling at price  $R^c$  if the buyer is a cousin and at price  $R^{nc}$  if he is not.

Condition (14) states that the quantity of transacted land must be smaller than the initial endowment in location  $x$ . It also provides the decomposition of the total amount of transacted land by tenure security, as well as by cousinage. Condition (15) characterizes the optimal market participation and cousinage decisions of sellers. Conditions (16) and (17) reflect sellers’ extraction of buyers’ willingness to pay under different cousinage situations. Condition (18) characterizes the city fringe.

Before solving the equilibrium, we derive the following two lemmas regarding cousinage decisions.

**Lemma 1 :** In a stable equilibrium, 1-owners only sell to cousin buyers.

**Proof :** See in Appendix C.

Lemma 1 implies that it is only possible to acquire a secure plot if transacting with a cousin. Yet, transactions between cousins involve information asymmetry, as insecure plots may also be sold to cousin buyers.

**Lemma 2 :** In a stable equilibrium, if there are transactions between non-cousins, they must always involve insecure plots ( $Q = q$ ).

**Proof :** This is a direct consequence of Lemma 1. Because 1-owners never sell to non-cousins, any transaction between non-cousins must therefore involve insecure plots ( $Q = q$ ).

Lemma 2 implies that there is no information asymmetry in transactions between non-cousins. With Lemmas 1 and 2, we see that transactions between cousins pool risky and non-risky plots, whereas transactions between non-cousins clearly separate a subset of risky plots. With these lemmas in mind, let us now solve for the equilibrium. We show that the city structure depends on the value of the social penalty  $J$  (see full details in Appendix C). Intuitively, the main qualitative difference when increasing the social penalty is that  $q$ -owners tend to sell more to non-cousins (in order to avoid the social penalty) and are more likely to drop out of the market. For ease of presentation and without major loss in generality, we will focus, in the rest of this subsection, on the case where  $J \leq \underline{J} = \pi R_a \frac{1-q}{q}$ , which encompasses situations in which cousinage is relatively mild, as practiced in urban areas in Senegal for instance (as observed by Smith, 2004).<sup>25</sup> In that case, however, transactions only occur among cousins. We present the other cases where  $J > \underline{J}$  and where non-cousins may transact with each other in Appendix C. We have the following proposition :

**Proposition 4 :** *Let us denote the social penalty threshold  $\underline{J} = \pi R_a \frac{1-q}{q}$ , and the zone boundary thresholds  $\underline{x}(J) = \frac{1}{t} \left( y - \frac{R_a + J}{\pi(1-q) + q} - u \right)$  and  $\bar{x}(J) = \frac{1}{t} (y - (R_a + J) - u)$ . The city extends until the city boundary  $x_a^*$  and is organized in the three following zones, moving outward from the city center :*

- **Zone 1 (fully residential) :** *On  $[0, \underline{x}(J)[$ , all landowners (irrespective of the tenure security level of their plot) participate in the land market and exclusively sell to cousins. The unique price in each location  $x$  is  $R^c(x) = [\pi + q(1 - \pi)] (y - xt - u)$ .*
- **Zone 2 (mixed agricultural and residential, partial market participation of  $q$ -sellers) :** *On  $]\underline{x}(J), \bar{x}(J)[$ , all 1-sellers and a share of  $q$ -sellers participate in the land market and exclusively sell to their respective cousins. The mass of  $q$ -sellers selling to cousins in  $x$  is  $L_q^c(x, J) = \frac{\pi(1-q)(y-xt-u)}{R_a + J - q(y-xt-u)} - \pi$ . The unique price in each location  $x$  is  $R^c(x) = R_a + J$ .*
- **Zone 3 (mixed agricultural/residential,  $q$ -sellers dropping out of the market) :** *On  $]\bar{x}(J), x_a^*[$ , all 1-sellers participate in the land market and sell to their cousins, whereas all  $q$ -sellers keep their plots under agricultural use. The unique price in location  $x$  is  $R^c(x) = y - xt - u$ .*

**Proof :** *See the proof of the Extended Proposition 4 in Appendix C.*

Given Lemmas 1 and 2,  $q$ -owners participating in the market face a trade-off between selling to a non-cousin, and selling to a cousin at a higher price while facing the social penalty  $J$ . Since the penalty is sufficiently low,  $q$ -owners always prefer to sell to their cousins.<sup>26</sup> In

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25. As we will see later in the subsection, the institution of cousinage is socially justified when  $J$  is sufficiently small.

26. We derive in Appendix C all the other city configurations for  $J > \underline{J}$ . In four of these cases, there are zones where some or all  $q$ -owners sell to both cousins and non-cousins. We also show the intuitive result that the number of  $q$ -owners selling to cousins decreases when the penalty increases.

terms of city size, we see that the city extends all the way to  $x_a^* > x_a$ . Indeed, the cousinage institution reduces the asymmetry of information as compared to the benchmark model, so that some 1-owners now have an incentive to sell further away from the city center (to their cousins). This leads to a larger city, with plots under urban and agricultural use coexisting at the periphery (i.e., not all landowners decide to participate in the market).

Figure 2.3 shows the spatial configuration of the city. On Zone 1, the fully urban part of the city, the slope of the land price curve is  $-(\pi + q(1 - \pi))t$ . As before, land prices exactly compensate expected commuting costs on this zone. Zone 2 and 3 correspond to the peri-urban part of the city, where some plots are residential and others remain agricultural. On Zone 2, some  $q$ -owners (but not all  $q$ -owners) drop out of the market. Thus, their net profit from informal sales (that are conducted exclusively with cousins) is equalized to the agricultural land rent. This explains the flatness of the land price curve and the price set at a markup that is exactly equal to  $J$  above the agricultural land rent.<sup>27</sup>

On Zone 3, only 1-owners participate in the market. Thus, the slope of the land price curve is again equal to  $-t$ . Since  $\bar{x}(J)$  tends towards  $x_a^*$  when the social penalty tends towards zero, this zone tends to disappear for low values of  $J$ . When  $J \rightarrow 0^+$ , Zone 3 disappears (see Figure 2.3, with  $\bar{x}(J) \rightarrow x_a^*$ ) and we are left with only two zones in the city (Zones 1 and 2), where the land price in Zone 2 tends towards the flat agricultural land rent.<sup>28</sup>

### 2.3.2.3 Surplus gains from cousinage

We now derive the competitive surplus of the city, which can be expressed as a function of  $J$ . For instance, in the case  $J < \underline{J}$ , it can be written as :<sup>29</sup>

$$\begin{aligned} \Phi(J) = & \pi \int_0^{x_a^*} (y - xt - u - R_a) dx + (q + \theta(1 - q))(1 - \pi) \int_0^{\bar{x}(J)} (y - xt - u - R_a) dx \\ & + (q + \theta(1 - q)) \int_{\bar{x}(J)}^{\bar{x}(J)} L_q^c(x, J)(y - xt - u - R_a) dx \end{aligned}$$

For  $J > \underline{J}$ , the formula for  $\Phi$  changes with the city configurations presented in Appendix Figure 2.9.  $\Phi$  is a continuous and decreasing function of  $J$ . The surplus difference between the cousinage and benchmark competitive equilibria,  $\Phi - \Gamma$ , is thus also continuous and a decrea-

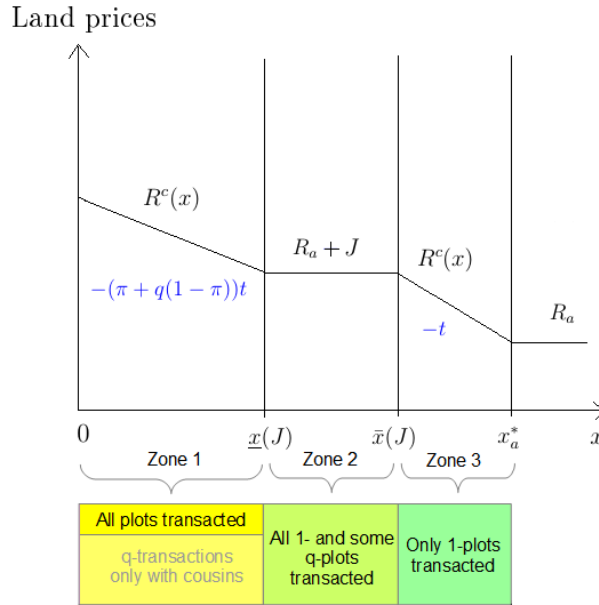
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27. Note that the flatness of the land price curve on Zone 2 means that, moving outwards from the city center, the proportion of  $q$ -sellers decreases in a way that reduces the risk on transacted plots so as to exactly compensate the increase in expected commuting costs. Indeed, it can easily be checked that :  $\frac{\partial R^c(x)}{\partial x} = (1 - q)(y_u - xt - u) \frac{\partial \pi^c(x)}{\partial x} - (\pi^c(x) + q(1 - \pi^c(x))) = 0$ .

28. In Appendix C, we present a figure that plots the payoffs of sellers underlying their participation and cousinage decisions (see Figure 2.10).

29. Note that, because  $J$  is non-monetary, it is not directly accounted for in the city surplus definition and only affects this surplus indirectly, through the modification of landowners' decisions.

FIGURE 2.3 – City structure and land prices (trust model)



Note : This figure represents the equilibrium land price, market participation and ethnic matching as a function of distance to the city center when  $J < \bar{J}$ . The slopes of the land price curve are indicated in blue.

sing function of  $J$ . We show in Appendix C that  $\Phi - \Gamma > 0$  when  $J$  is close to 0 and  $\Phi - \Gamma < 0$  in  $J = \bar{J}$ . We therefore have the following proposition.

**Proposition 5 :** *There exists a penalty threshold  $J_0(\theta) \in ]0, \bar{J}[$  such that, for  $0 < J < J_0(\theta)$  (respectively  $J > J_0(\theta)$ ), cousinage increases (respectively decreases) the city surplus in comparison with the benchmark model.*

**Proof :** *See Appendix C.*

The intuition underpinning the proposition is as follows : Low values of the social penalty increase the surplus (in comparison with the benchmark model), as they incentivize participation to the market and cousinage relationships that address information asymmetry through trusted transactions among cousins. When the penalty increases, however, the market participation of owners of insecure plots is reduced (since  $\underline{x}(J)$ ,  $\bar{x}(J)$  and  $L_q^c(x, J)$  are all decreasing function of  $J$ ), which tends to mitigate the benefits from cousinage, as too few plots are sold on the market. For larger values of the penalty, the latter effect dominates the former, and the surplus might be lower under the trust model than under the benchmark model. Another way to look at this result is to note that the merit of cousinage is to introduce trust among cousins (through the threat of punishing deception), but that the threat itself needs to be small, as it tends to deter market participation.

### 2.3.3 Theoretical dominance : trust or registration ?

We can now compare the surplus under the registration and the trust models. It is intuitive to see that the registration system has a greater potential to increase the surplus because it removes both tenure insecurity and asymmetry of information. On the contrary, reliance on cousinage can only, at best, remove information asymmetry by allowing buyers to better assess the quality of the plot they purchase, so that sellers of secure plots can get a higher benefit and also sell at the periphery of the city. When the formalization cost  $k$  tends towards zero, the competitive equilibrium under the registration model yields an optimal city size  $x_a^*$  (i.e., the city size under the benchmark model with no tenure insecurity) with full market participation of all landowners throughout the city. The trust model also yields a city of similar size, but some landowners find it more profitable to keep their land under agricultural use and do not participate in the market. When the formalization cost  $k$  tends towards zero, tenure insecurity is completely suppressed through registration, whereas this is never the case in the trust model for any intensity of the cousinage penalty. Therefore, when registration costs tend towards zero, the registration system dominates the trust system. However, considering more realistic situations where the registration cost is non zero, the comparison of the two property right systems becomes more complex. In fact, their ranking depends on the relative size of the registration cost  $k$  and the social penalty  $J$ . This result is detailed in the following proposition :

**Proposition 6 :** *The ranking of the registration and trust models (in terms of competitive surplus attained) depends on the relative intensities of the registration cost  $k$  and the cousinage penalty  $J$ . For low values of  $k$ , the registration system is always preferable (irrespective of the value of the social penalty  $J$ ). For high values of  $k$ , there exists a threshold for the cousinage penalty below which (respectively above which) the trust model performs better (respectively worse) than the registration model. Mathematically, it means that there exists a positive threshold  $\hat{k}(\theta) \in ]0, \bar{k}]$  such that :*

- *If  $k < \hat{k}(\theta)$  , the competitive surplus is always greater under the registration model, irrespective of the value of the cousinage penalty  $J$  ;*
- *If  $\hat{k}(\theta) < k < +\infty$ , there exists a threshold  $\tilde{J}(k, \theta)$  such that, if  $J < \tilde{J}(k, \theta)$  (respectively  $J > \tilde{J}(k, \theta)$ ),<sup>30</sup> the competitive surplus under the trust model is greater (respectively smaller) than the competitive surplus under the registration model.*

**Proof :** *See Appendix C.*

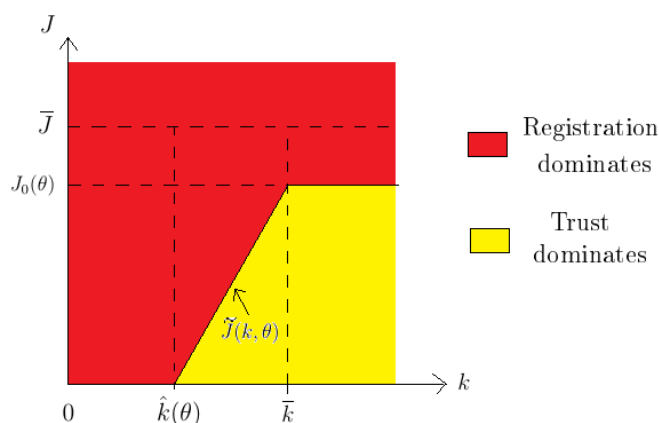
Proposition 6 implies that, for any sufficiently low value of the registration cost, the registration

30. In Appendix C, we show that  $\tilde{J}(k, \theta)$  is increasing in  $k$ . This means that the larger the registration cost, the larger the value of the social penalty threshold below which the trust model is preferable to the registration model.



model is always preferable. Trusted relationships can only efficiently substitute for registration in cases where registration costs are high and social penalties are low. The proposition can be illustrated graphically by Figure 2.4. To better visualize our result, observe that the equation of the upward sloping segment starting in  $\hat{k}(\theta)$  is  $\tilde{J}(k, \theta)$ . The combination of registration costs and social penalties below that line (the yellow area up to  $\bar{k}$ , defined in Proposition 2) is such that the trust system maximizes the city surplus, as compared to the registration system. According to Proposition 2, in the zone  $k > \bar{k}$ , the city under the registration system is fully informal and the total surplus under the registration system is thus constant and independent of  $k$  (and equal to the benchmark surplus in the absence of a property registration system). Since Proposition 5 tells us that the trust system increases the benchmark surplus if and only if  $J < J_0(\theta)$ , the trust system dominates the registration system in the yellow area beyond  $k = \bar{k}$  and below  $J = J_0(\theta)$ .

FIGURE 2.4 – The ranking of registration and trust models



Note : This graph represents which of the registration or the trust equilibrium yields the greater surplus for different combinations of the registration cost ( $k$ ) and the social penalty ( $J$ ).

## 2.4 A hybrid model with trust and registration

In the preceding section, we sequentially presented two types of property rights regimes : an impersonal system based on the registration of land property rights, and an interpersonal system based on trusted relationships between land buyers and sellers. In fact, both regimes usually co-exist in today’s sub-Saharan African cities, due to the fact that the introduction of formal/modern property rights that allow for impersonal exchange has not replaced the traditional institutions that make interpersonal exchange possible.

In this section, we investigate what this coexistence of systems implies in terms of city structure and surplus. To do this, we combine the features of our registration and trust models



in a single urban land use model. As shown in Appendix D, we find that the overall structure of the city depends on both the value of the registration cost  $k$  and the cousinage penalty  $J$ . For the sake of brevity, we only present results for the most likely but most complex case where the formalization cost is high ( $\underline{k} < k < \bar{k}$ ) and where  $J$  is low ( $J < \underline{J}$ , as in Section 3).<sup>31</sup>

### 2.4.1 Competitive equilibrium

In the hybrid version of the model, landowners may decide to participate in the land market or not. If participating, they may decide to register their land or to sell it informally. If selling it informally, they may choose to sell it to a cousin or to a non-cousin.<sup>32</sup> The three decisions of landowners can be written as functions of location, the plot's intrinsic level of tenure security, the formal price of land, and the informal prices of land sold to cousins and to non-cousins. The benefit of a seller is a function of the same variables and of his market participation, registration and cousinage decisions. This leads to the following updated version of the equilibrium definition :

**Definition 4 :** *An equilibrium is a set of market participation, registration, and “cousinage” decisions, prices in each location  $x$  and a city fringe that satisfies the following equilibrium conditions :*

$$\left\{ \begin{array}{l} L(x) = L_f(x) + L_q(x) + L_1(x) \leq 1 \quad \text{for any } x \quad (19) \\ (P^*(x, Q, R_f, R^c, R^{nc}), F^*(x, Q, R_f, R^c, R^{nc}), C^*(x, Q, R_f, R^c, R^{nc})) \\ \quad \in \text{ArgMax } B(P, F, C, x, Q, R_f, R^c, R^{nc}) \quad \text{for any } x \quad (20) \\ \quad (P, F, C) \in \{0, 1\} \times \{0, 1\} \times \{c, nc\} \\ R_f(x) = \psi(x, u | F = 1) \quad \text{for any } x \text{ where } L_f(x) > 0 \quad (21) \\ R^c(x) = \psi(x, u | F = 0, C = c) \quad \text{for any } x \text{ where } L^c(x) > 0 \quad (22) \\ R^{nc}(x) = \psi(x, u | F = 0, C = nc) \quad \text{for any } x \text{ where } L^{nc}(x) > 0 \quad (23) \\ x_b = \min x \text{ s.t. } B^*(x_b, 1, R_f, R^c, R^{nc}) = B^*(x_b, q, R_f, R^c, R^{nc}) = R_a \quad (24) \end{array} \right.$$

where  $B^*(x, Q, R_f, R^c, R^{nc}) \equiv B(P^*, F^*, C^*, x, Q, R_f, R^c, R^{nc})$  is the optimized payoff (i.e. after taking the optimal participation, formalization and cousinage decisions) of a seller of a plot of security level  $Q$  in location  $x$  selling at price  $R_f$  if the plot is formal,  $R^c$  if the plot is informal and the buyer is a cousin, and at price  $R^{nc}$  if the plot is informal and the buyer is not

31. Throughout this section, we assume, in addition to the previous sections' assumptions, that  $y - u > R_a \frac{1}{\pi q(1-\pi)}$ . This somewhat stronger hypothesis reduces the number of cases to be studied without changing the intuition of the model (See Appendix D for details).

32. Observe that cousinage and registration decisions are exclusive of one another. Once a landowner registers his plot, transactions occur at arm's length, so that ethnic bilateral relations do not play any role.

a cousin.

We now have 6 equilibrium conditions. As before, condition (19) says that the quantity of land sold must be smaller than the initial endowment in location  $x$ . Condition (20) characterizes the optimal market participation, registration and cousinage decisions of sellers. Conditions (21)-(23) reflect sellers' extraction of buyers' willingness to pay under the different land tenure situations (as regards security and registration) and social link configurations, where  $L^C(x)$  is the quantity of land transacted informally with a cousin ( $C = c$ ) or a non-cousin buyer ( $C = nc$ ).<sup>33</sup> Condition (24) characterizes the city fringe.

Before presenting the equilibrium, observe that Lemmas 1 and 2 remain valid in the hybrid model (i.e., 1-owners always sell to their cousins and transactions between non-cousins always involve insecure plots). The structure of the competitive equilibrium city now depends on both the intensity of the cousinage penalty and on the registration cost, as illustrated by the following proposition (see Appendix D for the full and detailed resolution and for the resolution of the equilibrium for other values of  $k$  and  $J$ ) :

**Proposition 7 :** *In equilibrium, the city is organized in four zones. Denoting the boundary zone threshold  $\hat{x}(k, J) = \frac{1}{t} \left( y - \frac{k-J}{(1-q)(1-\pi)} - u \right)$ , we have :*

- **Zone 1 (mixed formal and informal residential zone)** : *On  $[0, \hat{x}(k, J)[$ , all owners (irrespective of the initial tenure security level of their plot) participate in the market. Some  $q$ -owners register their plot before the sale (in quantity  $L_{fq}(x, k, J) = 1 - \frac{\pi(1-q)(y-xt-u)}{(1-q)(y-xt-u)+J-k}$ ), though some do not and sell exclusively to their cousins. 1-owners do not register their secure plots and sell them exclusively to their cousins. The informal price in each location  $x$  is  $R^c(x) = y - xt - u - k + J$  and the formal price for registered plots is  $R_f(x) = y - xt - u$ .*
- **Zone 2 (informal residential zone, full market participation)** : *On  $] \hat{x}(k, J), \underline{x}(J)[$ , all owners ( $q$ - and 1-owners) sell their plot informally and exclusively to cousins. In each location  $x$ , the price for these informal sales is  $R^c(x) = (\pi(1-q) + q)(y - xt - u)$ .*
- **Zone 3 (mixed informal residential and agricultural zone, partial market participation of  $q$ -owners)** : *On  $] \underline{x}(J), \bar{x}(J)[$ , all 1-owners and some  $q$ -owners sell their plots exclusively to cousins. The rest of  $q$ -owners drop out of the market. The mass of  $q$ -owners selling their plot in  $x$  to cousins is  $L_q^c(x, J) = \frac{\pi(1-q)(y-xt-u)}{R_a + J - q(y-xt-u)} - \pi$ . The price in each location  $x$  is  $R^c(x) = R_a + J$ .*
- **Zone 4 (mixed informal residential and agricultural zone, all  $q$ -owners dropping out of the market)** : *On  $] \bar{x}(J), x_a^*[$ , all 1-owners sell their plot exclusively to cousins and all  $q$ -owners drop out of the market. The price in each location  $x$  is  $R^c(x) = y - xt - u$ .*
- *The city boundary is at  $x_b = x_a^* = \frac{1}{t} [y - R_a - u]$ .*

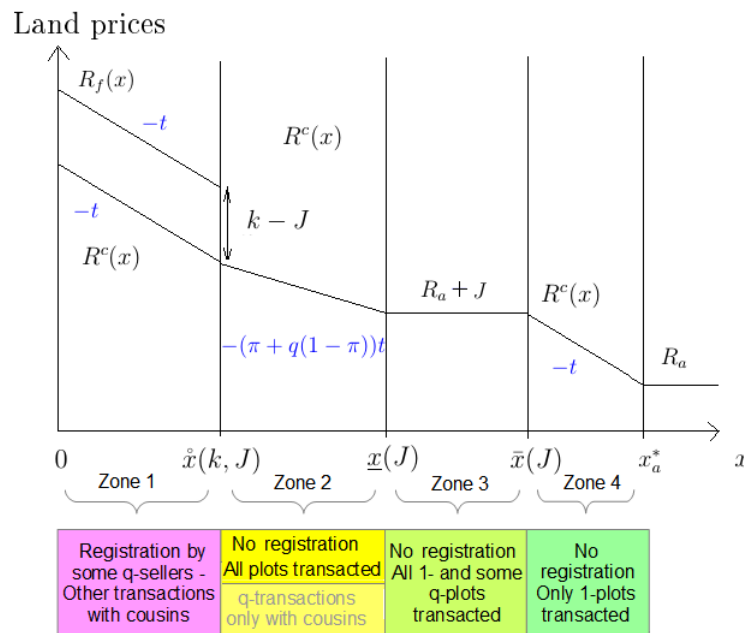
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33. Observe that  $L_q(x) + L_1(x) = L^c(x) + L^{nc}(x)$

**Proof :** See Appendix D.

The structure of the city and the corresponding equilibrium land prices are represented on Figure 2.5.<sup>34</sup> In the central residential zone (Zone 1, which has mixed registered and non-registered plots), the registered price curve has slope  $-t$ , reflecting the standard trade-off between proximity to the center and land prices under full tenure security. There is a constant markup between the registered price curve and non-registered price curve equal to  $k - J$ . This ensures that  $q$ -sellers are indifferent between registering at cost  $k$  and selling informally to cousins while incurring social penalty  $J$ . On the peripheral residential zone (Zone 2, where all plots are non-registered), the slope of the land price curve is  $-(\pi(1 - q) + q)t$ , reflecting the trade-off between the informal land price and expected transport costs. Zones 3 and 4 are the greater periphery of the city, where residential and agricultural land uses coexist. As in Section 3.2, it is easy to see that, since  $\bar{x}(J)$  tends towards  $x_a^*$  when the social penalty tends towards zero, Zone 4 tends to disappear for low values of  $J$  and the greater periphery is then mostly Zone 3, where the land price tends towards the agricultural land rent.

FIGURE 2.5 – City structure and land prices in the hybrid model



Note : This figure represents the equilibrium land price, market participation, registration and ethnic matching as a function of distance to the city center when  $k > \underline{k}$  and  $J < \underline{J}$ . The slopes of the land price curve are indicated in blue.

34. In Appendix D, we present a figure that plots the payoffs of sellers underlying their participation, registration and cousinage decisions (see Figure 2.18).

We have the following proposition :

**Proposition 8 :** *Registration and bilateral trust relationships are substitutes : If the registration cost increases, some landowners will shift from registering their plots to engaging in trusted relationships. If the social penalty increases, some landowners will shift from engaging in trusted relationships to registering their plots.*

**Proof :** *Let us first look at an increase in  $k$ . Inspection of  $\hat{x}(k, J)$  in Proposition 7 shows that it is a decreasing function of  $k$  and an increasing function of  $J$ , whereas  $L_{fq}(x)$  is a decreasing function of  $k$  and an increasing function of  $J$ . It follows that an increase in  $k$  reduces both the zone over which plots are registered (Zone 1) and the proportion of landowners registering their plot in each location, resulting in an unambiguous reduction in the overall number of registered plots. Landowners who do not register their plots anymore while remaining in Zone 1 all resort to bilateral trusted relationships. Landowners who are now within the boundaries of Zone 2 also all resort to trusted relationships. The resulting effect is an unambiguous increase in the overall number of transactions under trusted relationships. Let us now focus on an increase in  $J$ . Considering that  $\hat{x}(k, J)$  is shifted to the right,  $\underline{x}(J)$  and  $\bar{x}(J)$  are shifted to the left,  $L_{q, S=1}^c(x, J)$  is reduced and  $L_{qf}(x, k, J)$  is increased, it is easy to see that fewer landowners resort to trusted relationships and more to registering their plot.*

The above proposition illustrates how, in a context of costly registration, social relationships can partially address information asymmetry issues at the periphery of the city in the hybrid model, as it did in the trust version of the model. This is in line with the persistence of trusted relationships in the periphery of sub-Saharan African cities (as documented by Smith, 2004) where registration is relatively scarce (see Selod and Tobin, 2018, and Picard and Selod, 2020). It also predicts that, if registration becomes more affordable over time, the role of ethnic relationships governing land transaction could be phased out. In the polar case with  $k = 0$ , ethnic relationships are not mobilized anymore. Mathematically, we see that, when  $k$  tends towards zero,  $\hat{x}(k) = \frac{1}{t} [y - R_a - k - u]$  tends towards  $x_a^*$  and the informal zone of the city disappears.

Finally, we try to compare the surplus under the hybrid model with that of the trust and registration models. Recall that the model involves several externalities associated with the agents' private decisions to participate in the market, register and transact with cousins. It is thus not straightforward to predict how the hybrid model will rank in comparison with the other two models. Although the comparison is mathematically intricate, we are able to show the following proposition for small values of the cousinage penalty :

**Proposition 9 :**

- *When the registration cost is sufficiently low, the registration model leads to a greater surplus than the hybrid model, which itself leads to a greater surplus than the trust model.*
- *When registration cost is sufficiently high, the hybrid and trust models provide greater surpluses than the registration model.*

**Proof :** *See Appendix D.*

The intuition for the first part of the first item in Proposition 9 is straightforward. When registration costs are low, adding the possibility of registration to the trust model allows for an efficient substitution of registration to trusted relationships. This substitution, which occurs close to the city center reduces both the risk of conflict and information asymmetry, whereas trusted relationships only addressed information asymmetry without reducing the risk of conflict. The possibility of cheap registration allows all owners of risky plots to enter the market, with a fraction of them deciding to register. The second part of the first item in Proposition 9 sheds light on the desirability of a full registration system when the registration cost becomes low. In that case, the possibility of circumventing registration through trusted relationships is harmful as it leaves tenure risks intact. In this context, it makes sense for governments to make registration compulsory.

On the contrary, the second item in Proposition 9 reflects the fact that, when registration costs are high, adding the possibility of establishing trusted relationships in the registration model allows some owners to forego costly registration for trusted relationships that relatively efficiently addresses information asymmetry and encourages more low-risk plot owners to sell at the outskirts of the city. In the case of developing countries where registration costs are likely to be high, our results thus indicate that the existence of trusted relationships can be an efficient substitute to an inefficient land administration.<sup>35</sup>

## 2.5 Conclusion

In this paper, we proposed a series of models to shed light on alternative ways whereby households respond to the fundamental issue of tenure insecurity in sub-Saharan African cities. We first developed a pure registration model with information asymmetry between buyers and sellers that produced a series of results. First, the model made explicit how formal property rights protect land owners by making land tenure secure, but also how they facilitate transactions by reducing asymmetries of information between potential buyers and sellers (as

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35. Finally, note that it is technically difficult to compare the surpluses of the hybrid and trust models. But it is possible to exhibit sufficient conditions for the hybrid model to dominate the trust model in the vicinity of  $\bar{k}$ .

all market participants know that formally recognized property rights cannot be contested). The model also showed that when registration costs are high, the proportion of formal land plots decreases with distance to the city center, a pattern that is observed in many sub-Saharan African cities (see e.g., Durand-Lasserve, Durand-Lasserve and Selod, 2015, Bertrand, 2016, Bank, 2019 for evidence of this in the case of Bamako, Mali and Yaounde, Cameroon). Finally, the model predicted that at the periphery of the city, plots are pooled on the informal periurban land market irrespective of their intrinsic risk, and that the existence of information asymmetry leads to a reduction in the city size, compared to the case with perfect information or with no formalization cost. As in Picard and Selod (2020), the latter result reflects a market failure that stems from information asymmetry in a context of tenure insecurity.

We then developed a model without registration but with ethnic matching along trusted relationships and interpersonal obligations between sellers and buyers. The pure trust model showed that, in some cases, trust can remove information asymmetry by generating a separating equilibrium where, on the informal market, riskless plots are sold to “allied” buyers and risky plots to “non-allied” buyers. Trusted relationships, however, cannot address the intrinsic problem of tenure insecurity (which requires a formal property right system). The size of the city is also greater because, although some owners of risky plots drop out of the market, owners of riskless plots can get a higher profit from their sale and therefore do not drop out of the market. Further comparing our trust and our registration settings, we found that the registration system is potentially more efficient, because it can reduce tenure insecurity in addition to addressing information asymmetry. The registration cost, however, tends to limit market transactions at the periphery of cities so that, when registration costs are very high, the pure registration model is not necessarily the best option.

Eventually, we developed a hybrid model where both registration and trusted relationships are possible, leading to the following conclusions : First, the model predicts that registration will occur in central parts of the city, whereas trust will be relied upon mainly in peri-urban areas. This is consistent with the observation that land transactions in peri-urban areas often involve interpersonal relationships. Second, we found that trusted relationships are a substitute to registration : A higher registration cost leads more people to engage in ethnic matching. Conversely, if policies are able to bring down the cost of registration, the model predicts that ethnic matching will be phased out. Although we focused on the role of registration cost in deriving our result, the transition towards a full registration system could be accelerated by cultural change and the weakening of the norms governing kinship relationships (Canut and Smith, 2006). Finally, our hybrid model showed that when registration costs are high, allowing households to transact informally along trusted relationships leads to a greater economic surplus. This second best result implies that, as long as registration costs remain high, informal transactions need not be discouraged and can even improve the efficiency of the economy. In

a sense, this mirrors an ongoing debate in the policy world regarding the role played by the different tenure situations along a “continuum of land rights” (Habitat, 2012) and the contributions of these tenure situations to the overall welfare. Proponents of this approach have claimed that the promotion of freehold titles as the unique acceptable solution to hold land has been misguided and our results lend some credit to their position. Even though the continuum approach focuses on the benefits of weaker but more affordable documentation to legitimize property, our focus on one of the extremities of the continuum where land is held without any documentation shows that informal transactions can be beneficial when made according to trusted relationships. In fact, it should not be forgotten that land tenure is above all a social relationship and that registration is just an impersonal means of recognition of this relationship. However, as property rights become more affordable, the pure registration model becomes preferable and informal land transactions reduce rather than increase the surplus. In that context, the establishment of a fully formal land system will result in secure, denser, and more productive cities. We leave the study of underlying factors governing these changes and the speed at which they could happen for future research.

## 2.6 Appendix A - Benchmark model

### 2.6.1 Proof of Proposition 1 - Competitive equilibrium in the benchmark model

To derive the competitive equilibrium, we study, in each  $x$ , all possible combinations of participation decisions that 1- and  $q$ -owners may take to satisfy (2.4) subject to (2.5). We then study the stability of these configurations and retain only the stable one. We finally verify that this stable configuration verifies the equilibrium conditions (2.3)-(2.6).

**Sellers’ participation decisions and spatial city configuration** We consider the three possible cases in terms of 1-sellers’ participation decisions, i.e.  $L_1(x) = \pi, L_1(x) \in ]0, \pi[$  or  $L_1(x) = 0$ . For each case, we then derive the implications for the participation decisions of  $q$ -sellers and find the set of compatible city locations for these participation decisions.

- Let’s start with the case  $L_1(x) = \pi$ , which means that all 1-owners participate in the market. Because  $q$ -owners face the same payoff function as 1-owners (since they cannot be distinguished from one another), all of them also participate in the market so that  $L_q(x) = 1 - \pi$ . Therefore, the proportion of 1-sellers among all sellers in  $x$ ,  $\pi(x) \equiv \frac{L_1(x)}{L_1(x)+L_q(x)}$ , is equal to  $\pi$ . Plugging this expression into the participation constraint of 1-sellers  $B(P = 1, x, Q = 1, R) \geq R_a$  simplifies to  $x \leq \frac{1}{t} (y - \frac{R_a}{\pi+q(1-\pi)} - u) = x_a$  as defined in Proposition 1. We have shown that :

$$L_1(x) = \pi \Rightarrow (L_1(x), L_q(x)) = (\pi, 1 - \pi) \Rightarrow x \leq x_a$$

- Let's consider the second case  $L_1(x) \in ]0, \pi[$ , which means that only a fraction of 1-owners located in  $x$  sell their land, requiring indifference between participation and non-participation with  $B(P = 1, x, Q = 1, R) = \{\pi(x) + q(1 - \pi(x))\}(y - xt - u) = R_a$ . Because  $q$ -owners face the same payoff as 1-owners, they are also indifferent between participation and non-participation in the market. The above indifference condition provides an explicit formula for  $\pi(x)$  and thus for the ratio  $\frac{L_q(x)}{L_1(x)} = \frac{(y - xt - u - R_a)}{R_a - q(y - xt - u)}$ . Observe that the numerator in this ratio represents the maximum net gain that a seller can obtain from a sale in location  $x$  (since the buyer of a plot would be willing to pay  $y - xt - u$  if he knew for sure that the plot is secure). Given that plots are transacted in  $x$  under information asymmetry, the numerator of  $\frac{L_q(x)}{L_1(x)}$  is necessarily positive, which implies  $x < \frac{1}{t}(y - R_a - u) \equiv x_a^*$ . Furthermore, in order to have  $\frac{L_q(x)}{L_1(x)} > 0$ , we must also have  $R_a - q(y - xt - u) > 0$ , which requires that  $x > \frac{1}{t}(y - \frac{R_a}{q} - u \equiv x_a^q)$ . We have shown that :

$$L_1(x) \in ]0, \pi[ \Rightarrow (L_1(x), L_q(x)) \in ]0, \pi[ \times ]0, 1 - \pi[ \Rightarrow x \in ]x_a^q, x_a^*[$$

- In the third case,  $L_1(x) = 0$ , which means that 1-owners prefer not to sell. As  $q$ -owners have the same payoffs as 1-owners, they also prefer not to sell, so that  $L_1(x) = L_q(x) = 0$ . Observe that we are in a polar case where the function  $\pi(x)$  is actually not defined. From a buyer's perspective, given the shares of secure and insecure plots in location  $x$ , if a plot were to be offered on the market, it would be a secure plot with probability  $\pi$ . Non-participation thus requires  $R_a \geq (\pi + (1 - \pi)q)(y - xt - u)$ , where the RHS is the willingness to pay of a buyer in  $x$ . The latter inequality boils down to  $x \geq x_a$ . We have shown that :

$$L_1(x) = 0 \Rightarrow (L_1(x), L_q(x)) = (0, 0) \Rightarrow x \geq x_a$$

We have derived necessary conditions for the three above cases. Since it can easily be checked that  $x_a^q < x_a < x_a^*$ , this implies the following spatial configuration :

- For any  $x \leq x_a^q$ , we have  $(L_1(x), L_q(x)) = (\pi, 1 - \pi)$ .
- For any  $x \geq x_a^*$ , we have  $(L_1(x), L_q(x)) = (0, 0)$ .
- On the interval  $x \in ]x_a^q, x_a[$ , one may encounter any  $(L_1(x), L_q(x)) \in ]0, \pi[ \times ]0, 1 - \pi[$  (second case) or  $(L_1(x), L_q(x)) = (\pi, 1 - \pi)$  (first case).
- For  $x = x_a$ , one may encounter any  $(L_1(x), L_q(x)) \in ]0, \pi[ \times ]0, 1 - \pi[$  (second case) or  $(L_1(x), L_q(x)) = (\pi, 1 - \pi)$  (first case) or  $(L_1(x), L_q(x)) = (0, 0)$  (third case).
- On the interval  $x \in ]x_a, x_a^*[$ , one may encounter any  $(L_1(x), L_q(x)) \in ]0, \pi[ \times ]0, 1 - \pi[$  (second case) or  $(L_1(x), L_q(x)) = (0, 0)$  (third case).

**Stability of the different configurations** The multiplicity of solutions for  $L_1(x)$  and  $L_q(x)$  on  $x \in ]x_a^q, x_a^*[$  implies that we potentially have a continuum of equilibria. To study the stability of each of the possible combinations identified, we look at whether each combination is robust



to a small deviation in the participation decisions made by sellers in  $x$ . We have three cases, depending on whether we have full-participation, no-participation or partial participation in the market. We have the following results for each one of these cases :

- The full-participation case  $((L_1(x), L_q(x)) = (\pi, 1 - \pi))$  is stable on  $[0, x_a]$ . To show this, observe that the participation constraint of owners is  $\{\pi + q(1 - \pi)\} (y - xt - u) > R_a$ . If a mass  $\varepsilon$  of owners stops selling, owners will now compare  $\{\pi(x) + q(1 - \pi(x))\} (y - xt - u)$  and  $R_a$  to decide whether to participate in the market. As buyers will expect deviant owners to include  $\varepsilon\pi$  1-owners and  $\varepsilon(1 - \pi)$   $q$ -owners,  $\pi(x)$  remains unchanged and equal to  $\pi$ . It follows that the market participation constraint is unchanged so that deviant sellers will come back to their initial decision.
- The no-participation case  $((L_1(x), L_q(x)) = (0, 0))$  is stable on  $]x_a, x_a^*]$ . To show this, observe that this case is characterized by the participation constraint  $R_a > (\pi + (1 - \pi)q)(y - xt - u)$ , where the RHS is the expected plot price in case of a land sale (given the proportions of 1 and  $q$ -owners). If a mass  $\varepsilon$  of owners starts selling, buyers will expect these deviant owners to include  $\varepsilon\pi$  1-owners and  $\varepsilon(1 - \pi)$   $q$ -owners, leading to  $\pi(x) = \pi$ . As in the previous case, the participation constraint is unchanged, so that deviant owners come back to their initial decision.
- The partial participation cases  $((L_1(x), L_q(x)) \in ]0, \pi[ \times ]0, 1 - \pi[)$  are not stable on  $]x_a^q, x_a^*]$ . To show this, observe that these cases are characterized by equality  $\left[ \frac{L_1(x)(1-q)}{L_1(x)+L_q(x)} + q \right] (y - xt - u) = R_a$  which reflects owners' indifference between participating and not participating in the market. We need to consider two sub-cases here, depending on whether  $x \in ]x_a^q, x_a[$  or  $x \in ]x_a, x_a^*]$ .
  - First, consider  $x < x_a$ . This is equivalent to  $[\pi(1 - q) + q] (y - xt - u) > R_a$ . And, as we know that  $[\pi(x)(1 - q) + q] (y - xt - u) = R_a$ , we clearly have :  $\pi(x) < \pi$ . Consider now that a mass  $\varepsilon$  of owners start selling. Buyers expect that  $\frac{\pi - L_1(x)}{1 - L_1(x) - L_q(x)} \varepsilon$  of them are 1-sellers and that  $\frac{1 - \pi - L_q(x)}{1 - L_1(x) - L_q(x)} \varepsilon$  are  $q$ -sellers.<sup>36</sup> Denoting  $\eta = \frac{\varepsilon}{1 - L_1(x) - L_q(x)}$ , the price of a land plot becomes  $[\Pi(x, \eta)(1 - q) + q] (y - xt - u)$  where  $\Pi(x, \eta) = \frac{L_1(x) + \eta(\pi - L_1(x))}{L_1(x) + \eta(\pi - L_1(x)) + L_q(x) + \eta(1 - \pi - L_q(x))}$ . It can easily be shown that  $\frac{\partial \Pi}{\partial \eta} = \frac{\pi(L_1(x) + L_q(x)) - L_1(x)}{[(L_1(x) + L_q(x))(1 - \eta) + \eta]^2} > 0$  because  $\pi(x) < \pi$ . The new price of land is therefore increased by the deviation and becomes strictly greater than  $R_a$ . Consequently, the deviation triggers a cumulative process whereby all owners enter the market until we reach the stable configuration with full participation  $(L_1(x), L_q(x)) = (\pi, 1 - \pi)$ .
  - Second, consider  $x > x_a$ . This is equivalent to  $[\pi(1 - q) + q] (y - xt - u) < R_a$ . And,

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36. This is because all owners that were initially not selling are equally likely to start selling. The formula is obtained by recognizing that a mass  $\pi - L_1(x)$  of 1-owners and  $1 - \pi - L_q(x)$  of  $q$ -owners was initially not participating in the market.

as we know that  $[\pi(x)(1-q) + q](y - tx - u) = R_a$ , we clearly have  $\pi(x) > \pi$ . Consider that a mass  $\varepsilon$  of owners start selling. Here again, buyers expect that  $\frac{\pi - L_1(x)}{1 - L_1(x) - L_q(x)} \varepsilon$  of them are 1-sellers and that  $\frac{1 - \pi - L_q(x)}{1 - L_1(x) - L_q(x)} \varepsilon$  are  $q$ -sellers. The price of a land plot becomes  $\Pi(x, \eta)$ , as defined in the previous case. However, we now have  $\frac{\partial \Pi}{\partial \eta} < 0$  because  $\pi(x) > \pi$ . The new price of land is therefore decreased by the deviation and becomes strictly smaller than  $R_a$ . This triggers a cumulative process whereby all owners stop participating in the market until we reach the stable equilibrium with no participation  $(L_1(x), L_q(x)) = (0, 0)$ .

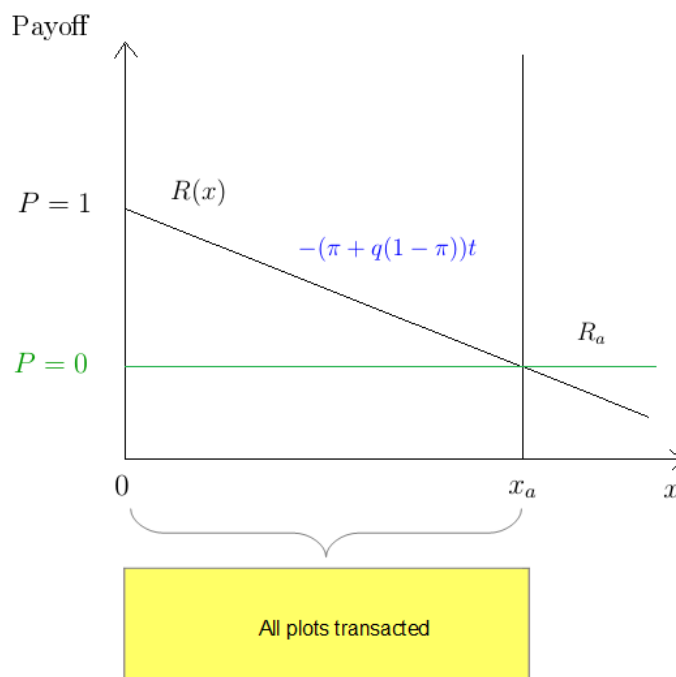
On each interval for  $x$ , we select the only stable cases. This leads to a unique possible configuration with full sale of all 1-plots and  $q$ -plots on  $[0, x_a]$  and no sale on  $]x_a, +\infty[$ .

**Compatibility with equilibrium conditions** It is easy to verify that the selected stable Pareto-optimal configuration satisfies the 4 equilibrium conditions for each  $x \in [0, x_a]$  :

- $L_1(x) + L_q(x) = 1$  so that (2.3) is verified.
- $B(P = 1 | x, Q \in \{q, 1\}, R) = (\pi(1-q) + q)(y - tx - u) > R_a$  so that (2.4) is verified.
- $R(x) = (\pi(1-q) + q)(y - tx - u)$  so that (2.5) is verified.
- $\pi(1-q) + q)(y_u - tx_a - u) = R_a$  so that (2.6) is verified.

## 2.6.2 Payoffs of land owners

FIGURE 2.6 – Payoffs of land owners



Note : This figure represents the equilibrium payoffs of sellers as a function of distance to the city center and their market participation decisions. The slope of the payoff curves are indicated in blue.

## 2.7 Appendix B - Registration model

### 2.7.1 Proof of Proposition 2 - Competitive equilibrium in the registration model

For this proof, we denote  $L_{fq}(x)$  (resp.  $L_{f1}(x)$ ) the mass of plots in  $x$ , that were originally of tenure security  $q$  (resp. 1) and that are registered by owners before being sold. Therefore, we have :  $L_f(x) = L_{fq}(x) + L_{f1}(x)$ .

To derive the competitive equilibrium, we follow the same steps as in the proof of Proposition 1 : we study, in each  $x$ , all possible combinations of participation and registration decisions that 1- and  $q$ -owners may take to satisfy (9) subject to (10 and 11). In each location, we determine which combinations of participation and formalization decisions are possible and study their stability. We then select the unique stable configuration and verify that it satisfies the

equilibrium conditions (8)-(12).

**Sellers' participation and registration decisions and spatial city configuration** In a fashion similar to the proof of Proposition 1 for the benchmark model, we show below that the decisions of all sellers in  $x$  can be uniquely characterized by the pair of variables  $(L_{f1}(x), L_1(x))$  given that uniquely determine  $L_{fq}(x)$  and  $L_q(x)$ . We now analyze the seven possible combinations of decisions, i.e. :  $(L_{f1}(x), L_1(x)) = (\pi, 0)$ ,  $(L_{f1}(x), L_1(x)) = (0, \pi)$ ,  $(L_{f1}(x), L_1(x)) = (\alpha, \pi - \alpha)$ ,  $(L_{f1}(x), L_1(x)) = (0, 0)$ ,  $(L_{f1}(x), L_1(x)) = (\alpha, 0)$ ,  $(L_{f1}(x), L_1(x)) = (0, \alpha)$  and  $(L_{f1}(x), L_1(x)) = (\alpha, \beta)$  where  $\alpha > 0$ ,  $\beta > 0$  and  $\alpha + \beta \in ]0, \pi[$  :

- If  $(L_{f1}(x), L_1(x)) = (\pi, 0)$  (i.e., all 1-owners register their plot and sell), then the payoff maximization constraint, the symmetry between 1- and  $q$ -owners' decisions (because of their identical payoffs), and the equivalence  $\check{x}(k) < \hat{x}(k) \Leftrightarrow k > \underline{k}$  imply that :

$$(L_{f1}(x), L_{fq}(x), L_1(x), L_q(x)) = (\pi, 1 - \pi, 0, 0) \\ \Rightarrow (k > \underline{k} \text{ and } x < \check{x}(k)) \text{ or } (k < \underline{k} \text{ and } x < \hat{x}(k)).$$

- If  $(L_{f1}(x), L_1(x)) = (0, \pi)$  (i.e., all 1-owners sell informally), then the payoff maximization constraint and the equivalence  $\check{x}(k) < x_a \Leftrightarrow k > \underline{k}$  imply :

$$(L_{f1}(x), L_{fq}(x), L_1(x), L_q(x)) = (0, 0, \pi, 1 - \pi) \Rightarrow k > \underline{k} \text{ and } \check{x}(k) < x < x_a.$$

- If  $(L_{f1}(x), L_1(x)) = (\alpha, \pi - \alpha)$  with  $\alpha \in ]0, \pi[$  (i.e., all 1-owners sell, some informally and some after registering their plot), then the payoff maximization constraint implies :  $L_q(x) = \frac{L_1(x)k}{(1-q)(y-xt-u)-k}$ . The conditions  $L_q(x) > 0$  and  $L_1(x) < \pi$  are incompatible so that this combination is in fact not possible.

- If  $(L_{f1}(x), L_1(x)) = (0, 0)$  (i.e., no 1-owner participates in the market), then the payoff maximization constraint and the equivalence  $x_a > \hat{x}(k) \Leftrightarrow k > \underline{k}$  imply :

$$(L_{f1}(x), L_{fq}(x), L_1(x), L_q(x)) = (0, 0, 0, 0) \\ \Rightarrow (k > \underline{k} \text{ and } x > x_a) \text{ or } (k < \underline{k} \text{ and } x > \hat{x}(k)).$$

- If  $(L_{f1}(x), L_1(x)) = (\alpha, 0)$  with  $\alpha \in ]0, \pi[$  (i.e., some 1-owners sell after registering their plot), indifference between not participating in the market and selling after registering implies that the interval for  $x$  is a singleton that corresponds to the limit of the formal zone,  $\hat{x}(k)$ . Because we have a continuous framework, we can overlook this border case of measure zero.

- If  $(L_{f1}(x), L_1(x)) = (0, \alpha)$  where  $\alpha \in ]0, \pi[$  (i.e., some 1-owners sell informally), then the payoff maximization constraint and the conditions  $\pi > L_1(x) > 0$  and  $1 - \pi > L_q(x) > 0$  imply :

$$(L_{f1}(x), L_{fq}(x), L_1(x), L_q(x)) = (0, 0, \alpha, \gamma(\alpha))$$

$$\text{where } \alpha \in ]0, \pi[ \text{ and } \gamma(\alpha) \left( \frac{R_a}{y_u - xt - u} - q \right) = \alpha \left( 1 - \frac{R_a}{y_u - xt - u} \right) \\ \Rightarrow \max(x_\alpha, \hat{x}(k)) < x < \bar{x}_\alpha.$$

where  $x_\alpha = \frac{1}{t} \left( y - R_a \frac{1-\pi+\alpha}{q(1-\pi)+\alpha} - u \right)$ ,  $\bar{x}_\alpha = \frac{1}{t} \left( y - R_a \frac{\pi+\gamma(\alpha)}{\pi+q\gamma(\alpha)} - u \right)$ . Note that this interval for  $x$  is always included in  $]x_a^q, x_a^*]$ .

- If  $(L_{f1}(x), L_1(x)) = (\alpha, \beta)$  with  $\alpha > 0$ ,  $\beta > 0$  and  $\alpha + \beta \in ]0, \pi[$  (i.e., some 1-owners participate in the market, some of them sell informally, and some after registering their plot). If this case occurs, it will only be for the singleton  $x = \hat{x}(k)$ . We discount this case of measure zero.

**Stability of the different configurations** We now determine which of the four remaining cases are robust to a small deviation in the decisions of sellers (which cases are stable). The proof follows a reasoning similar to that of the benchmark case (see Appendix A).

- The full registration and full participation case  $((L_{f1}(x), L_1(x)) = (\pi, 0))$  is stable on  $[0, \check{x}(k)[$  if  $k > \underline{k}$  (idem on  $[0, \hat{x}(k)[$  if  $k < \underline{k}$ ). To show this, we consider deviations on the registration and participation decisions :
  - If a mass  $\varepsilon$  of owners stop registering to sell informally, then buyers expect that there are  $\varepsilon\pi$  1-owners and  $\varepsilon(1 - \pi)$   $q$ -owners. Therefore,  $\pi(x) = \pi$  and the same payoff maximization constraint,  $y - xt - u - k > (\pi(1 - q) + q)(y - xt - u)$  and  $y - xt - u - k > R_a$ , are still verified. Therefore, deviant owners come back to their initial registration decisions.
  - If a mass  $\varepsilon$  of owners stops participating in the market, land prices are unchanged at  $y - xt - u$ . Therefore, deviant owners come back to their initial decisions.
- The no-registration and full participation case (i.e.,  $(L_{f1}(x), L_1(x)) = (0, \pi)$ ), in zone  $]\check{x}(k), x_a[$  if  $k > \underline{k}$ , is stable. This is because :
  - If a mass  $\varepsilon$  of owners start registering their plot before selling, then buyers expect them to be in proportions  $\varepsilon\pi$  1-owners and  $\varepsilon(1 - \pi)$   $q$ -owners. Thus,  $\pi(x)$  remains equal to  $\pi$  and the payoff maximization constraint is unchanged. Therefore, deviant owners come back to their initial decisions.
  - If a mass  $\varepsilon$  of owners stop participating in the market, then buyers expect them to be in proportions  $\varepsilon\pi$  1-owners and  $\varepsilon(1 - \pi)$   $q$ -owners. Thus,  $\pi(x)$  remains equal to  $\pi$  and the payoff maximization constraint is unchanged. Therefore, deviant owners come back to their initial decisions.
- The no-participation case (i.e.,  $(L_{f1}(x), L_1(x)) = (0, 0)$ ), in zone  $]x_a, +\infty[$  if  $k > \underline{k}$  and in zone  $]\hat{x}(k), +\infty[$  if  $k < \underline{k}$  is stable. Indeed we see that :

- If a mass  $\varepsilon$  of owners start selling on the informal market, then buyers will expect them to be in proportions  $\varepsilon\pi$  1-owners and  $\varepsilon(1 - \pi)$   $q$ -owners. Therefore,  $\pi(x) = \pi$ . The payoff maximization constraint is unchanged and deviant owners come back to their initial decisions.
- If a mass  $\varepsilon$  of owners start selling on the formal market, then the payoff maximization constraint is unchanged and deviant owners come back to their initial decisions.
- The no-registration but partial participation case (i.e.,  $(L_{f1}(x), L_1(x)) = (0, \alpha)$  with  $\alpha \in ]0, \pi[$ ), possible when  $\max(x_\alpha, \hat{x}(k)) < x < \bar{x}_\alpha$  with the payoff maximization constraint  $(y - xt - u) \left[ \frac{L_1(x)(1-q)}{L_1(x) + L_q(x)} + q \right] = R_a$ , is not stable, for the same reason as in the benchmark model.

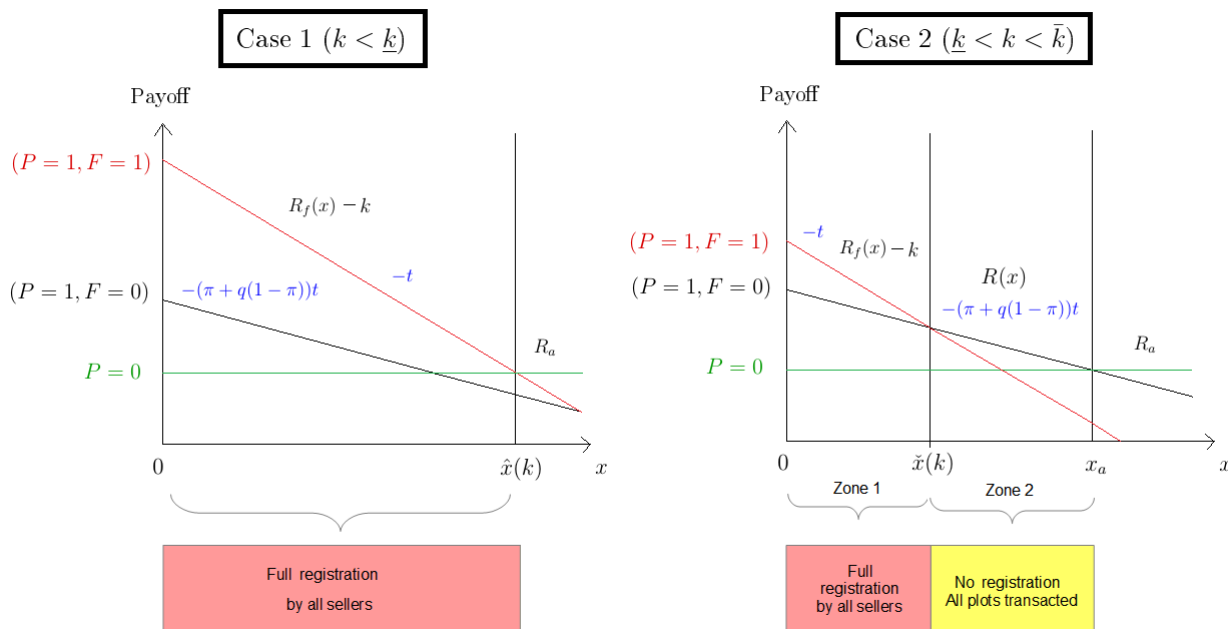
We select the only stable combination on each interval :

- When  $k > \underline{k}$ , we have :
  - Full registration and full participation on  $[0, \check{x}(k)[$
  - No formalization but full participation on  $]\check{x}(k), x_a[$
  - No participation on  $]x_a, +\infty[$
- When  $k \leq \underline{k}$ , we have :
  - Full registration and full participation on  $[0, \hat{x}(k)[$
  - No participation on  $]\hat{x}(k), +\infty[$

**Compatibility with equilibrium conditions** It is easy to verify that the configuration selected satisfies the 6 equilibrium conditions (8)-(12) when  $k > \underline{k}$  and when  $k \leq \underline{k}$ .

## 2.7.2 Payoffs of land owners

FIGURE 2.7 – Payoffs of land owners



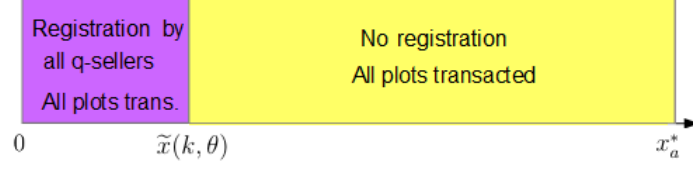
Note : This figure represents the equilibrium payoffs of sellers as a function of distance to the city center, their market participation and registration decisions when  $k < \bar{k}$  and when  $\bar{k} < k < \tilde{k}$ . The slopes of the payoff curves are indicated in blue.

## 2.7.3 Suboptimality of the competitive equilibrium in the registration model

To determine the optimal configuration, we compare the contributions to the surplus associated with each decision of 1- and  $q$ -owners. For a secure plot, an informal allocation contributes more to the surplus than a formal allocation (if  $k > 0$ ), because the formalization cost is avoided. An informal allocation is preferable over keeping the plot under agricultural use if and only if  $y - xt - u - R_a > 0$ , i.e.  $x < x_a^*$ . For an insecure plot, a formal allocation is preferable over an informal allocation if and only if  $y - xt - u - R_a - k > (\theta(1 - q) + q)(y - xt - u - R_a)$ , i.e.  $x < \tilde{x}(k, \theta) = \frac{1}{t} \left( y - \frac{k}{(1-q)(1-\theta)} - u - R_a \right)$ . An informal allocation is preferable over keeping the plot under agricultural use if and only if  $q(y - xt - u - R_a) \geq 0$ , i.e.  $x \leq x_a^*$ . Since  $\tilde{x}(k, \theta) < x_a^*$ , we do not need to compare the contribution of a formal allocation with that of a non-allocation (i.e., the plot remaining agricultural). The optimal allocation therefore consists of two zones : On  $[0, \tilde{x}(k, \theta)[$ , all  $q$ -plots are registered and allocated to a migrant whereas all 1-plots are allocated informally to a migrant. On  $]\tilde{x}(k, \theta), x_a^*]$ , all plots are allocated informally.

The optimal city has the structure depicted in Figure 2.8.

FIGURE 2.8 – Optimal city structure in the registration model



## 2.8 Appendix C - Trust model

### 2.8.1 Proof of Lemma 1

We reason by contradiction. Let's assume that, at a stable equilibrium, 1-sellers do not only sell to cousins, then they either (i) sell to both cousins and non-cousins or (ii) they sell only to non-cousins. To show that 1-sellers only sell to cousins, we sequentially show that (i) and (ii) cannot be true :

- If there is a stable equilibrium in which 1-sellers sell both to cousins and non-cousins, then we have  $\pi^c(x) > 0$  and  $\pi^{nc}(x) > 0$  and the payoff of 1-sellers is the same when selling to a cousin or a non-cousin, which means that :

$$\psi(x, u|C = c) = \psi(x, u|C = nc)$$

Given that we have, by definition :

$$\begin{cases} \psi(x, u|C = c) = \{\pi^c(x) + q(1 - \pi^c(x))\}(y - tx - u) \\ \psi(x, u|C = nc) = \{\pi^{nc}(x) + q(1 - \pi^{nc}(x))\}(y - tx - u) \end{cases}$$

the equality of payoffs implies  $\pi^c(x) = \pi^{nc}(x)$ . Then, the payoff of  $q$ -sellers selling to cousins is  $\psi(x, u|C = c) - J$  and the payoff of  $q$ -sellers selling to non-cousins is  $\psi(x, u|C = nc) = \psi(x, u|C = c)$ . Thus,  $q$ -sellers all prefer to sell to non-cousins and do so. Therefore,  $\pi^c(x) = 1$  (all sellers selling to cousins are 1-sellers), while  $\pi^{nc}(x) < 1$  (because 1-sellers only make up a limited proportion of the sellers selling to non-cousins). This contradicts  $\pi^c(x) = \pi^{nc}(x)$  and thus our initial assumption.

- If there is a stable equilibrium in which 1-sellers sell only to non-cousins, then we have  $\pi^{nc}(x) > \pi^c(x) = 0$  and the payoff of 1-sellers is strictly larger when selling to a non-cousin than when selling to a cousin, which means that :

$$\psi(x, u|C = nc) > \psi(x, u|C = c)$$



Then, the payoff of  $q$ -sellers selling to cousins is  $\psi(x, u|C = c) - J$  and the payoff of  $q$ -sellers selling to non-cousins is  $\psi(x, u|C = nc)$ , which is strictly larger than  $\psi(x, u|C = c) - J$ . Thus,  $q$ -sellers all prefer to sell to non-cousins and do so. Therefore, all sellers sell to non-cousins and  $\pi^{nc}(x) = \pi$ . A deviating 1-seller selling to a cousin would get a payoff of  $\{\pi + q(1 - \pi)\}(y - tx - u)$ , as the buyer would assume that a probability  $\pi$  for the seller to be a 1-seller. This payoff is exactly equal to  $\psi(x, u|C = nc)$ , so that the deviating seller would not come back to selling to a non-cousin and would increase  $\pi^c(x)$  to 1, thereby triggering a transition away from the equilibrium where 1-sellers sell only to cousins. Thus, this equilibrium would be unstable, which contradicts our initial assumption.

Both cases have led to a contradiction. Consequently, at a stable equilibrium, 1-sellers only sell to cousins.

## 2.8.2 Proof of Proposition 4 - Competitive equilibrium in the trust model

Here, we provide a more complete version of Proposition 4. Proposition 4 corresponds to the first case (low value of the social penalty) highlighted in the Extended Proposition 4.

### Extended Proposition 4

**Extended Proposition 4 :** Denoting the social penalty thresholds  $\underline{J} = \pi R_a \frac{1-q}{q}$  and  $\bar{J} = R_a \frac{1-q}{q}$ , and the zone boundary thresholds  $\underline{x}(J) = \frac{1}{t} \left( y - \frac{R_a + J}{\pi(1-q) + q} - u \right)$  and  $\bar{x}(J) = \frac{1}{t} (y - (R_a + J) - u)$ , there are five possible cases, depending on the magnitude of the cousinage penalty :<sup>37</sup>

- **Case 1 :  $J < \underline{J}$ .** The city boundary is at  $x_a^*$  and the city is organized in the three following zones, moving outward from the city center :
  - **Zone 1 (fully residential) :** On  $[0, \underline{x}(J)[$ , all landowners (irrespective of the tenure security level of their plot) participate in the land market and exclusively sell to cousins. The unique price in each location  $x$  is  $R^c(x) = [\pi + q(1 - \pi)](y - xt - u)$ .
  - **Zone 2 (mixed agricultural and residential, partial market participation of  $q$ -sellers) :** On  $]\underline{x}(J), \bar{x}(J)[$ , all 1-sellers and a share of  $q$ -sellers participate in the land market and exclusively sell to their respective cousins. The mass of  $q$ -sellers selling to cousins in  $x$  is  $L_q^c(x, J) = \frac{\pi(1-q)(y-xt-u)}{R_a + J - q(y-xt-u)} - \pi$ . The unique price in each location  $x$  is  $R^c(x) = R_a + J$ .
  - **Zone 3 (mixed agricultural/residential,  $q$ -sellers dropping out of the market) :** On  $]\bar{x}(J), x_a^*[$ , all 1-sellers participate in the land market and sell to their cousins,

37. Here we assume that  $y - \frac{R_a}{q} - u > 0$ , which is necessary to exclude unrealistic cases where risky plots never get sold under high values of  $J$ . It is a more restrictive assumption than our previous condition  $y - \frac{R_a}{\pi + q(1-\pi)} - u > 0$  for a non-degenerate city to exist under the benchmark model.

whereas all  $q$ -sellers keep their plots under agricultural use. The unique price in location  $x$  is  $R^c(x) = y - xt - u$ .

- **Case 2 :**  $J < J \leq \bar{J}$ . The city boundary is at  $x_a^*$  and the city is organized in four zones, moving outwards from the city center : (i) a zone where all 1-owners and  $q$ -owners sell to a cousin; (ii) a zone where all 1-owners sell to a cousin and all  $q$ -owners sell (a fraction of them selling to cousins and the rest to non-cousins); (iii) a zone where all 1-owners and a share of  $q$ -owners sell to their respective cousins; and (iv) a zone where all 1-owners sell to their cousins whereas  $q$ -owners do not participate in the land market.
- **Case 3 :**  $\pi(1 - q)(y - u) > J > \bar{J}$ . The city boundary is at  $x_a^*$  and the city is organized in four zones, moving outwards from the city center : (i) a zone where all 1-owners and  $q$ -owners sell to a cousin; (ii) a zone where all 1-owners sell to a cousin and all  $q$ -owners sell (a fraction selling to cousins and another fraction to non-cousins); (iii) a zone where all 1-owners sell to their cousins and  $q$ -owners all sell to non-cousins; and (iv) a zone where all 1-owners sell to their cousins, whereas  $q$ -owners do not participate in the land market.
- **Case 4 :**  $(1 - q)(y - u) > J > \pi(1 - q)(y - u)$  : The city structure is identical to Case 3, but without zone (i).
- **Case 5 :**  $J > (1 - q)(y - u)$  : The city structure is identical to Case 3, but without zones (i) and (ii).

#### Proof of Extended Proposition 4

For this proof, we denote  $L_1^c(x)$  the quantity of secure land sold to cousins,  $L_q^c(x)$  the quantity of insecure land sold to cousins and  $L^{nc}(x)$  the quantity of (insecure) land sold to non-cousins. Note that we have  $L_1^c(x) + L_q^c(x) + L^{nc}(x) = L_1(x) + L_q(x)$ .

To derive the competitive equilibrium, we study, in each  $x$ , all possible combinations of participation and cousinage decisions that 1- and  $q$ -owners may take to satisfy (15) subject to (16 and 17). We then study the stability of these combinations. In some locations, we will see that more than one combination is possible and stable. In that case, we select the Pareto-dominant combination, i.e. the combination that unambiguously benefits owners the most (as 1-owners and  $q$ -owners prefer the same combinations). We check that this configuration satisfies the equilibrium conditions (14)-(18).

**Sellers' participation and cousinage decisions and spatial city configuration** Given Lemmas 1 and 2, it is clear that the decisions taken by all sellers in location  $x$  can be uniquely

characterized by the triple  $(L_1^c(x), L_q^c(x), L^{nc}(x))$ . We distinguish the following situations :

- If  $(L_1^c(x), L_q^c(x), L^{nc}(x)) = (\pi, 1 - \pi, 0)$ , then, denoting  $\underline{x}(J) \equiv \frac{1}{t} \left( y - \frac{J}{\pi(1-q)} - u \right)$ , the payoff maximization constraint implies :

$$(L_1^c(x), L_q^c(x), L^{nc}(x)) = (\pi, 1 - \pi, 0) \Rightarrow (J > \underline{J} \text{ and } x < \underline{x}(J)) \text{ or } (J < \underline{J} \text{ and } x < \underline{x}(J))$$

- If  $(L_1^c(x), L_q^c(x), L^{nc}(x)) = (\pi, 0, 1 - \pi)$ , then, denoting  $\tilde{x}(J) \equiv \frac{1}{t} \left( y - \frac{J}{1-q} - u \right)$  and  $x_a^q = \frac{1}{t} \left( y - \frac{R_a}{q} - u \right)$ , the payoff maximization constraint implies :

$$(L_1^c(x), L_q^c(x), L^{nc}(x)) = (\pi, 0, 1 - \pi) \Rightarrow (J > \bar{J} \text{ and } \tilde{x}(J) < x < x_a^q).$$

- If  $(L_1^c(x), L_q^c(x), L^{nc}(x)) = (\pi, \alpha, 1 - \pi - \alpha)$  where  $\alpha \in ]0, 1 - \pi[$ , then the payoff maximization constraint implies  $L_q^c(x) = \frac{\pi(1-q)(y-xt-u)}{J} - \pi$  and :

$$\begin{aligned} (L_1^c(x), L_q^c(x), L^{nc}(x)) &= (\pi, \alpha, 1 - \pi - \alpha) \text{ where } \alpha \in ]0, 1 - \pi[ \\ &\Rightarrow (J > \bar{J} \text{ and } \tilde{x}(J) > x > \underline{x}(J)) \text{ or } (\bar{J} > J > \underline{J} \text{ and } x_a^q > x > \underline{x}(J)). \end{aligned}$$

- If  $(L_1^c(x), L_q^c(x), L^{nc}(x)) = (\pi, 0, 0)$ , then the payoff maximization constraint implies :

$$(L_1^c(x), L_q^c(x), L^{nc}(x)) = (\pi, 0, 0) \Rightarrow (J > \bar{J} \text{ and } x_a^* > x > x_a^q) \text{ or } (J < \bar{J} \text{ and } x_a^* > x > \bar{x}(J))$$

- If  $(L_1^c(x), L_q^c(x), L^{nc}(x)) = (\alpha, 0, 0)$  where  $\alpha \in ]0, \pi[$ , then it is easy to see that the payoff maximization constraint implies that the case is in fact not possible.

- If  $(L_1^c(x), L_q^c(x), L^{nc}(x)) = (0, 0, 0)$ , then the payoff maximization constraint implies :

$$(L_1^c(x), L_q^c(x), L^{nc}(x)) = (0, 0, 0) \Rightarrow x > x_a.$$

- If  $(L_1^c(x), L_q^c(x), L^{nc}(x)) = (\pi, \alpha, 0)$  where  $\alpha \in ]0, 1 - \pi[$ , then the payoff maximization constraint implies  $L_{q,S=1}^c(x) = \frac{\pi(1-q)(y_u-xt-u)}{R_a+J-q(y_u-xt-u)} - \pi$  and :

$$\begin{aligned} (L_1^c(x), L_q^c(x), L^{nc}(x)) &= (\pi, \alpha, 0) \text{ where } \alpha \in ]0, 1 - \pi[ \\ &\Rightarrow (\bar{J} > J > \underline{J} \text{ and } \bar{x}(J) > x > x_a^q) \text{ or } (\underline{J} > J \text{ and } \bar{x}(J) > x > \underline{x}(J)). \end{aligned}$$

- If  $(L_1^c(x), L_q^c(x), L^{nc}(x)) = (\pi, \alpha, \beta)$  where  $\alpha > 0, \beta > 0$  and  $\alpha + \beta \in ]0, 1 - \pi[$ , then the payoff maximization constraint implies that it is possible only on the singleton  $x = x_a^q$ . We discard this case of measure zero.

**Stability of the different configurations** Using the same approach as before, it can easily be shown that :

- All “corner” combinations (where all 1-owners in a given location adopt the same decisions, and all  $q$ -owners adopt the same decisions) are stable. As before, this is done by showing that a small enough deviation in participation and cousinage decisions does not change the strict ranking of owners’ decisions so that they return to their initially optimal decisions.
- We now show that the case  $(L_1^c(x), L_q^c(x), L^{nc}(x)) = (\pi, \alpha, 1 - \pi - \alpha)$  where  $\alpha \in ]0, 1 - \pi[$  is stable on  $]x(J), \bar{x}(J)[$  if  $J > \bar{J}$  (respectively on  $]x(J), x_a^q[$  if  $\bar{J} > J > \underline{J}$ ) :
  - If a mass  $\varepsilon$  of owners who used to sell to cousins stop selling (or start selling to non-cousins), buyers expect these deviant owners to include  $\varepsilon \frac{\pi}{\alpha + \pi}$  1-owners and  $\varepsilon \frac{\alpha}{\alpha + \pi}$   $q$ -owners. Therefore, the land price for transactions between cousins and the land price for transactions between non-cousins remain unaltered. All payoffs and the payoff maximization constraint are preserved, so that deviant owners come back to their initial decisions.
  - If a mass  $\varepsilon$  of owners who used to sell to non-cousins stop selling, land prices and thus payoffs remain unaltered. Therefore, deviant owners come back to their initial decisions.
  - If a mass  $\varepsilon$  of owners who used to sell to non-cousins start selling to cousins (those can only be  $q$ -owners), the land price for transactions between cousins is reduced from  $\left(\frac{\pi(1-q)}{\alpha + \pi} + q\right)(y - xt - u) - J$  (which is equal to  $q(y - xt - u)$  since  $q$ -owners are indifferent between selling to cousins and non-cousins) to  $\left(\frac{\pi(1-q)}{\alpha + \varepsilon + \pi} + q\right)(y - xt - u) - J$ . It is easy to see that the new price is lower than the former price, so that  $q$ -owners now strictly prefer selling to non-cousins, while 1-owners still prefer selling to cousins. Therefore, 1-owners do not change their decisions and some  $q$ -owners shift from selling to cousins to selling to non-cousins. This cumulative shift lasts until the benefit obtained by  $q$ -owners when selling to cousins becomes equal to their benefit when selling to non-cousins. At this point, we are back to the initial combination of owners’ decisions.
- The case  $(L_1^c(x), L_q^c(x), L^{nc}(x)) = (\pi, \alpha, 0)$  for  $\alpha \in ]0, 1 - \pi[$  is stable on  $]x_a^q, \bar{x}(J)[$  if  $\bar{J} > J > \underline{J}$  and on  $]x(J), \bar{x}(J)[$  if  $\underline{J} > J$  :
  - If a mass  $\varepsilon$  of owners stop selling to cousins, then buyers assume that deviant owners include  $\varepsilon \frac{\pi}{\alpha + \pi}$  1-owners and  $\varepsilon \frac{\alpha}{\alpha + \pi}$   $q$ -owners. Therefore, the price of land transacted between cousins is unaltered, payoffs are preserved and deviant owners come back to their initial decisions.
  - If a mass  $\varepsilon$  of owners starts selling to non-cousins, payoffs are unaltered and they come back to their initial decisions.

- If a mass  $\varepsilon$  of owners starts selling to cousins, then they must be  $q$ -owners as all 1-owners are already selling. The price of land transacted between cousins is reduced from  $\left(\frac{\pi(1-q)}{\alpha+\pi} + q\right)(y - xt - u) - J$  (which is equal to  $R_a$ ) to  $\left(\frac{\pi(1-q)}{\alpha+\varepsilon+\pi} + q\right)(y - xt - u) - J$ , which is strictly below the agricultural rent  $R_a$ . Therefore, although 1-owners still prefer selling to cousins,  $q$ -owners now strictly prefer keeping their land under agricultural use. Consequently, 1-owners do not change their decisions and some  $q$ -owners shift from selling to cousins to keeping their land under agricultural use. This cumulative shift lasts until the benefit obtained by  $q$ -owners when selling to cousins becomes equal to the agricultural rent. At this point, we are back to the initial combination of owners' decisions.

**Selection of the Pareto-dominant configuration** In the periphery of the city, several stable combinations are possible, depending on the relative size of  $J$  and  $R_a$ . These combinations include the no-participation case and either the partial or the total participation case. As before, we selected the situation unambiguously preferred by owners. We therefore obtain the following city structure, depending on  $J$  :

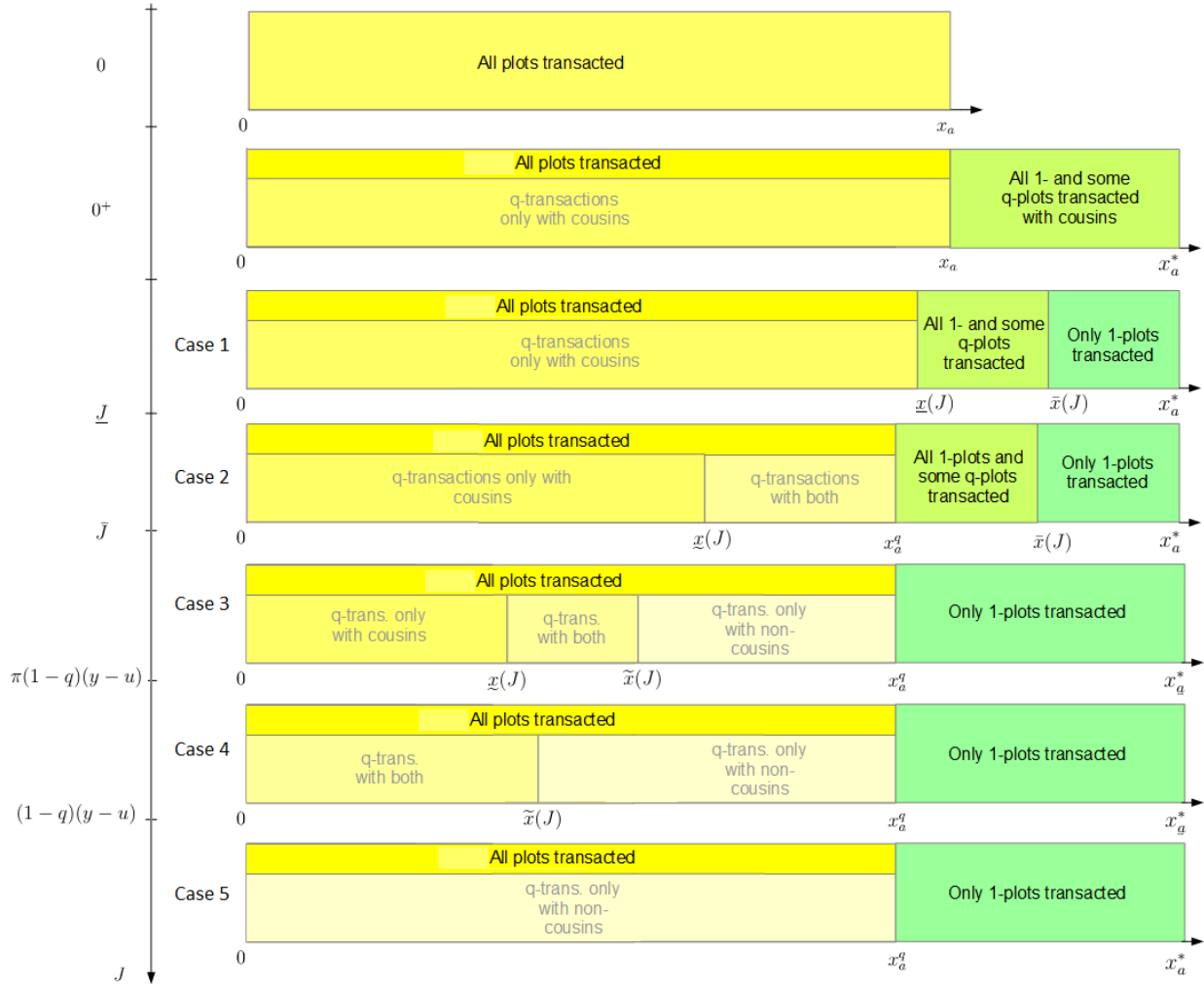
- If the cousinage penalty  $J$  is low, i.e.  $J < \underline{J}$ , then the city is organized in three zones :
  - Zone 1 : On  $[0, \underline{x}(J)[$ , all owners participate in the market and sell their plot to a cousin. The price on that segment is  $R^c(x) = [\pi + q(1 - \pi)](y - tx - u)$ .
  - Zone 2 : On  $[\underline{x}(J), \bar{x}(J)[$ , all 1-owners and a share of  $q$ -owners sell their plot to cousins. The number of  $q$ -owners selling their plot in  $x$  is  $L_q^c(x) = \frac{\pi(1-q)(y-xt-u)}{R_a+J-q(y-xt-u)} - \pi$ . The price is  $R^c(x) = R_a + J$ .
  - Zone 3 : On  $[\bar{x}(J), x_a^*[$ , all 1-owners sell their plot to cousins, while all  $q$ -owners keep their plot for agricultural use. The price is  $R^c(x) = y - xt - u$ .
  - The city boundary is at  $x_a^* = \frac{1}{t} [y - R_a - u]$ .
- If the cousinage penalty  $J$  is intermediate, i.e.  $\underline{J} < J < \bar{J}$ , then the city is organized in four zones :
  - Zone 1 : On  $[0, \underline{x}(J)[$ , all owners participate in the market and sell their plot to a cousin. The price on that segment is  $R^c(x) = [\pi + q(1 - \pi)](y - tx - u)$ .
  - Zone 2 : On  $[\underline{x}(J), x_a^q[$ , all owners participate in the market. 1-owners only sell to cousins, while  $q$ -owners sell both to cousins and non-cousins. The prices on that segment are  $R^c(x) = q(y - tx - u) + J$  and  $R^{nc}(x) = q(y_u - xt - u)$ .
  - Zone 3 : On  $[x_a^q, \bar{x}(J)[$ , all 1-owners and a share of  $q$ -owners sell their plot. They all sell to cousins. The number of  $q$ -owners selling their plot in  $x$  is  $L_q^c(x) = \frac{\pi(1-q)(y-xt-u)}{R_a+J-q(y-xt-u)} - \pi$ . The price is  $R^c(x) = R_a + J$ .
  - Zone 4 : On  $[\bar{x}(J), x_a^*[$ , all 1-owners sell their plot to cousins, while all  $q$ -owners keep their plot for agricultural use. The price is  $R^c(x) = y - xt - u$ .

- The city boundary is at  $x_a^* = \frac{1}{t} [y - R_a - u]$ .
- If the cousinage penalty  $J$  is high, i.e.  $\bar{J} < J$ , then the city is organized in four zones :
  - Zone 1 : On  $[0, \underline{x}(J)[$ , all owners participate in the market and sell their plot to a cousin. The price on that segment is  $R^c(x) = [\pi + q(1 - \pi)](y - xt - u)$ .
  - Zone 2 : On  $[\underline{x}(J), \tilde{x}(J)[$ , all owners participate in the market. 1-owners only sell to cousins, while  $q$ -owners sell both to cousins and non-cousins. The prices on that segment are  $R^c(x) = q(y - xt - u) + J$  and  $R^{nc}(x) = q(y_u - xt - u)$ .
  - Zone 3 : On  $[\tilde{x}(J), x_a^q[$ , all owners participate in the market. 1-owners only sell to cousins, while  $q$ -owners only sell to non-cousins. The price of secure plots on that segment is  $R^c(x) = y - xt - u$  and the price of insecure plots is  $R^{nc}(x) = q(y - xt - u)$ .
  - Zone 4 : On  $]x_a^q, x_a^*[$ , all 1-owners sell their plot to cousins, while all  $q$ -owners keep it for agricultural use. The price is  $R^c(x) = y - xt - u$ .
- The city boundary is at  $x_a^* = \frac{1}{t} [y - R_a - u]$ .

**Compatibility with equilibrium conditions** It is easy to show that the equilibrium selected on each interval of  $J$  satisfies equilibrium conditions (14)-(18).

Figure 2.9 summarizes the results of the Extended Proposition 4.

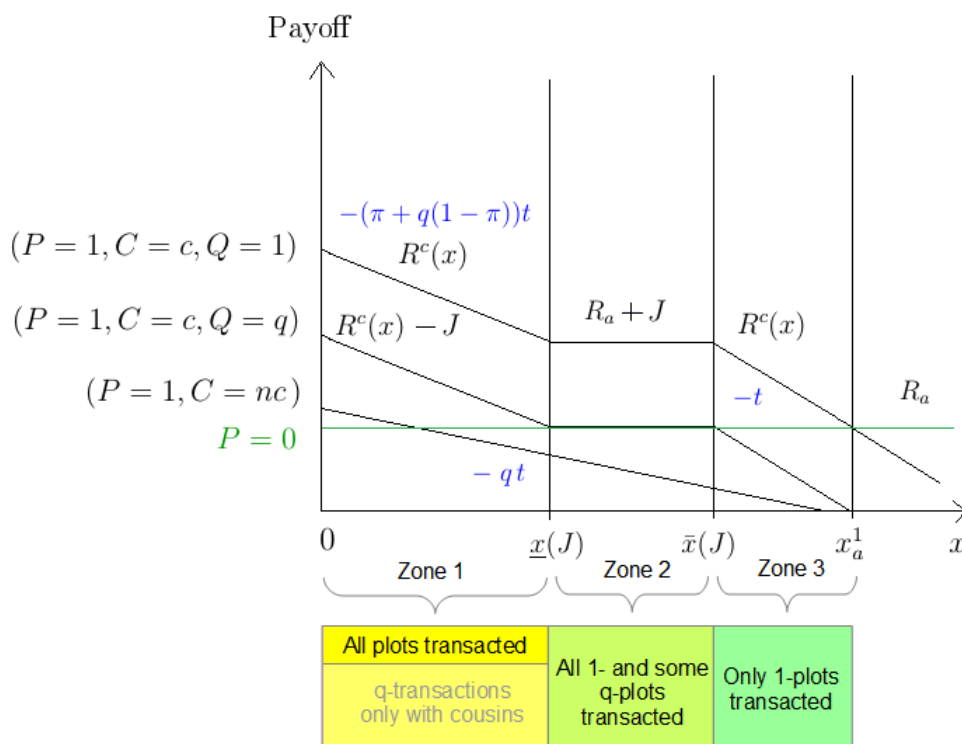
FIGURE 2.9 – City structure in the trust model



Note : This figure represents the city structure as a function of distance to the city center and for different levels of the social penalty ( $J$ ).

### 2.8.3 Payoffs of land owners

FIGURE 2.10 – Payoffs of land owners



Note : This figure represents the equilibrium payoffs of sellers as a function of distance to the city center, their market participation and ethnic matching decisions when  $J < \underline{J}$ . The slopes of the payoff curves are indicated in blue.

### 2.8.4 Proof of Proposition 5

It is easy to show that  $\Phi$  decreases with  $J$  on  $[0, \bar{J}]$ . First, note that, as long as  $x < x_a^*$ , the surplus is increased if a plot is sold rather than kept under agricultural use. This is because in each  $x$ , the contribution to the (net) surplus of a secure plot is either  $y - xt - u - R_a > 0$  if the plot is sold (to a cousin or a non-cousin) or 0 (if it is kept under agricultural use). Similarly, the (net) contribution to the surplus of an insecure plot is either  $(q + \theta(1 - q))(y - xt - u - R_a) > 0$  or 0. Second, note that, in each  $x$ , the share of transacted plots decreases with  $J$ , for  $J > 0$ . This is because the numbers of transacted secure plots on  $[0, x_a^*]$  and the number of transacted insecure plots on  $[0, x_a^q]$  do not vary with  $J$ , whereas the number of insecure plots transacted on  $[x_a^q, x_a^*]$  decreases with  $J$ . To see this, note that the number of insecure plots sold in  $x \in [x_a^q, x_a^*]$  is :



$$\begin{cases} \frac{\pi(1-q)(y-xt-u)}{R_a+J-q(y-xt-u)} - \pi & \text{if } 0 < \frac{\pi(1-q)(y-xt-u)}{R_a+J-q(y-xt-u)} - \pi < 1 \\ 0 & \text{if } \frac{\pi(1-q)(y-xt-u)}{R_a+J-q(y-xt-u)} - \pi \leq 0 \\ 1 & \text{if } \frac{\pi(1-q)(y-xt-u)}{R_a+J-q(y-xt-u)} - \pi \geq 1, \end{cases}$$

where  $\frac{\pi(1-q)(y-xt-u)}{R_a+J-q(y-xt-u)} - \pi$  clearly decreases with  $J$ .

Furthermore, the surplus under the trust model is strictly greater than the surplus in the benchmark model when  $J \rightarrow 0^+$ . Indeed, in that case, the equilibrium city in the trust model replicates the equilibrium city in the benchmark model, while adding an additional built-up zone  $[x_a, x_a^*]$ . Eventually, when  $J \geq \bar{J}$ , the surplus is independent on  $J$  and equal to :

$$\Phi = \pi \int_0^{x_a^*} (y-xt-u-R_a)dx + (q+\theta(1-q))(1-\pi) \int_0^{x_a^q} (y-xt-u-R_a)dx$$

which is strictly below the surplus of the benchmark model.<sup>38</sup>

## 2.8.5 Proof of Proposition 6

Let us define  $\Omega(k, J) \equiv \Lambda(k) - \Phi(J)$ . It is clear that  $\psi$  is a continuous function of  $k$  and  $J$ . It decreases with  $k$  and increases with  $J$ . Additionally, it is clear that  $\Omega(0, +\infty) > 0$ ,  $\Omega(0, 0^+) > 0$ ,  $\Omega(+\infty, 0^+) < 0$  and  $\Omega(+\infty, +\infty) \geq 0$ .

$\Omega(0, 0^+) > 0$ ,  $\Omega(+\infty, 0^+) = \Omega(\bar{k}, 0^+) < 0$  and  $\Omega(., 0^+)$  increasing implies that there exists  $\hat{k}(\theta) \in ]0, \bar{k}]$  such that  $\Omega(\hat{k}(\theta), 0^+) = 0$ .

For all  $k \in [0, \hat{k}(\theta)[$ , we have  $\Omega(k, 0^+) > 0$ . Thus,  $\Omega(k, J) > 0$  for all  $J$  and the registering system is always better than the social norm (i.e., whatever the intensity of the social norm).

For all  $k \in ]\hat{k}(\theta), +\infty[$ , we have  $\Omega(k, 0^+) < 0$ ,  $\Omega(k, +\infty) > 0$  (because  $\Omega(+\infty, +\infty) > 0$ ) and  $\Omega(k, .)$  is increasing. Thus, there exists  $\tilde{J}(k, \theta)$  such that  $\Omega(k, J) < 0$  for all  $J < \tilde{J}(k, \theta)$  and  $\Omega(k, J) > 0$  for all  $J > \tilde{J}(k, \theta)$ . It is clear that  $\tilde{J}$  is an increasing function of  $k$ , as  $\Omega(., .)$  increases with  $k$ , and that  $\tilde{J}$  is constant for  $k > \bar{k}$ .

Consequently, the registering system is preferable to the social norm only if the social penalty is high enough and the social norm is preferable if the social penalty is low enough.

38. Because  $\Phi - \Gamma = -\frac{(1-\pi)\pi(1-q)^2R_a^2(q(\pi+q(1-\pi))+(1-q)(\pi+2(1-\pi)q)\theta)}{2q^2(\pi+q(1-\pi))^2t} < 0$ .

## 2.9 Appendix D - Hybrid model

### 2.9.1 Proof of Proposition 7 - Competitive equilibrium in the hybrid model

Similarly to the previous versions of the model, to derive the competitive equilibrium, we study, in each  $x$ , all possible combinations of participation, registration and cousinage decisions that 1- and  $q$ -owners may take to satisfy (20) subject to (21, 22 and 23). We then study their stability. In some locations, we will see that more than one combination is possible and stable. In that case, we select the Pareto-dominant combination that unambiguously benefits owners the most (we will see that 1-owners and  $q$ -owners prefer the same combinations).<sup>39</sup> We then verify that the selected configuration satisfies the equilibrium conditions (19)-(24).

**Determination of sellers' possible participation and cousinage decisions** Given Lemmas 1 and 2, which still hold in this hybrid version of the model, it is clear that the decisions taken by all sellers in location  $x$  can be uniquely characterized by the 5-uple of variables  $(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x))$ . We therefore can have the following combinations :

- If  $(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (0, 0, \pi, 1 - \pi, 0)$ , the payoff maximization constraint has different implications depending on the values of  $k$  and  $J$  :
- If  $k > R_a \frac{1-q}{q}$  :

$$\begin{aligned} (L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) &= (0, 0, \pi, 1 - \pi, 0) \\ \Rightarrow (\pi k > J > \pi R_a \frac{1-q}{q} \text{ and } \underline{x}(J) > x > \hat{x}(k, J)) \\ &\text{or } (\pi R_a \frac{1-q}{q} > J \text{ and } \underline{x}(J) > x > \hat{x}(k, J)) \end{aligned}$$

- If  $R_a \frac{1-q}{q} > k > \underline{k}$  :

$$\begin{aligned} (L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) &= (0, 0, \pi, 1 - \pi, 0) \\ \Rightarrow (k(\pi(1-q) + q) - R_a(1-q)(1-\pi) > J \text{ and } \underline{x}(J) > x > \hat{x}(k, J)) \end{aligned}$$

- If  $\underline{k} > k$  :

$$(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (0, 0, \pi, 1 - \pi, 0) \text{ is impossible.}$$

- If  $(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (0, 0, \pi, 0, 1 - \pi)$ , then the implications of the payoff maximization constraint also depends on  $k$  and  $J$ . Denoting  $\ddot{x}(k) \equiv \frac{1}{t} \left( y - \frac{k}{1-q} - u \right)$ , these implications are :

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39. We assume, without changing the model's main results, that  $\bar{k} > R_a \frac{1-q}{\pi q}$ , which allows to reduce the number of possible cases to be studied.

— If  $k > R_a \frac{1-q}{q}$  :

$$(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (0, 0, \pi, 0, 1 - \pi)$$

$$\Rightarrow (J > k \text{ and } x_a^q > x > \check{x}(k)) \text{ or } (k > J > R_a \frac{1-q}{q} \text{ and } x_a^q > x > \tilde{x}(J))$$

— If  $k < R_a \frac{1-q}{q}$  :

$$(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (0, 0, \pi, 0, 1 - \pi) \text{ is impossible.}$$

— If  $(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (\pi, 0, 0, 0, 1 - \pi)$ , then the payoff maximization constraint implies that this case is impossible.

— If  $(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (\pi, 1 - \pi, 0, 0, 0)$ , then the payoff maximization constraint implies :

— If  $k > \underline{k}$  :

$$(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (\pi, 1 - \pi, 0, 0, 0) \Rightarrow \check{x}(k) > x$$

— If  $k < \underline{k}$  :

$$(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (\pi, 1 - \pi, 0, 0, 0) \Rightarrow \hat{x}(k) > x.$$

— If  $(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (0, 1 - \pi, \pi, 0, 0)$ , the payoff maximization constraint implies :

— If  $k > R_a \frac{1-q}{q}$  :

$$(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x))$$

$$= (0, 1 - \pi, \pi, 0, 0) \Rightarrow (J > k \text{ and } \check{x}(k) > x)$$

— If  $k < R_a \frac{1-q}{q}$  :

$$(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x))$$

$$= (0, 1 - \pi, \pi, 0, 0) \Rightarrow (J > k \text{ and } \hat{x}(k) > x).$$

— If  $(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (0, 0, 0, 0, 0)$ , then the payoff maximization constraint implies :

$$(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (0, 0, 0, 0, 0)$$

$$\Rightarrow (k > \underline{k} \text{ and } x > x_a) \text{ or } (k < \underline{k} \text{ and } x > \hat{x}(k)).$$

— If  $(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (0, \beta, \pi, 1 - \pi - \beta, 0)$  where  $\beta \in ]0, 1 - \pi[$ , then the payoff maximization constraint implies :

— If  $k > R_a \frac{1-q}{q}$  :

$$(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (0, \beta, \pi, 1 - \pi - \beta, 0) \quad \text{where } \beta \in ]0, 1 - \pi[ \\ \Rightarrow (\pi k > J \text{ and } \hat{x}(k, J) > x) \text{ or } (k > J > \pi k \text{ and } \hat{x}(k) > x)$$

— If  $\underline{k} < k < R_a \frac{1-q}{q}$  :

$$(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (0, \beta, \pi, 1 - \pi - \beta, 0) \text{ where } \beta \in ]0, 1 - \pi[ \\ \Rightarrow ((\pi(1-q) + q)k - R_a(1-\pi)(1-q) > J \text{ and } \hat{x}(k, J) > x) \\ \text{or } (k > J > (\pi(1-q) + q)c - R_a(1-\pi)(1-q) \text{ and } \hat{x}(k) > x)$$

— If  $k < \underline{k}$  :

$$(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (0, \beta, \pi, 1 - \pi - \beta, 0) \text{ where } \beta \in ]0, 1 - \pi[ \\ \Rightarrow (J < k \text{ and } \hat{x}(k) > x).$$

— If  $(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (0, \beta, \pi, 0, 1 - \pi - \beta)$  where  $\beta \in ]0, 1 - \pi[$ , then the payoff maximization constraint implies that it is only possible on the singleton  $x = \hat{x}(k)$ . As this case has measure zero, we disregard it.

— If  $(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (0, 0, \pi, 1 - \pi - \beta, \beta)$  where  $\beta \in ]0, 1 - \pi[$ , then the payoff maximization constraint implies :

— If  $\pi k > R_a \frac{1-q}{q}$  :

$$(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (0, 0, \pi, 1 - \pi - \beta, \beta) \text{ where } \beta \in ]0, 1 - \pi[ \\ \Rightarrow (k > J > \pi k \text{ and } \tilde{x}(J) > x > \hat{x}(k)) \\ \text{or } (\pi k > J > R_a \frac{1-q}{q} \text{ and } \tilde{x}(J) > x > \underline{x}(J)) \\ \text{or } (R_a \frac{1-q}{q} > J > \pi R_a \frac{1-q}{q} \text{ and } x_a^q > x > \underline{x}(J))$$

— If  $k > R_a \frac{1-q}{q} > \pi k$  :

$$(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (0, 0, \pi, 1 - \pi - \beta, \beta) \text{ where } \beta \in ]0, 1 - \pi[ \\ \Rightarrow (k > J > R_a \frac{1-q}{q} \text{ and } \tilde{x}(J) > x > \hat{x}(k)) \\ \text{or } (R_a \frac{1-q}{q} > J > \pi k \text{ and } x_a^q > x > \hat{x}(k)) \\ \text{or } (\pi k > J > \pi R_a \frac{1-q}{q} \text{ and } x_a^q > x > \underline{x}(J))$$

— If  $R_a \frac{1-q}{q} > k$  :

$$(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (0, 0, \pi, 1 - \pi - \beta, \beta)$$

where  $\alpha \in ]0, 1 - \pi[$  is impossible.

— If  $(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (\alpha, 0, \pi - \alpha, 1 - \pi - \beta, \beta)$  where  $\alpha \in ]0, \pi[$  and  $\beta \in ]0, 1 - \pi[$ , then the payoff maximization constraint implies that this case is possible on at most one singleton. We disregard this case because it is of measure zero.

— If  $(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (0, 0, \pi, 0, 0)$ , then the payoff maximization constraint implies :

— If  $k > R_a \frac{1-q}{q}$  :

$$(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (0, 0, \pi, 0, 0)$$

$$\Rightarrow (J > R_a \frac{1-q}{q} \text{ and } x_a^* > x > x_a^q) \text{ or } (R_a \frac{1-q}{q} > J \text{ and } x_a^* > x > \bar{x}(J))$$

— If  $k < R_a \frac{1-q}{q}$  :

$$(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (0, 0, \pi, 0, 0)$$

$$\Rightarrow (J > k \text{ and } x_a^* > x > \hat{x}(k)) \text{ or } (k > J \text{ and } x_a^* > x > \bar{x}(J)).$$

— If  $(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (0, 0, \pi, \beta, 0)$  where  $\beta \in ]0, 1 - \pi[$ , denoting  $J_{aux} = (k(\pi(1-q) + q) - R_a(1-\pi)(1-q))$ , then the payoff maximization constraint implies :

— If  $k > R_a \frac{1-q}{q}$  :

$$(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (0, 0, \pi, \beta, 0) \text{ where } \beta \in ]0, 1 - \pi[$$

$$\Rightarrow (R_a \frac{1-q}{q} > J > \pi R_a \frac{1-q}{q} \text{ and } \bar{x}(J) > x > x_a^q)$$

$$\text{or } (\pi R_a \frac{1-q}{q} > J \text{ and } \bar{x}(J) > x > \underline{x}(J))$$

— If  $\underline{k} < k < R_a \frac{1-q}{q}$  :

$$(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (0, 0, \pi, \beta, 0) \text{ where } \beta \in ]0, 1 - \pi[$$

$$\Rightarrow (k > J > J_{aux} \text{ and } \bar{x}(J) > x > \hat{x}(k))$$

$$\text{or } J_{aux} > J \text{ and } \bar{x}(J) > x > \underline{x}(J))$$

- If  $k < \underline{k}$  :
  - $(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (0, 0, \pi, \beta, 0)$  where  $\beta \in ]0, 1 - \pi[$
  - $\Rightarrow (k > J > 0 \text{ and } \bar{x}(J) > x > \hat{x}(k)).$
- In all other combinations of decisions where some  $q$ -owners participate in the market (proportion  $L_q^c(x) + L^{nc}(x) + L_{fq}(x) \in ]0, 1 - \pi[$ ) and all 1-owners participate in the informal market ( $L_1^c(x) + L_{f1}(x) = \pi$ ), the payoff maximization constraint implies that the corresponding interval for  $x$  is reduced to a singleton or the empty set.
- The payoff maximization constraint implies that the six following cases are reduced to a singleton or the empty set :
  - $(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (\alpha, 0, \pi - \alpha, 1 - \pi, 0)$  where  $\alpha \in ]0, \pi[$
  - $(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (\alpha, 0, \pi - \alpha, 0, 1 - \pi)$  where  $\alpha \in ]0, \pi[$
  - $(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (\alpha, \beta, \pi - \alpha, 1 - \pi - \beta, 0)$  where  $\alpha \in ]0, \pi[$  and  $\beta \in ]0, 1 - \pi[$
  - $(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (\alpha, \beta, \pi - \alpha, 0, 1 - \pi - \beta)$  where  $\alpha \in ]0, \pi[$  and  $\beta \in ]0, 1 - \pi[$
  - $(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (\pi, \beta, 0, 0, 1 - \pi - \beta)$  where  $\beta \in ]0, 1 - \pi[$
  - 1-sellers do not participate in the market but  $q$ -sellers do.
  - $q$ -owners do not participate in the market and 1-owners participate, at least partially, with cousinage decisions different from the cases previously analyzed.

**Stability of the equilibria** Using the same approach as before, it can easily be shown that :

- All “corner” combinations (where all 1-owners in a given location adopt the same decisions, and all  $q$ -owners adopt the same decisions) are stable. As before, this is done by showing that a small enough deviation in participation and cousinage decisions does not change the strict ranking of owners’ decisions so that they return to their initially optimal decisions.
- The case  $(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (0, \beta, \pi, 1 - \pi - \beta, 0)$  where  $\beta \in ]0, 1 - \pi[$  is stable :
  - If a mass  $\varepsilon$  of owners stop selling to cousins (i.e. they start formalizing, or they start selling to non-cousins, or they stop selling altogether), then buyers assume that deviant owners include  $\varepsilon \frac{\pi}{1 - \beta}$  1-owners and  $\varepsilon \frac{1 - \pi - \beta}{1 - \beta}$   $q$ -owners. Therefore, the price of land transacted between cousins is unaltered, payoffs are preserved and deviant owners come back to their initial decisions.
  - If a mass  $\varepsilon$  of owners start selling to cousins (i.e. if a mass  $\varepsilon$  of  $q$ -owners stops

formalizing), then buyers assume that deviant owners include only  $q$ -owners, as 1-owners were already all selling to cousins. Therefore, the price of land transacted between cousins is reduced and it becomes strictly more attractive for  $q$ -owners to sell after registration than to sell informally to cousins (while it remains more attractive for 1-owners to sell informally to cousins, because they do not face the social penalty). Therefore, the mass of  $q$ -owners selling informally to cousins decreases in favor of the mass of  $q$ -owners selling after registration until  $q$ -owners become indifferent between the two options. We are back to the initial configuration.

- Other deviations to owners' behaviors (e.g. when a mass  $\varepsilon$  of owners stop formalizing and sell to non-cousins) do not affect land prices (in our example, it is  $q$ -owners who start to sell to non-cousins, which does not affect the price of informal land traded between non-cousins). Because land prices are not affected, these deviations do not affect the ranking of payoffs and the deviations are reversed back to the initial configuration.
- The case  $(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (0, 0, \pi, \beta, 1 - \pi - \beta)$  where  $\beta \in ]0, 1 - \pi[$  is unstable (the proof is essentially the same as in previous sections and is available upon request).
- The case  $(L_{f1}(x), L_{fq}(x), L_1^c(x), L_q^c(x), L^{nc}(x)) = (0, 0, \pi, \beta, 0)$  where  $\beta \in ]0, 1 - \pi[$  is stable (the proof is the same as in the previous sections and is available upon request).

The stable configurations are presented in Figures 2.11, 2.12 and 2.13 for all possible combinations of  $k$  and  $J$  values. In those figures, we indicate with “1 :” and “ $q$  :” the decision of 1-owners and  $q$ -owners respectively, where “ $C = c$ ” and “ $C = nc$ ” refer to their decision to sell informally to cousins and non-cousins respectively, “ $f$ ” refers to registering and participating in the market, “no sale” refers to staying out of the market, and “partial” qualifies any of the above decisions to indicate that only a fraction of 1-owners or  $q$ -owners take that decision. For instance, on the first graph of Figure 2.11, “1 :  $C = c, q : C = nc$ ” indicates that all 1-owners informally participate in the market and sell to cousins and all  $q$ -owners informally participate in the market and sell to non-cousins.

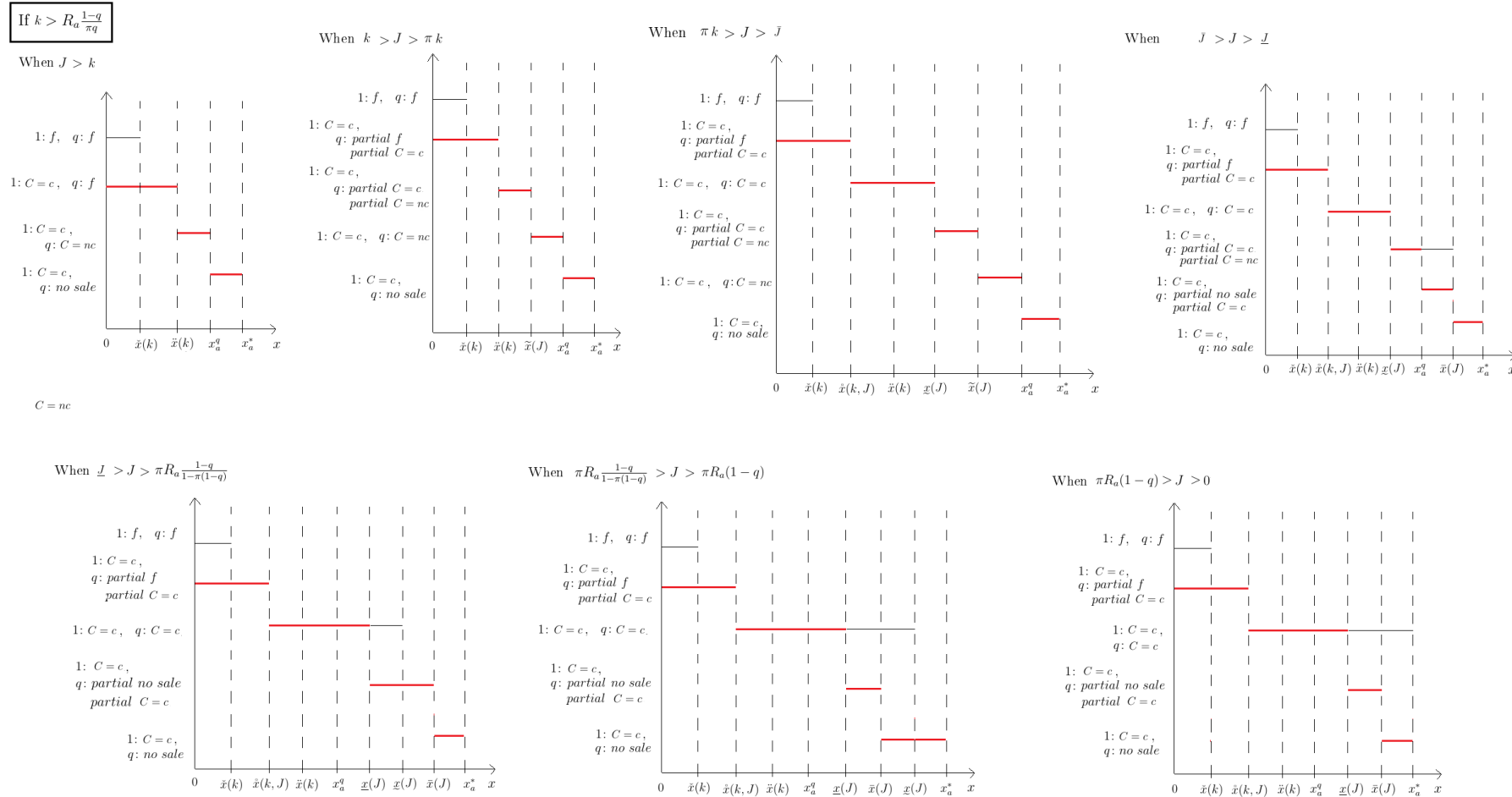
**Selection of the Pareto-dominant configurations** When several stable configurations are possible for given values of  $J$  and  $k$ , we select the one that benefits owners the most (as 1-owners and  $q$ -owners prefer the same combinations). The Pareto-dominant configuration is highlighted in red for each  $k$  and  $J$  value. For example, when  $k > R_a \frac{1-q}{\pi q}$  and  $\underline{J} > J > \pi R_a \frac{1-q}{1-\pi(1-q)}$  (i.e. bottom left graph in Figure 2.11), there are two possible configurations on  $x \in [0, \check{x}(k)]$ , one in which all 1-owners register their plot and one in which they sell informally. They prefer the second configuration where they sell informally, because it allows them to avoid incurring the registration cost.

**Compatibility with equilibrium conditions** It is easy to verify that the stable and Pareto-dominant configuration satisfies the 6 equilibrium conditions (19)-(24).

We present the spatial structure of the city for all values of  $k$  and  $J$  on Figures 2.14, 2.15, 2.16 and 2.17.

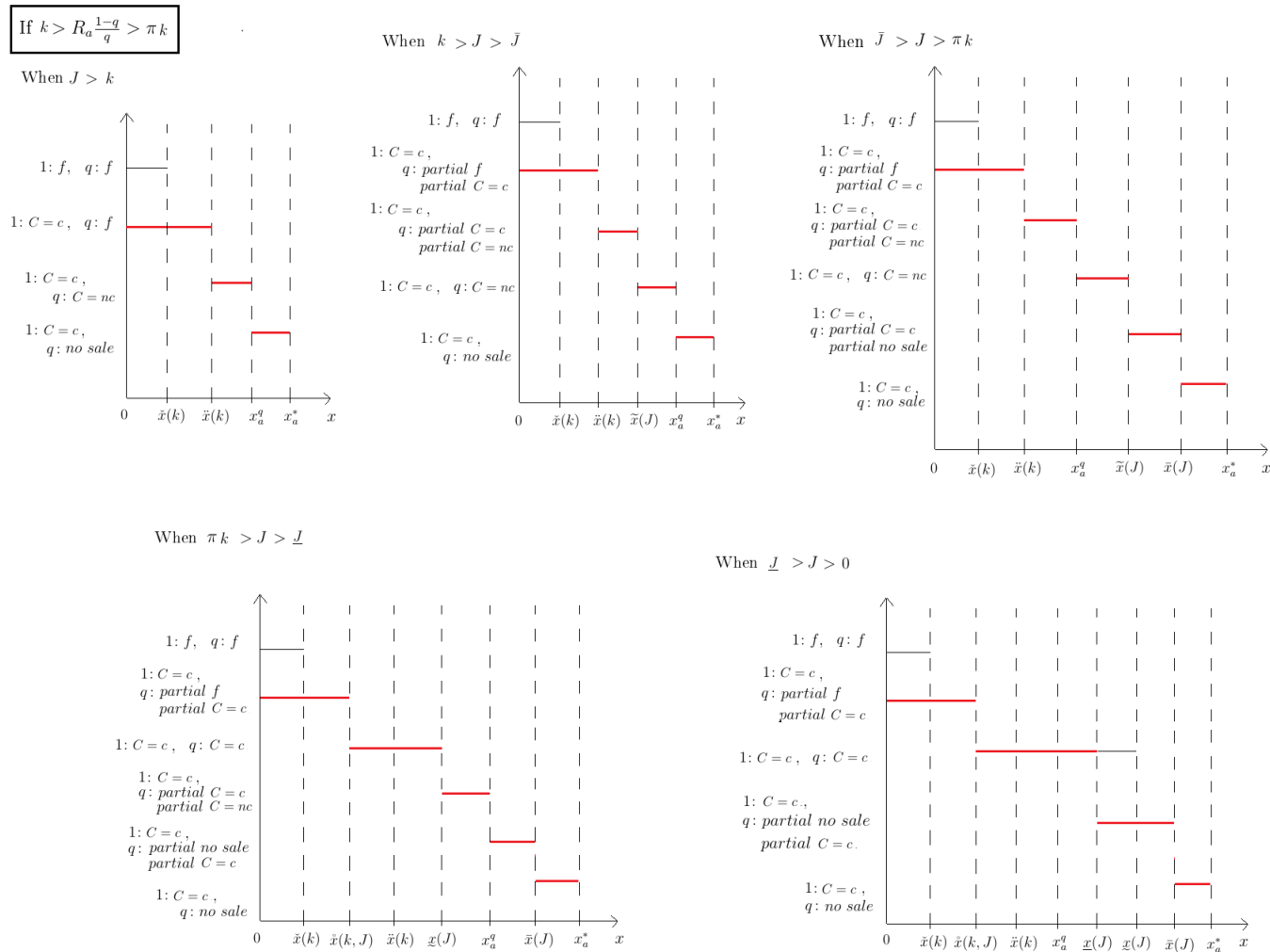


FIGURE 2.11 – Hybrid model equilibria (high registration cost)



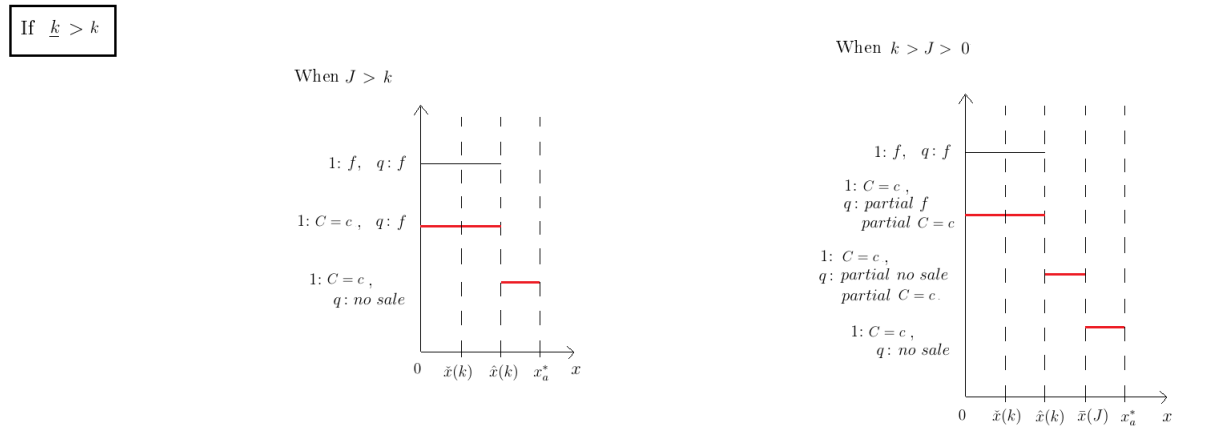
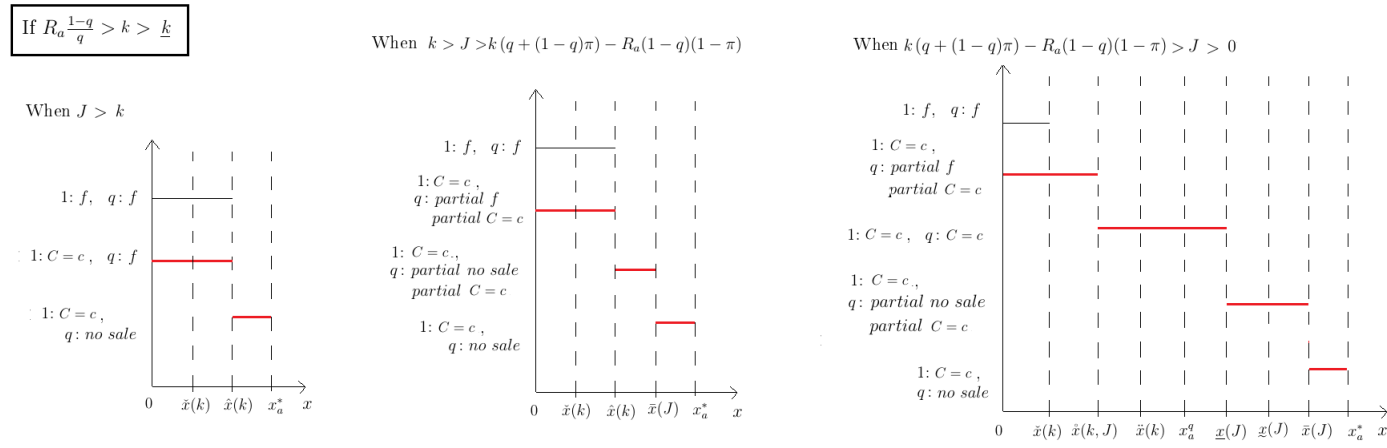
Note : This figure represents the stable equilibria for varying values of the registration cost  $k$  and the social penalty  $J$ . In case of multiple equilibria, the dominant equilibria are highlighted in red. Non participation in the market is not represented.

FIGURE 2.12 – Hybrid model equilibria (intermediate registration cost)



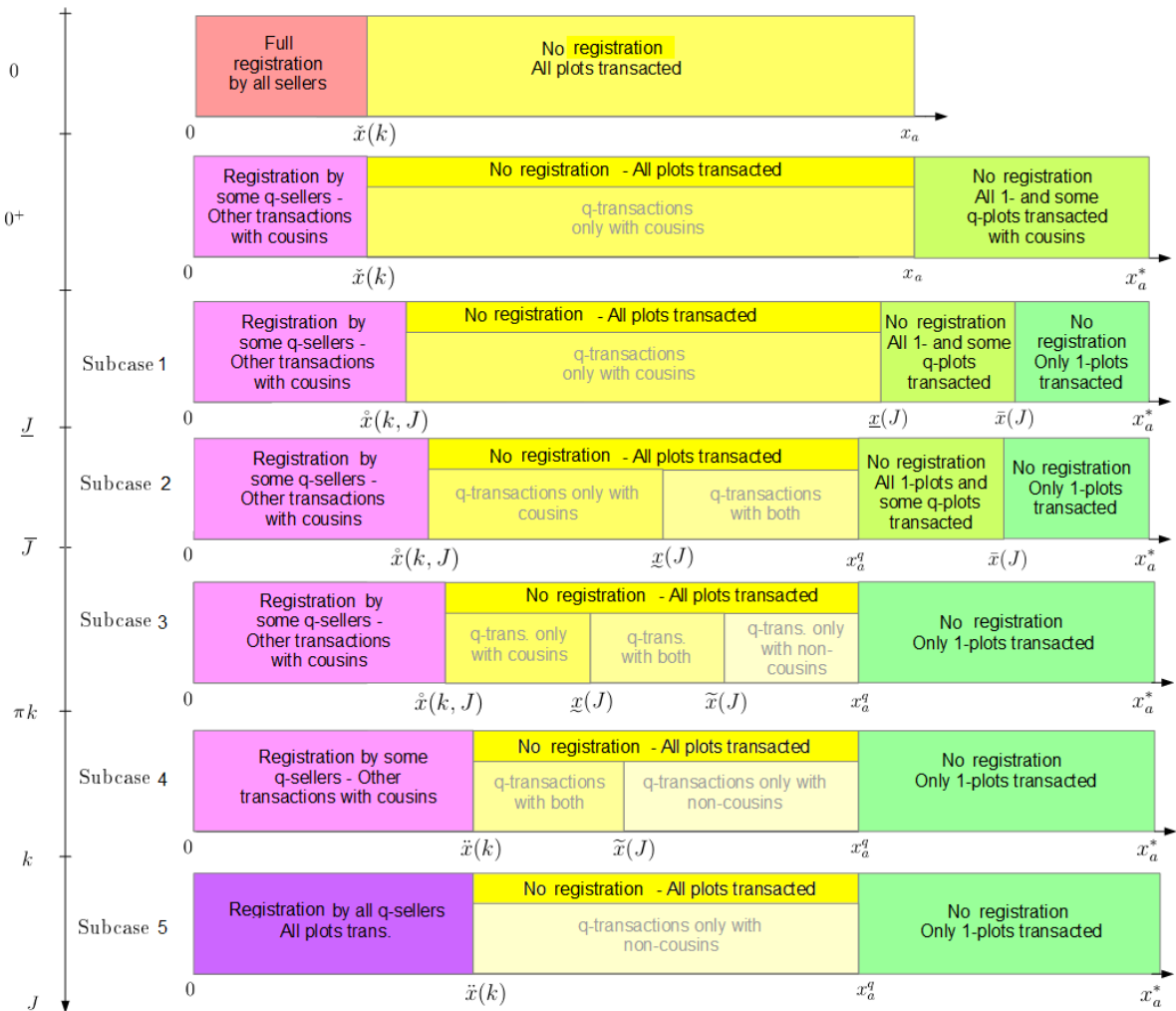
Note : This figure represents the stable equilibria for varying values of the registration cost  $k$  and the social penalty  $J$ . In case of multiple equilibria, the dominant equilibria are highlighted in red. Non-participation in the market is not represented.

FIGURE 2.13 – Hybrid model equilibria (low and very low registration cost)



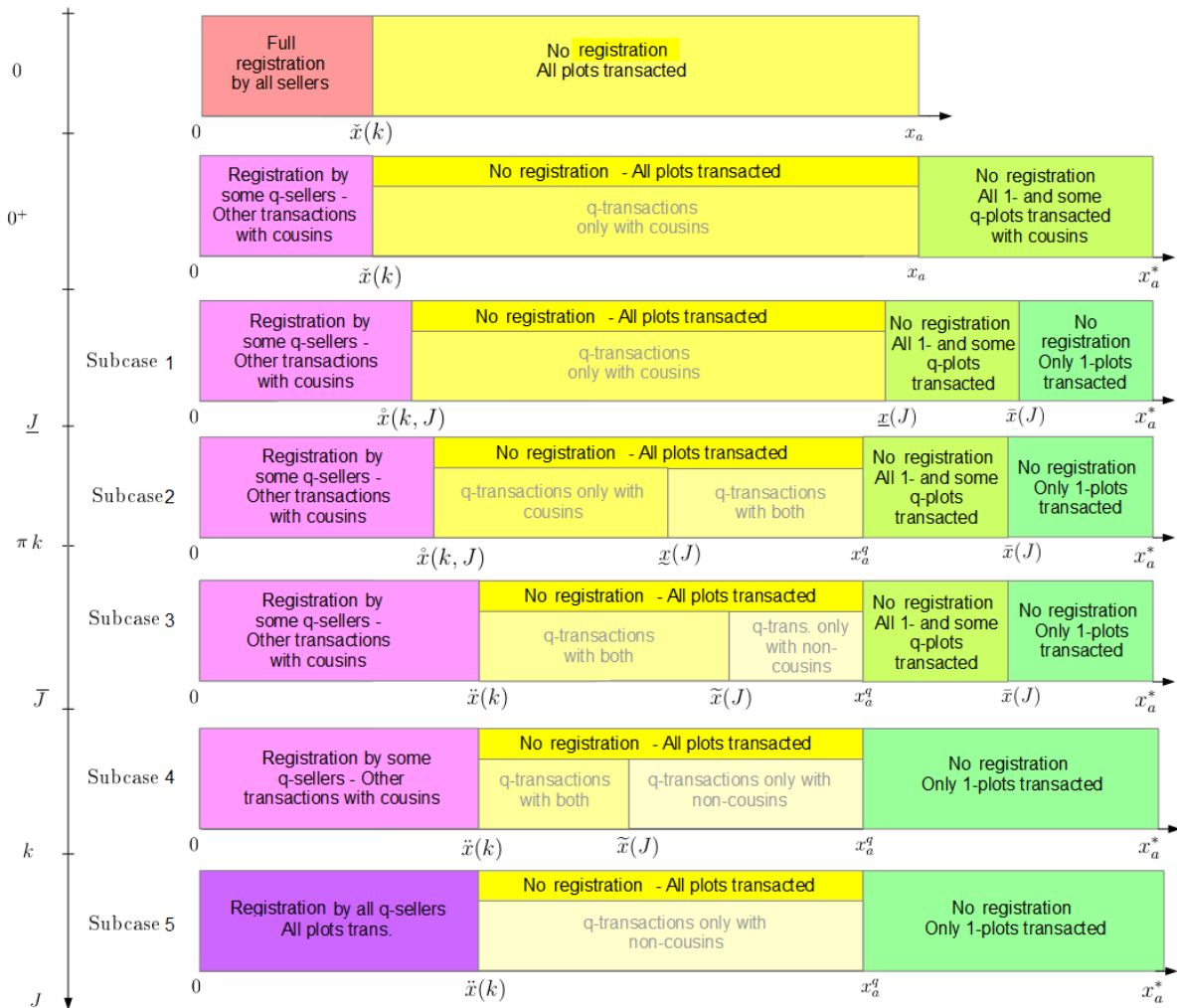
Note : This figure represents the stable equilibria for varying values of the registration cost  $k$  and the social penalty  $J$ . In case of multiple equilibria, the dominant equilibria are highlighted in red. Non-participation in the market is not represented.

FIGURE 2.14 – Hybrid model equilibrium city structure (high registration cost :  $\bar{k} > k > R_a \frac{1-q}{\pi q}$ )



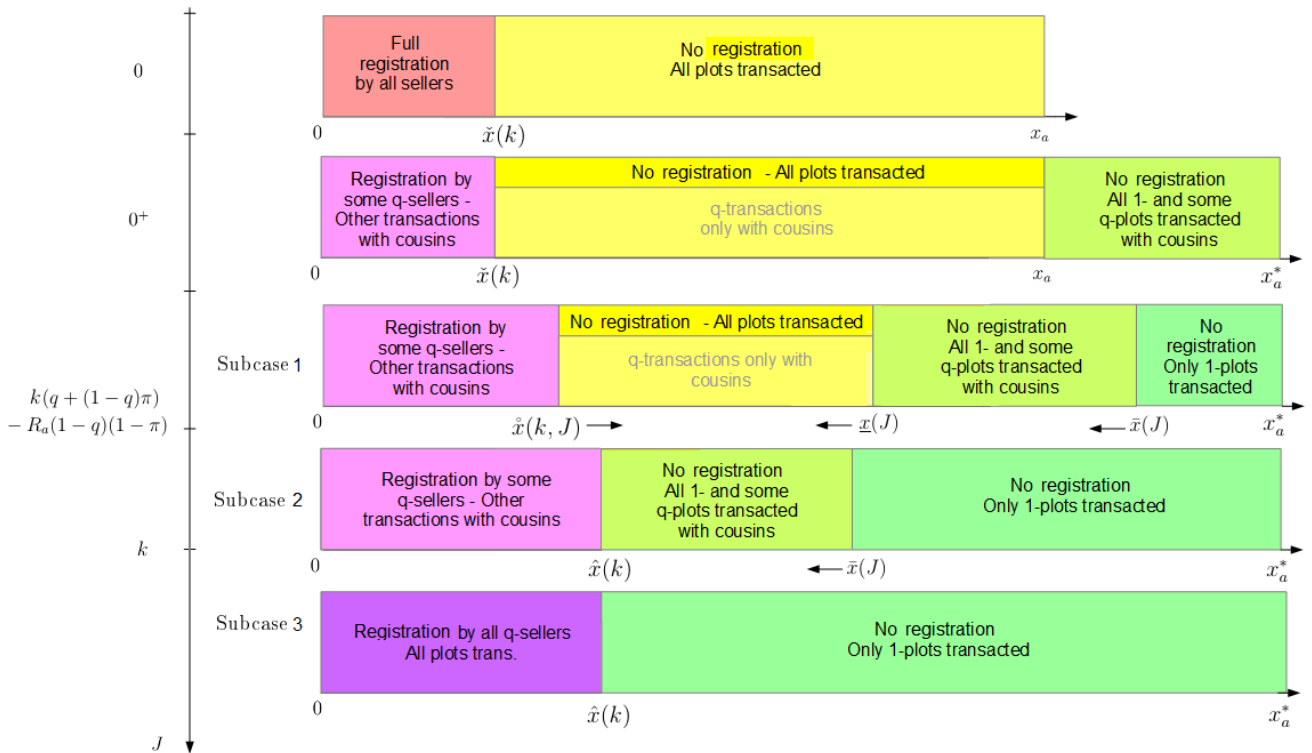
Note : This figure represents the city structure as a function of distance to the city center for high registration costs ( $k$ ) and for different levels of the social penalty ( $J$ ).

FIGURE 2.15 – Hybrid model equilibrium city structure (intermediate registration cost :  $k > R_a \frac{1-q}{q} > \pi k$ )



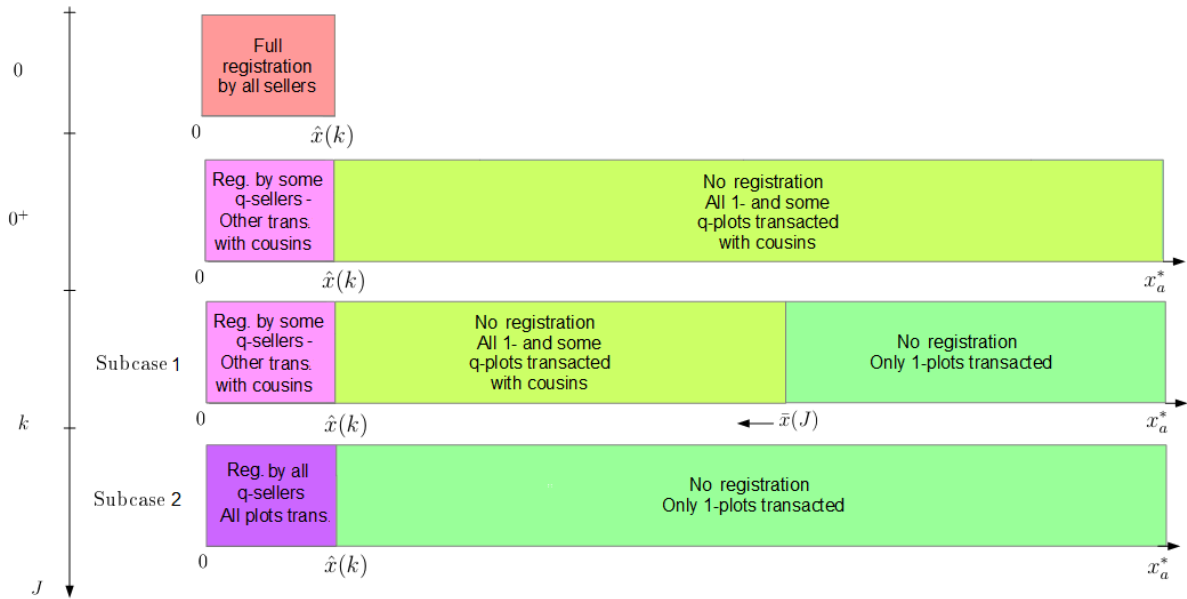
Note : This figure represents the city structure as a function of distance to the city center for intermediate registration costs ( $k$ ) and for different levels of the social penalty ( $J$ ).

FIGURE 2.16 – Hybrid model equilibrium city structure (low registration cost :  $R_a \frac{1-q}{q} > k > \underline{k}$ )



Note : This figure represents the city structure as a function of distance to the city center for low registration costs ( $k$ ) and for different levels of the social penalty ( $J$ ).

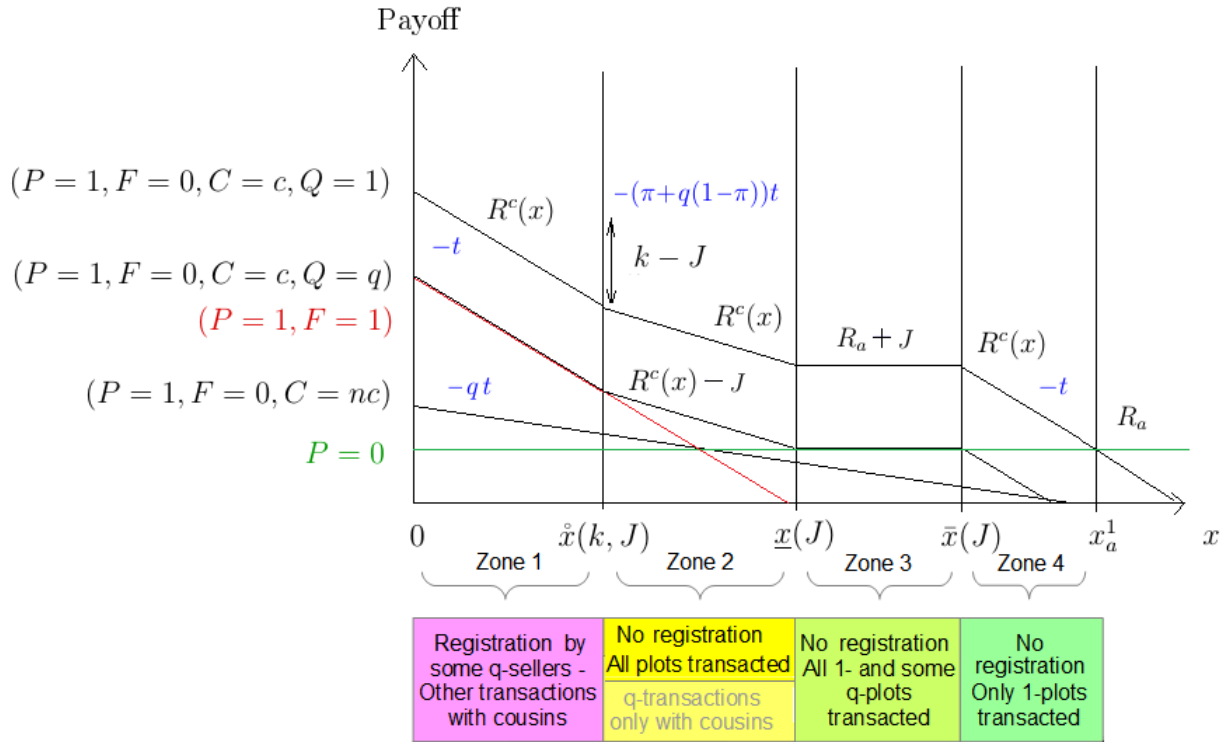
FIGURE 2.17 – Hybrid model equilibrium city structure (very low registration cost :  $\underline{k} > k$ )



Note : This figure represents the city structure as a function of distance to the city center for very low registration costs ( $k$ ) and for different levels of the social penalty ( $J$ ).

### 2.9.2 Payoffs of land owners

FIGURE 2.18 – Payoffs of land owners, depending on their participation, registration and cousinage decisions



Note : This figure represents the equilibrium payoffs of sellers as a function of distance to the city center, their market participation, registration and ethnic matching decisions when  $J < \underline{J}$  and  $k > \underline{k}$ . The slopes of the payoff curves are indicated in blue.

### 2.9.3 Proof Proposition 9

City surplus comparisons can be performed using the surplus formulas. It is easier, however, to derive the proof of Proposition 9 by comparing city structures in the trust, registration and hybrid models.

When  $k = 0$  and  $J \rightarrow 0^+$ , the hybrid model city extends between 0 and  $x_a^*$  and, in each location, all sellers sell informally, except a mass  $L_{fq}(x)$  of  $q$ -sellers, who sell after registering. In the trust model, all sellers sell informally on  $[0, x_a]$  and all sellers sell informally on  $[x_a, x_a^*]$ , except a mass  $L_q^c(x) = \frac{\pi(1-q)(y-xt-u)}{R_a+J-q(y-xt-u)} - \pi$  of  $q$ -sellers in each location  $x$ . In each location on interval  $[0, x_a^*]$ , a  $q$ -plot that is sold after registration yields a higher surplus than a  $q$ -plot that is sold informally or kept under agricultural use. Indeed,  $y - xt - u - R_a >$



$(q + \theta(1 - q))(y - xt - u - R_a)$  and  $y - xt - u - R_a > 0$ . Consequently, denoting  $\Theta(k, J)$  the surplus in the hybrid model, it is clear that, when  $k = 0$  and  $J \rightarrow 0^+$ , we have  $\Theta(0, J) - \Phi(J) > 0$  and the surplus in the hybrid model is greater than in the trust model. As both city surpluses are clearly continuous for  $J \in ]0, +\infty[$  and  $k \in ]0, +\infty[$ , this result holds for  $J$  sufficiently small and  $k$  sufficiently small.

When  $k = 0$  and  $J \rightarrow 0^+$  also, the registration model city corresponds to a fully formal zone between 0 and  $x_a^*$ . As all plots are registered before sale at no cost, tenure insecurity disappears and the surplus reaches its optimum. Therefore, it is clear that the surplus in the registration model is greater than in the hybrid model ( $\Theta(k, J) - \Lambda(k) < 0$ ) when  $k = 0$  and  $J \rightarrow 0^+$ . As all city surpluses are continuous for  $J \in ]0, +\infty[$  and  $k \in ]0, +\infty[$ , this result holds for  $J$  sufficiently small and  $k$  sufficiently small.

When  $k = \bar{k}$  and  $J \rightarrow 0^+$ , the cities in the hybrid model and in the trust model are the same and yield the same surplus.

When  $k = \bar{k}$  and  $J \rightarrow 0^+$ , we have  $\check{x}(k) = 0$ . The city in the registration model is fully informal (i.e., yellow zone between location 0 and  $x_a$ ) and the city in the hybrid model is fully informal between location 0 and  $x_a$  (i.e., yellow zone) and informal with partial participation in the market between  $x_a$  and  $x_a^*$  (i.e., light green zone). Consequently, the city in the hybrid model corresponds to the city in the registration model, plus an additional zone in the periphery. Thus, the city surplus is greater in the hybrid than in the registration model ( $\Theta(k, J) - \Lambda(k) > 0$ ) when  $k = \bar{k}$  and  $J \rightarrow 0^+$ . As all city surpluses are clearly continuous for  $J \in ]0, +\infty[$  and  $k \in ]0, +\infty[$ , this result holds for  $J$  sufficiently small and  $k$  sufficiently large.



## Chapitre 3

# Impacts of a French Urban Renewal Program on Local Housing Markets \*

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\*. This chapter corresponds to a joint work with Sylvain Chareyron, Assistant Professor at Université Paris-Est Créteil, and Florence Goffette-Nagot, Research Professor at CNRS-GATE. We are grateful to Gilles Duranton, Stephan Heblich, Camille Hémet, Miren Lafourcade and David Margolis for useful comments and suggestions, as well as to the participants to the EEA 2020, UEA Philadelphia 2019, EALE 2019, JMA 2019, AFSE 2019 conferences, the Munich Young Economists' Meetings 2019 and 2019 PPCR workshop and to the audience of the Lunch Seminar at the ERUDITE laboratory, the Lunch Seminar at GATE and the Labor and Public Economics Seminar of the Paris School of Economics. This paper also benefited from exchanges with Clément de Chaisemartin and Xavier d'Haultfœuille. This research benefited from funding from the Labex OSE, from the Chaire "Habiter ensemble la ville de demain", as part of Labex Intelligences des Mondes Urbains (IMU), University of Lyon, and from the Chaire of the Ministry for the Ecological and Solidary Transition (MTES), which we all gratefully acknowledge. Last but not least, we thank the MTES, the CGET and the ANRU, which gave us access to the data necessary to this research.

**Abstract:** Urban renewal programs have been implemented in many countries to fight housing decay, poverty concentration, and associated social ills in the last decades. In this paper, we propose an evaluation of a large-scale urban renewal program launched in France in 2004. Using a novel estimator aimed at avoiding bias in the estimation of treatment effects heterogeneous across treatment groups or time periods, and complementing its results with a more precise double fixed effects difference-in-differences estimator, we find no significant effect of the program on housing values and transaction volume. However, we do find a significant impact on the social profile of housing buyers and sellers: an increased number of upward transitions of housing units, from blue-collar sellers to intermediate category buyers or from intermediate category sellers to executive buyers, and reduced housing transactions among executives. Altogether, our findings suggest a renewed interest of upper socio-professional categories to invest or keep their property in the renovated neighborhoods.

**Keywords:** Place-based policies, urban renewal, housing prices, housing spillovers, difference-in-differences

**JEL classification:** D62, H23, R21, R31

### 3.1 Introduction

Urban renewal programs have been implemented in many countries in the last decades to fight housing decay, poverty concentration and associated social ills.<sup>1</sup> However, compared to other place-based policies, such as Enterprise Zones programs (see Papke, 1993; Neumark and Simpson, 2015 for surveys) or place-based subsidies to housing investments as LIHTC (Baum-Snow and Marion, 2009; Eriksen and Rosenthal, 2010), only few empirical studies of their impacts have been conducted and the results are mitigated. The outcomes of interest are mainly population social composition, housing prices as a signal of attractiveness, or crime rate. Some studies have found positive effects of renovation on housing prices (Galster, Tattian and Accordino, 2006; Rossi-Hansberg, Sarte and Owens III, 2010; Collins and Shester, 2013; Koster and Van Ommeren, 2019), but others have found limited (Ding, Simons and Baku, 2000; Aarland, Osland and Gjestland, 2017) or insignificant (Barthélémy, Michelangeli and Trannoy, 2007; Ahlfeldt, Maennig and Richter, 2017) effects of these programs. The pattern is similar for impacts on household income, employment or poverty rate (Van Beckhoven and Van Kempen, 2003; Collins and Shester, 2013; Guyon, 2017; González-Pampillón, Jofre-Monseny and Viladecans-Marsal, 2019). However, renewal programs seem to have had positive outcomes on crime (Aliprantis and Hartley, 2015; Alonso, Andrews and Jorda, 2019).

Analyses of urban renovation programs have often focused on city-level programs or state-level programs of moderate magnitudes (Ahlfeldt, Maennig and Richter, 2017; Rossi-Hansberg, Sarte and Owens III, 2010; Barthélémy, Michelangeli and Trannoy, 2007). To our knowledge, only three studies of large nationwide renewal programs have been conducted. A large-scale U.S. federal program has been studied by Collins and Shester (2013), but it was conducted more than 45 years ago and its effects were only investigated at the city level. Aliprantis and Hartley (2015) consider the impact of the U.S. program HOPE VI on crime, but only within the city of Chicago. Koster and Van Ommeren (2019) consider the overall impact of a nationwide renewal program, with however a limited level of financing of about €1 billion invested between 2007 and 2012.

In this paper, we analyze the impacts of a large-scale French urban renewal program, the *Programme National de Rénovation Urbaine* (PNRU hereafter). This program launched in 2004 consisted mainly in the renovation, demolition and construction of public housing, and marginally in the improvement and creation of public facilities. Our aim is to explore its impact on the attractiveness of the renovated neighborhoods by looking at changes in private housing markets.<sup>2</sup> We thus evaluate the program's externalities and not its direct effects on the value of renovated public housing units. Our contribution is threefold. First, we take

1. e.g. in the United States, the Netherlands, Spain, the United Kingdom, France.

2. This type of positive amenity effect produced by policy intervention on the housing stock is also explored by Baum-Snow and Marion (2009).

advantage of the exceptionally large scale of this program, which involved more than €47 billions investment and 594 neighborhoods located in about 150 different cities, to provide more reliable estimates. Indeed, the large number of control areas reduces the sensitivity of the counterfactual to unobserved shocks as shown by Ahlfeldt, Maennig and Richter (2017) and the large number of observations makes it possible to check the robustness of our main results on subsamples. Second, we use an estimator robust to potential treatment effect heterogeneity. Indeed, because renovation took place in very different contexts and started at different dates depending on the neighborhood, large heterogeneity in treatment effects across space and over time can be suspected.<sup>3</sup> This heterogeneity is combined with imbalance in treatment status along these same two dimensions. To get unbiased estimates of the program's impacts in such a context, we apply the novel methodology proposed by De Chaisemartin and D'Haultfœuille (forthcoming) for this very purpose. To the best of our knowledge, our paper is one of the first papers using this methodology and the first to use it to estimate the impact of an urban renewal program. Third, our data allow us to analyze a rarely investigated dimension of urban renewal, namely the impact of renovation on sellers' and buyers' social category.

Our identification strategy relies on difference-in-differences, exploiting both the existence of never treated neighborhoods that were initially eligible, and staggered start of renovation across renovated neighborhoods. The identification assumption is that, conditional on fixed effects and controls, the trends in the outcomes under study would have been the same in never-renovated neighborhoods and in renovated ones in the absence of renovation. This hypothesis will be checked using estimates of dynamic treatment effects before the start of renovation. Furthermore, as for renovated neighborhoods, the history of the program exposed in the following shows that the set of renovated neighborhoods was chosen at the beginning of the program and the starting year of renovation was not decided depending on the evolution of housing prices in these neighborhoods.

Our results indicate that renovation did not lead to a significant increase in housing values on average in the treated neighborhoods in the time frame considered. The results appear to be stable across subsamples defined to account for different treatment intensities, namely the level of funding per housing unit and the initial share of public housing, and for tension on the housing market, by separating renovated neighborhoods located in one of the four largest French urban units (Paris, Lyon, Marseille and Lille) from the others.<sup>4</sup> They are also robust

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3. As an illustration, four renovated neighborhoods are located in Paris municipality, where tension on the housing market is extreme, and six additional neighborhoods are located less than 8 kilometers from Paris center, whereas renovation also took place in some economically distressed urban units where public housing offices asked the National Agency for Urban Renewal (ANRU) not to replace one-for-one the demolished public housing units because of a lack of housing demand (Le Monde, 2019).

4. In the French statistical system, an urban unity is a municipality or a group of municipalities which includes a continuously built up zone (no cut of more than 200 meters between two constructions) with at least 2,000 inhabitants. We will also refer to urban units as cities.

to various sensitivity tests. It is still possible that the program had a small impact on housing values, albeit sufficiently small not to be captured by our analysis. This impact is in any case below 3.5%, the upperbound of the 95% confidence interval of our preferred estimate. We also find no impact on the volume of transactions. However, we do find that the program significantly affected the social profile of housing buyers and sellers in the renovated neighborhoods. Indeed, we find evidence that it led to an increased number of upward transitions of housing units, from a blue-collar seller to an intermediate category buyer or from an intermediate category seller to an executive buyer, and to a reduction of housing transactions among executives, suggesting an increased interest of upper socio-professional categories to invest in the renovated neighborhoods or to remain in them.

The following of the paper is organized as follows. Section 3.2 depicts the urban renewal program under study. Section 3.3 is dedicated to the presentation of the empirical strategy and Section 3.4 to the description of the data. We present our results in Section 3.5 and conclude in Section 3.6.

## **3.2 The French National Urban Renewal Program**

The present research focuses on the consequences of the PNRU program launched in France in 2004. This program had four distinct goals: restructuring neighborhoods, increasing social diversity, supporting sustainable development of territories and reducing inequalities between places and between populations. To this aim, a list of eligible neighborhoods located in urban units on the whole French territory was established. It included all of the 751 neighborhoods referred to as Sensitive Urban Zones (hereafter ZUS) that were designated by the State between 1996 and 2000 as targets of the French urban policy, based on the existence of large public housing developments and low employment-to-population ratios. This list also defined 166 additional neighborhoods called “Article 6” selected according to similar criteria. These eligible neighborhoods exhibited high levels of poverty and degradation of their buildings.

Municipalities to which these neighborhoods belong were asked to build renovation projects in coordination with local actors, in particular public housing offices. These projects were then submitted to the National Agency for Urban Renewal (ANRU hereafter) that was created to ensure the administrative follow-up of urban renewal operations. The Agency, in some cases, asked for modifications of the renovation projects and then decided whether to grant funding.<sup>5</sup> On the overall, €47 billions were invested from 2004 to 2020 in as many as 594 neighborhoods

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5. From the information available on the PNRU program and our discussions with the Agency, it is not clear how local projects were selected for renovation in practice. Not all ZUS were proposed for renovation by local authorities. And there does not seem to have been a simple index score according to which neighborhoods were graded, as was the case for renovation programs in some other countries. This forbids using a regression-discontinuity design as in Alonso, Andrews and Jorda (2019) or Koster and Van Ommeren (2019).

(see Figure A1 in Appendix for a map of the geographical distribution of funding at the departmental level).<sup>6,7</sup> For the sake of brevity, we will use the term “urban policy neighborhoods” or even “neighborhoods” to designate the set of eligible neighborhoods, both ZUS and “Article 6” neighborhoods. As for treated neighborhoods, we simply speak of “renovated neighborhoods”, be they observed before or after renovation started.<sup>8,9</sup>

The program affected directly close to 1 million dwellings, with 150,000 housing units demolished, 135,000 built, 315,000 rehabilitated and 350,000 concerned by their building’s rehabilitation (i.e. the beautification of public housing projects, with, for example, the setting up of a small front garden). A quarter of the budget was dedicated to the improvement of the urban environment and of public equipments and services, as well as economic and commercial spaces (ONZUS, 2013). Overall, an average of €79 millions was invested and 253 housing units destroyed in each renovated neighborhoods. This program contrasts with usual urban renewal programs studied in the literature, due not only to its large scale but also to the key role attributed to the massive demolition and reconstruction of public housing. Indeed, many large public housing developments erected in the post World War II era had strongly depreciated and were perceived as stigmatizing for these neighborhoods. They were demolished as a part of the PNRU local renovation plans.

### **3.3 Empirical strategy**

In order to estimate the impacts of the PNRU program, we rely on a difference-in-differences strategy exploiting both the existence of never treated neighborhoods that were initially eligible, and staggered start of renovation across renovated neighborhoods. The traditional difference-in-differences estimation consists in using a double fixed effects estimator (DFE hereafter), where group fixed effects control for time-constant group heterogeneity, and time fixed effects control for general time trends. Under the assumption of common trends and with constant treatment effects, this strategy allows for the unbiased estimation of the average treatment effect.

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6. The major contributors to the program were public housing offices, which provided about €20.5 billions. The ANRU comes next with around €11.5 billions. The remaining funding was given mainly by local authorities.

7. By way of comparison, the Dutch program considered in Koster and Van Ommeren (2019) involved an investment of about €1 billion in 83 neighborhoods.

8. All “Article 6” neighborhoods were renovated. In the analysis, we pool them with renovated ZUS, because they have quite similar socio-economic characteristics, and the transactions in “Article 6” neighborhoods are too scarce to allow for a separate analysis. They represent about 10% of all transactions in renovated neighborhoods in our sample.

9. As an illustration of the different geographical scales at stake in this paper, Figure A2 represents the urban unit of Grenoble in the Rhône-Alpes region in France. It shows the borders of Grenoble municipality and of the three types of neighborhoods we are interested in: ZUS neighborhoods that were renovated (“ZUS-renov”), “Article 6” neighborhoods that were all renovated (“Art6-renov”) and ZUS neighborhoods that were not renovated (“ZUS-norenov”).



However, recent papers considering staggered adoption designs, in which treatment of different groups starts at different times, have shown that the treatment effect estimated with a DFE regression is actually a weighted average of individual treatment effects, with weights that might be negative (Borusyak and Jaravel, 2017; Athey and Imbens, 2018; Goodman-Bacon, 2018; De Chaisemartin and D’Haultfœuille, forthcoming). If treatment effects are heterogeneous, then the DFE-based average treatment effect is likely to be biased. Moreover, De Chaisemartin and D’Haultfœuille (forthcoming) (hereafter DCDH) demonstrate that the DFE estimate is especially likely to involve negative weights and therefore give biased estimates if treatment effects differ between periods with many versus few treated groups, or between groups treated for many versus few periods.<sup>10</sup> As we will show in the following, imbalance in treatment status across groups and time periods are present in the case of PNRU’s impact on housing prices, as in many staggered adoption designs, and heterogeneity of treatment effects can be suspected.

To overcome a potential bias, DCDH propose an alternative estimator ( $DID_M$  in the following) that is robust to treatment effect heterogeneity across groups and time periods. This estimator consists in computing, at each time, a difference-in-differences based on switchers (i.e. groups of which treatment status changes at that time) as compared to groups with stable treatment. These differences-in-differences are then averaged over the whole observation period, with weights that depend on the number of switchers at each time.

In this section, we first describe how we implement the traditional DFE estimator, and then turn to the  $DID_M$  estimator, which corresponds to our preferred estimation, though we also present results based on the DFE estimator.

### 3.3.1 Double fixed effects estimator

To estimate the average treatment effect based on a DFE estimator, we use a hedonic regression in which the logarithm of the price of a housing transaction is regressed on the characteristics of the transacted housing unit and time trends at the urban unit level. A dummy indicates whether the housing unit is located in a neighborhood under renovation. Its coefficient is the estimate of the average time-constant effect of the renovation program on prices in renovated neighborhoods. In practice, the following equation is estimated:

$$\log(P_{itnu}) = \beta_T \mathbf{1}_{n \in \mathcal{R}, t - T(n) \geq 0} + \phi_t + \mu_n + X_{it} \beta + \gamma_u t + \gamma'_u t^2 + \varepsilon_{itnu} \quad (3.1)$$

where  $i$  is the identifier of the housing unit,  $t$  is the year of the transaction,  $n$  is the neighborhood in which the housing unit is located,  $u$  is its urban unit,  $\mathcal{R}$  is the set of renovated neighborhoods,  $T(n)$  is the date at which renovation was launched in neighborhood  $n$  (if  $n \in \mathcal{R}$ ),

10. See also Borusyak and Jaravel (2017).

$\phi_t$  is a time fixed effect,  $\mu_n$  is a neighborhood fixed effect,  $\gamma_u$  (resp.  $\gamma'_u$ ) is the linear (resp. square) time trend of housing prices in urban unit  $u$ .<sup>11</sup>  $X_{it}$  is a vector of characteristics of the transacted housing unit: the number of rooms interacted with an apartment or house indicator, number of bathrooms, period of construction, floor space per room, dummy equal to one if the dwelling is less than 5 years old, and distance of the transaction to the city center. In this specification, neighborhood fixed effects account for time-constant heterogeneity while urban units time trends and transacted housing units characteristics account for some time-varying heterogeneity.

Following Ahlfeldt, Maennig and Richter (2017), we also analyze the program's time-varying effects by introducing a time flexible structure into the previous equation:

$$\log(P_{itnu}) = \sum_{\Delta \in S} \beta_{\Delta} \mathbf{1}_{n \in \mathcal{R}, t - T(n) \in \{\Delta - 1, \Delta\}} + \phi_t + \mu_n + X_{it}\beta + \gamma_u t + \gamma'_u t^2 + \varepsilon_{itnu} \quad (3.2)$$

In this time-varying specification,  $\Delta \in S$ , where  $S = \{-11, -9, -7, -5, -3, -1, 1, 3, 5, 7, 9, 11\}$ . Time-varying effects are grouped by pairs, because the dataset on housing prices is available only every even year.  $\mathbf{1}_{n \in \mathcal{R}, t - T(n) \in \{\Delta - 1, \Delta\}}$  is then a dummy function equal to one if and only if renovation in neighborhood  $n$  started  $\Delta - 1$  or  $\Delta$  years before the transaction.<sup>12</sup> The reference for the computation of the program impacts are years  $T(n) - 2$  for neighborhoods where renovation started on an even year and  $T(n) - 1$  for neighborhoods where renovation started on an uneven year.  $\beta_{\Delta}$  is then the effect of the program after  $\Delta - 1$  or  $\Delta$  years.

We include in the sample the transactions that occurred in an urban policy neighborhood. We exclude however transactions located less than 500 meters away from the border of a renovated neighborhood so as to avoid spillovers from a renovated neighborhood to a nearby non-renovated neighborhood. The set of control observations therefore consists of transactions in non-renovated urban policy neighborhoods outside of the 500 meter buffer around renovated neighborhoods. The inclusion of non-renovated urban policy neighborhoods as controls is the most natural, as renovated neighborhoods have been chosen among urban policy neighborhoods and are relatively similar (see Table 3.2 below for the descriptive statistics of renovated and non-renovated neighborhoods). In the robustness checks, we also employ matching and weighting procedures to make sure that the existing differences between the treated and control groups do not affect our estimates. Moreover, given the staggered adoption design and our empirical specification, the identification of treatment effects also exploits transactions in renovated neighborhoods which occurred before the start of renovation. The difference-in-differences method is based on the common trend hypothesis, which states that the evolution

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11. The quadratic functional form is especially useful to account for the reversal of housing prices after the 2008's crisis, while keeping the number of estimated coefficients reasonable. We separate Paris commune from the rest of the Parisian urban unit in order to account for different time trends in the two areas.

12. If  $\Delta$  is negative, the dummy is equal to one when renovation started  $|\Delta|$  or  $|\Delta| + 1$  years after the transaction.

of housing prices should be the same in the non-renovated and renovated neighborhoods in the absence of renovation. In practice, this hypothesis is tested by verifying the absence of pre-trends, that is, the estimated  $\beta_\Delta$  being not significantly different from 0 when  $\Delta < 0$ .

We also estimate the impact of the program on the volume of transactions. To this aim, observations are aggregated at the level of neighborhoods and equations similar to Equations (3.1) and (3.2) are estimated, replacing the log price by the number of transactions in the neighborhood and suppressing housing unit characteristics. Eventually, because one of the aims of the PNRU program is to bring new social categories in renovated neighborhoods so as to foster a change in the social profile of their inhabitants, we also consider the PNRU's impacts on the socio-professional category of housing buyers and sellers, for which we similarly estimate a linear probability model of the probability for a housing buyer to be an executive (resp. a blue-collar, resp. intermediate professional category) or for a housing seller to be an executive (resp. blue-collar, resp. intermediate professional category). We therefore have six regressions corresponding to Equations (3.1) or (3.2), in which the outcome is a dummy equal to 1 if the housing buyer is an executive (resp. a blue-collar or intermediate category, resp. if the housing seller belongs to each of these categories) and in which the characteristics of the transacted housing unit have been removed, because they are themselves largely determined by the socio-professional category of the housing buyer or seller.

### 3.3.2 DID<sub>M</sub> estimator

As previously explained, the DFE estimator is likely to yield biased estimates if treatment effects are heterogeneous across time periods or across groups in staggered adoption designs. This bias is especially of concern if treatment effects differ between periods with many versus few treated groups, or between groups treated for many versus few periods.

In the case of the PNRU program, treatment effects on housing prices are likely to be highly heterogeneous across periods and neighborhoods for at least four reasons. First, with respect to heterogeneity across time periods, treatment effects might differ depending on period, especially because the 2008 housing crisis may have altered the impacts of the program in the following years. Then, with respect to heterogeneity across neighborhoods, the impact of renovation on housing prices is likely to depend on the tension on the urban unit's housing market. Given that our sample includes renovated neighborhoods located in 199 different urban units, this is likely to be a major source of heterogeneity. Furthermore, treatment effects may also depend on characteristics of the neighborhood itself, such as the share of public housing or the local level of criminality, or on characteristics of the renovation operations, such as the level of funding invested in the neighborhood or the share of demolitions. Finally, we can think that the most promising renovation projects were launched first, so that neighborhoods belonging to the first generations of renewal might have stronger treatment effects. This potential hetero-

ogeneity in treatment effects is combined with imbalance in treatment status in our data, as will be shown in Table 3.1.

Given these features, we use the alternative estimator proposed by DCDH. The  $DID_M$  estimator consists, in our case, in computing the average over the study period of difference-in-differences estimated for each year on neighborhoods where renovation started during this year (these neighborhoods are called “switchers”) compared to neighborhoods not entering the treatment at the same date (i.e. non-renovated ZUS and renovated neighborhoods in which renovation has not started yet). This estimator can be used to compute instantaneous treatment effects (i.e. one period after the treatment starts) as well as time-varying treatment effects,  $i$  periods after the treatment starts. In the latter case, the average evolution of housing prices between  $T(n) - 1$  and  $T(n) + i$  in neighborhoods where renovation starts at time  $T(n)$  is compared to that of neighborhoods that remain untreated at the same dates. As with the DFE estimator, we estimate the impact of the treatment  $\{0,1\}$ ,  $\{2,3\}$ ,  $\{4,5\}$ ,  $\{6,7\}$ ,  $\{8,9\}$  and  $\{10,11\}$  years after renovation started in the neighborhood and use the same control variables.<sup>13</sup> The standard errors are computed using a block bootstrap at the neighborhood level.

The  $DID_M$  estimator relies on two assumptions. The first one requires that, in each period with switchers, at least one neighborhood keeps its treatment status. This happens in our setting because the sample includes never treated neighborhoods. The second hypothesis generalizes the common trend hypothesis of more traditional difference-in-differences estimations. It requires that the mean evolution of switching groups’ outcomes would have been the same, in the absence of treatment, as that of control groups. In our case, this implies that, had renovation not been undertaken, housing prices in neighborhoods where renovation starts would have evolved in the same way as in non-renovated or in not-yet-renovated neighborhoods. The test of this hypothesis is based on the estimation of placebo effects for housing prices’ evolutions between two consecutive periods before the start of the treatment. More specifically, the placebo effect  $-i$  for groups entering the treatment at time  $T(n)$  is based on the evolution of housing prices between  $T(n) - i - 1$  and  $T(n) - i$ .

The  $DID_M$  estimator is demanding in terms of data, as the estimate of the  $+i$  temporal effect is based on neighborhoods in which transactions occurred at time  $T(n) - 1$ ,  $T(n)$  and  $T(n) + i$ .<sup>14</sup> By way of comparison, the classical DFE estimator only requires each neighborhood to have transactions at two distinct dates at least, whatever the date. Moreover, the  $DID_M$

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13. The  $DID_M$  estimator is implemented using the `did_multipligt` Stata package. Because the `trend` option of this package only allows linear or non parametric trends, and the latter would consume too many degrees of freedom given the number of urban units in the sample, we include linear urban unit trends and not quadratic ones as with the DFE estimator. The placebo coefficients show that this change in the form of urban unit trends still allows to verify the extended parallel trends assumption.

14. Observations at  $T(n) - 1$  and  $T(n)$  are required to define the change in the treatment status of the neighborhood. As noted by DCDH, the properties of the  $DID_M$  estimator hold even if some groups appear or disappear over time. As to placebo effects, they require a neighborhood to be observed in the data at four different periods, namely at time  $T(n) - 1$  and  $T(n)$ , and at  $T(n) - i - 1$  and  $T(n) - i$  for placebo effect  $-i$ .

estimator is valid for controls at the neighborhood  $\times$  period level and is therefore estimated here on data aggregated at this level. These two features of the  $DID_M$  estimator yield larger standard errors than with the more classical DFE estimator. This is why we also show results based on DFE regressions.

## 3.4 Data

### 3.4.1 Data sources

Our analysis exploits a dataset derived from notaries registration of housing transactions and covering metropolitan France between 2000 and 2014 in even years.<sup>15</sup> The data comprise the date and price of transaction, the geographical coordinates of the housing unit transacted, some of its characteristics (among which apartment or house, number of rooms, number of bathrooms, floorspace, construction period and plot land area for houses) and some characteristics of the buyer and seller (occupation, marital status, municipality of residence, sex, nationality, year of birth). Given our empirical strategy, we only retain from this dataset transactions located in an urban policy neighborhood. We apply to this dataset the same treatments as those employed by the French National Institute for Statistics (INSEE) to produce housing prices indices at the local level (*Indice Notaires-INSEE*). First, we suppress atypical housing units.<sup>16</sup> Second, we keep only private sales of housing units free of occupation, exclusively dedicated to housing and acquired in full ownership. Third, we suppress housing units with non-standard dimensions or price.<sup>17</sup> Eventually, in order to deal with some records of bad quality in terms of match between characteristics of the housing unit and transaction price, we run the baseline regression corresponding to Equation (3.1) and set aside the 5% of transactions for which the gap between predicted and observed price is the largest. After these treatments, the database contains about 72,000 transactions located in 647 neighborhoods.

We merge this data with information on PNRU operations in the 572 renovated neighborhoods located in metropolitan France. This information, provided by the National Agency for Urban Renewal (ANRU), includes the amounts allocated by the Agency to each neighborhood, the amounts provided by other financing partners, such as social landlords or municipalities,

15. The French Ministry for an Ecological and Inclusive Transition that gave us access to this data only purchased even years from the French Notaries Association.

16. i.e. for apartments: artist's workshop, maid room, attic awaiting conversion, caretaker's dwelling, loft, villa, high standing; and for houses: chalet, tower, windmill, old train station, farm, large property, castle, private mansion, host house, villa.

17. i.e. we keep, for apartments: units with less than or 9 rooms, a floor space comprised between 10 and 200 square meters, a price between €1,500 and €5,000,000, a square meter price of less than €25,000; for houses: units with less than or 13 rooms, more than 20 square meters and less than 300 square meters, more than 9 square meters lot size, a price of more than €1,500, and, if the house is located outside the Parisian urban area, the house must have a price lower than €15,000,000.

the number of housing units demolished, constructed and renovated, and the dates at which the Agency supplied funds in each neighborhood. Finally, we complete the data with local-level socio-economic and income characteristics from the 1999 French Census (*Recensement de la Population 1999*) and localized fiscal revenues data (*Revenus Fiscaux Localisés 2001*) provided by the French Institute of Statistics (INSEE).

These different data sources are not all at the same geographical scale. While housing transactions are located according to their geographical coordinates, information on investments made for renewal operations are available at the level of urban policy neighborhoods while Census and revenue data are available at the IRIS level (an infra-communal geographical unit defined for statistical purposes and corresponding to around 1,800 to 5,000 inhabitants). With the help of a geographical information system, we find the urban policy neighborhood corresponding to each transaction and define treatment indicators at the transaction level. Then, as urban policy neighborhood borders do not match IRIS borders, the former comprising several IRIS or parts of IRIS, we use the intersection rates between IRIS and neighborhoods to estimate the socio-economic characteristics at the urban policy neighborhood level and report this information for each transaction.

### **3.4.2 Descriptive statistics**

The distribution of transactions in the renovated and non-renovated neighborhoods is displayed in Table 3.1. It can be noted that the treatment group is larger than the control group, both in terms of number of neighborhoods and of transactions, with 415 renovated neighborhoods and 232 non-renovated ones. In addition, the number of renovated neighborhoods represented in our sample, 415, is lower than the 572 selected in the program in metropolitan France. This difference is due to the fact that, in a sizable number of renovated neighborhoods, no transaction took place at the dates under study, because these neighborhoods are small and largely constituted of public housing units. There are on average 111.6 transactions (s.d. 204.3) per neighborhood for the 14-years period observed in our dataset.<sup>18</sup> When comparing renovated and non-renovated neighborhoods, the number of transactions over the period is higher in renovated neighborhoods by about 34 transactions.

Focusing on transactions located in renovated neighborhoods, Table 3.1 also shows the distribution of the year of first funding obtained from the renewal agency (ANRU). In most renewed neighborhoods (230 out of the 415 renovated neighborhoods in our sample), ANRU signed its first financial commitment as early as 2004. In a sizable number of neighborhoods (122), the first funding was obtained between 2005 and 2007. Only in 63 neighborhoods did renovation start between 2008 and 2014. The distribution of treatment adoption over time and across neighborhoods is hence highly non-uniform, especially as there are neighborhoods

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18. We remind that only even years are observed



treated for the most part of the observation period and others treated only at the end of the period.

Table 3.1 – Number of neighborhoods and transactions, by type of urban policy neighborhood and starting date of renewal operations

	Non-renovated neighborhoods		Renovated neighborhoods	
	# neighb.	# transactions	# neighb.	# transactions
Total	232	20,851	415	51,342
Starting year of renov.				
2004			230	32,895
2005			69	7,947
2006			22	2,099
2007			31	2,059
2008			22	1,826
2009			18	1,711
2010			6	300
2011			7	1,735
2012			2	14
2013			3	469
2014			2	127
2015			3	160

Table 3.2 presents some descriptive statistics of the housing transactions data. It shows that the mean transaction price is lower in renovated than in non-renovated neighborhoods, with €105,000 per transaction in renovated neighborhoods versus €136,000 in the others. The floor space, the share of houses and the share of blue-collar and white-collar workers among housing sellers and buyers are also greater in renovated neighborhoods. Yet, the proportions of inhabitants who are French citizens, blue-collar or executives are quite similar, as well as the share of intermediate category housing buyers and sellers.

Figure 3.1 shows the evolution of average housing prices in renovated and non-renovated neighborhoods (1) in the Parisian urban unit, (2) in Lyon, Marseille and Lille pooled together, and (3) in all the other urban units in our sample. Although standard deviations are very large, we can observe that prices exhibit similar patterns of evolution in each of the three sub-samples. Prices in non-renovated neighborhoods are generally higher and the gap with renovated neighborhoods appears to increase over time. Figure 3.2 complements this figure by decomposing the sample of transactions depending on the starting year of renovation in the neighborhood. It shows that whatever the starting year, the evolution of prices before renovation is similar to that of non-renovated areas. Figure A3 in Appendix is the counterpart of

Table 3.2 – Descriptive statistics on transactions. Renovated and non-renovated neighborhoods

	Non-renovated neighborhoods		Renovated neighborhoods	
	mean	sd	mean	sd
Price (Euros)	136,119	105,395	105,504	64,881
Floor space (m <sup>2</sup> )	63.5	28.0	68.0	26.7
<b>Number of rooms</b>				
1	0.12	0.32	0.08	0.27
2	0.23	0.42	0.18	0.39
3	0.27	0.44	0.29	0.45
4	0.25	0.43	0.28	0.45
≥ 5	0.14	0.34	0.17	0.37
<b>Number of bathrooms</b>				
None	0.03	0.17	0.02	0.15
1	0.88	0.33	0.89	0.32
≥ 2	0.04	0.20	0.04	0.20
Unknown	0.05	0.22	0.05	0.22
Detached housing (%)	0.13	0.33	0.16	0.37
Building less than 5 years	0.00	0.05	0.01	0.07
<b>Building period</b>				
≤ 1913	0.13	0.34	0.05	0.23
1914-1947	0.09	0.29	0.10	0.30
1948-1969	0.23	0.42	0.23	0.42
1970-1980	0.20	0.40	0.28	0.45
1981-1991	0.06	0.24	0.05	0.23
1992-2000	0.03	0.16	0.02	0.14
2001-2010	0.01	0.12	0.02	0.12
2011-2020	0.00	0.05	0.01	0.07
Unknown	0.24	0.43	0.24	0.43
<b>Year of transaction</b>				
2000	0.13	0.34	0.13	0.33
2002	0.12	0.33	0.12	0.33
2004	0.14	0.35	0.15	0.36
2006	0.12	0.32	0.12	0.33
2008	0.13	0.33	0.13	0.34
2010	0.13	0.34	0.12	0.33
2012	0.11	0.32	0.11	0.31
2014	0.13	0.33	0.12	0.33
<b>Seller professional category</b>				
Executive	0.18	0.38	0.13	0.33
Intermediate category	0.19	0.39	0.18	0.38
Blue-collar and white-collar	0.22	0.41	0.26	0.44
<b>Buyer professional category</b>				
Executive	0.22	0.42	0.15	0.36
Intermediate category	0.28	0.45	0.26	0.44
Blue-collar and white-collar	0.31	0.46	0.40	0.49
<b>Distance to city center (km)</b>				
Paris	16.96	7.21	14.66	8.60
Lyon, Marseille, Lille	6.35	7.30	5.84	4.53
Other urban units	3.92	4.92	3.01	2.13
<b>Characteristics of neighborhood in 1999</b>				
% public housing	50.8	21.2	56.3	20.5
% vacant housing	6.3	3.6	7.9	4.5
% single-family housing	27.7	22.9	23.7	20.8
% owner-occupiers	29.0	14.3	25.3	12.7
% French citizenship	87.9	7.7	85.6	8.5
% blue-collar workers	36.2	10.7	36.9	9.0
% executives	9.9	5.6	9.3	4.5
Unemployment rate	22.1	7.2	24.6	7.5
Average income in 2001	11,015	2,413	10,056	2,339
Observations		20,851		51,342



Figure 3.1 for the volume of transactions per neighborhood. Here also, there are no significant differences between neighborhoods in the treatment group and other neighborhoods. Eventually, the same type of graph is drawn in Figure A4 for the shares of housing buyers and sellers in the three socio-professional categories under study. These graphs show that these shares followed close to parallel trends in renovated and non-renovated neighborhoods before most renovation projects started. After the start of renovation, the shares of executive buyers and executive sellers seem to have decreased in renovated neighborhoods relatively to non-renovated ones, while the gap between the shares of intermediate category buyers in treated and non-treated areas seems to have progressively disappeared, although the large standard deviations do not allow to draw any conclusion.

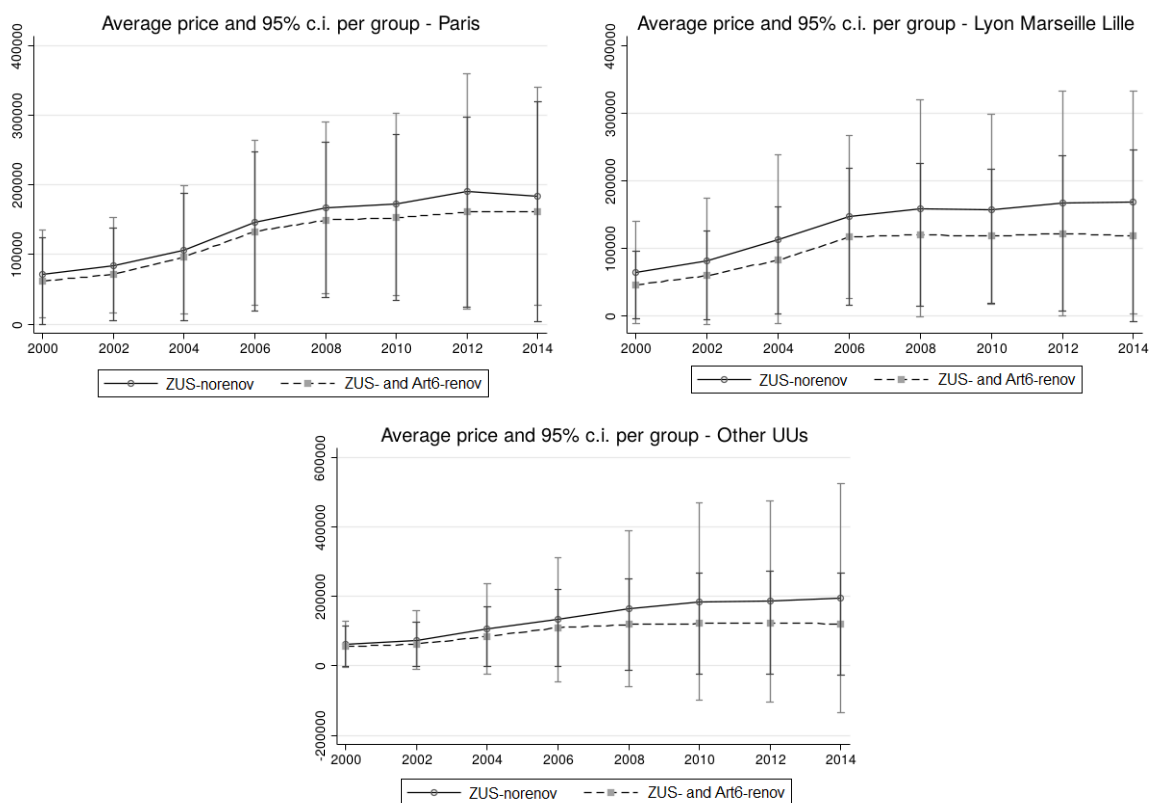


Figure 3.1 – Evolution of average housing prices in renovated and non renovated urban policy neighborhoods in the Parisian urban unit (top left graph), Lyon, Marseille and Lille urban units (top right graph), in the other urban units (bottom graph)

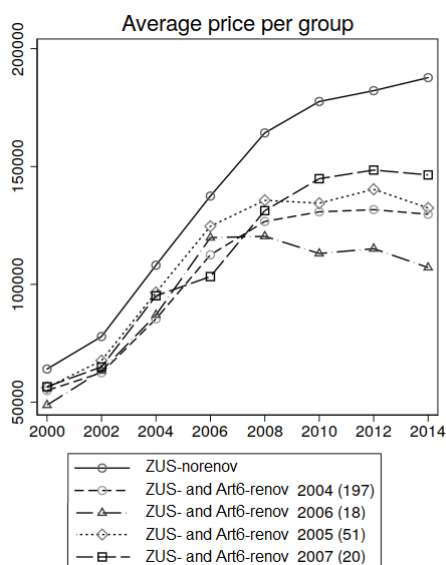


Figure 3.2 – Evolution of average housing prices in renovated and non renovated urban policy neighborhoods, depending on the starting date of renovation. Number of neighborhoods in parentheses. Neighborhoods where renovation started after 2007 are not shown for the sake of readability.

### 3.5 Results

In this section, we first discuss the respective advantages of our two estimators. We then present the results, starting with the global impact of the program on housing prices over the whole period following the first renovation operation and the time-varying treatment impacts. After that, we test the common trend hypothesis, explore the potential for heterogeneous impacts and present some robustness checks. Finally, we evaluate the effects of the program on two complementary outcomes: transaction volumes and socio-professional categories of buyers and sellers.

#### 3.5.1 Relative advantages of the DFE and DID<sub>M</sub> estimators

To start with, we apply the two steps suggested by DCDH in order to evaluate the potentiality of bias in the DFE estimate. We first compute the weights implied in the decomposition of the DFE estimator as an average of neighborhood-level treatment effects.<sup>19</sup> We find that 27.1% of these weights are negative and that they are significantly correlated with the year of the transaction (with a correlation coefficient of 0.468) and with the starting year of renovation (with a correlation coefficient of -0.375). Given that the individual treatment effects are likely

19. The following results are obtained with the `twowayfeweights` Stata package.

to depend on these two dimensions for reasons explained before, the estimation of the average treatment effect based on the DFE estimator might be biased. We then compute the ratio of the absolute value of the DFE estimate ( $|\hat{\beta}_T|$  in Equation (3.1)) over the standard deviation of weights, which is an indicator of the amount of treatment effect heterogeneity that would lead to a DFE estimate with a sign opposite to that of all individual treatment effects. The value of this ratio is 7.1, which suggests that only a large amount of treatment effect heterogeneity would lead to a DFE estimate of opposite sign as compared to the real impact of the program. Although this observation tends to be reassuring with respect to the quality of the DFE estimate, such a large heterogeneity in treatment effects can not be totally excluded. The results regarding the reliability of the DFE estimate are thus ambiguous and advocates in favor of  $DID_M$  estimations, of which unbiasedness is ascertained.

On the other hand, the DFE estimator can be combined with matching and weighting procedures in order to improve the comparability of treated and control groups, which is not possible with the  $DID_M$  estimator. Additionally, the DFE estimator has the advantage of yielding more precise estimates than the  $DID_M$  estimator. Indeed, several specificities of the  $DID_M$  estimator increase the size of standard errors. First, the  $DID_M$  method uses data aggregated at the level of neighborhood  $\times$  pair of years. Second, it uses fewer neighborhoods than the DFE method, because the requirement for a neighborhood to be taken into account in the estimation is more stringent, as explained in Section 3.3. Eventually, as noted by DCDH, in the very stylized case where errors can be assumed to be homoskedastic and uncorrelated, the Gauss-Markov theorem implies that the DFE estimator is the lowest variance estimator. All these factors are likely to explain the larger standard deviation of the  $DID_M$  estimates that will be observed in the results in the next paragraphs. The bias-variance trade-off between the  $DID_M$  and the DFE estimators conjectured by DCDH is hence verified in our setting, with the  $DID_M$  estimator allowing for the alleviation of bias and the DFE estimator for the reduction of variance.

Given the mitigated results regarding the DFE estimate's bias and its merit in terms of variance, we present in the following results based on both DFE and  $DID_M$  estimators.

### 3.5.2 Urban renewal policy impact on property prices

**Global treatment effects.** We start by analyzing the global effect of the program on housing prices at the aggregate level of France, estimating Equation (3.1) for the DFE estimation and then its  $DID_M$  counterpart. These results are presented in Table 3.3, where explanatory variables are progressively introduced. In Column 1, only neighborhood and year fixed effects are included in the regression. In Column 2, housing controls are added. In Column 3, the distance of the transaction to the center of the urban unit is further introduced. Eventually, in

Column 4, urban unit trends complete the set of control variables.<sup>20</sup> Table 3.3 indicates that the estimated effect of the PNRU program on housing prices tends to zero with the introduction of additional control variables. Indeed, the estimated effect varies, in the case of the DID<sub>M</sub> method, from a non-significant effect of around -6.5% in Column 1 to a non-significant effect of around 0.3% in our preferred specification in Column 4. In the case of the DFE method, the estimated effect varies from a non-significant -5.9% in Column 1 to a non-significant effect of around 1.1% in Column 4. Introducing housing characteristics especially mitigates the estimated DID<sub>M</sub> coefficient and, to a lesser extent, the DFE coefficient, which suggests that housing units transacted in neighborhoods under renovation probably experienced a decrease in quality relatively to housing units transacted in control neighborhoods. When all explanatory variables are included, the estimate of global treatment effects given by the DFE estimator (1.1%) is compatible to that obtained with the DID<sub>M</sub> estimator (0.3%), given the size of the standard errors. On the overall, Table 3.3 suggests that the program did not have a significant impact on housing prices, or that this effect was smaller than 3.5% (resp. 2.9%) on average according to the upper bound of the confidence interval of the DID<sub>M</sub> (resp. DFE) coefficient in Column 4.

**Time-varying treatment effects.** Figure 3.3 displays the time-varying effects of the program based on DID<sub>M</sub> and DFE estimates, with the same control variables as in Column 4 of Table 3.3. This temporal decomposition of effects increases confidence intervals in both methods, due to a decrease in the number of observations available for the computation of each estimate. Nevertheless, the graphs seem to corroborate the results of Table 3.3. Indeed, non-negligible point estimates are obtained after 4-5 and 6-7 years in the DFE method, but they are not significant at the 5% level and point estimates go down to 0 after 8-9 and 10 years. The DID<sub>M</sub> method, based on a more robust but less precise identification strategy, exhibits a similar pattern with, nonetheless, one significant effect after 4-5 years. Overall, the time-varying estimates thus confirm the absence of a significant or sustained impact of the program on housing prices.

**Placebos and pre-trends.** Both identification methods used in this paper are based on the hypothesis that the evolution of housing prices is the same in the treated and control neighborhoods before the start of renovation. Figure 3.3 presents, for the DID<sub>M</sub> method (left panel),

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20. Table A1 in Appendix gives the estimated coefficients for the control variables in the four DFE estimations. Most control variables are very significant and their estimated effects on housing prices are consistent across specifications and in line with common sense. In particular, estimated year fixed effects suggest that housing prices increased from 2000 to 2008, but decreased afterwards on average, which is consistent with the timing of the 2008 crisis.

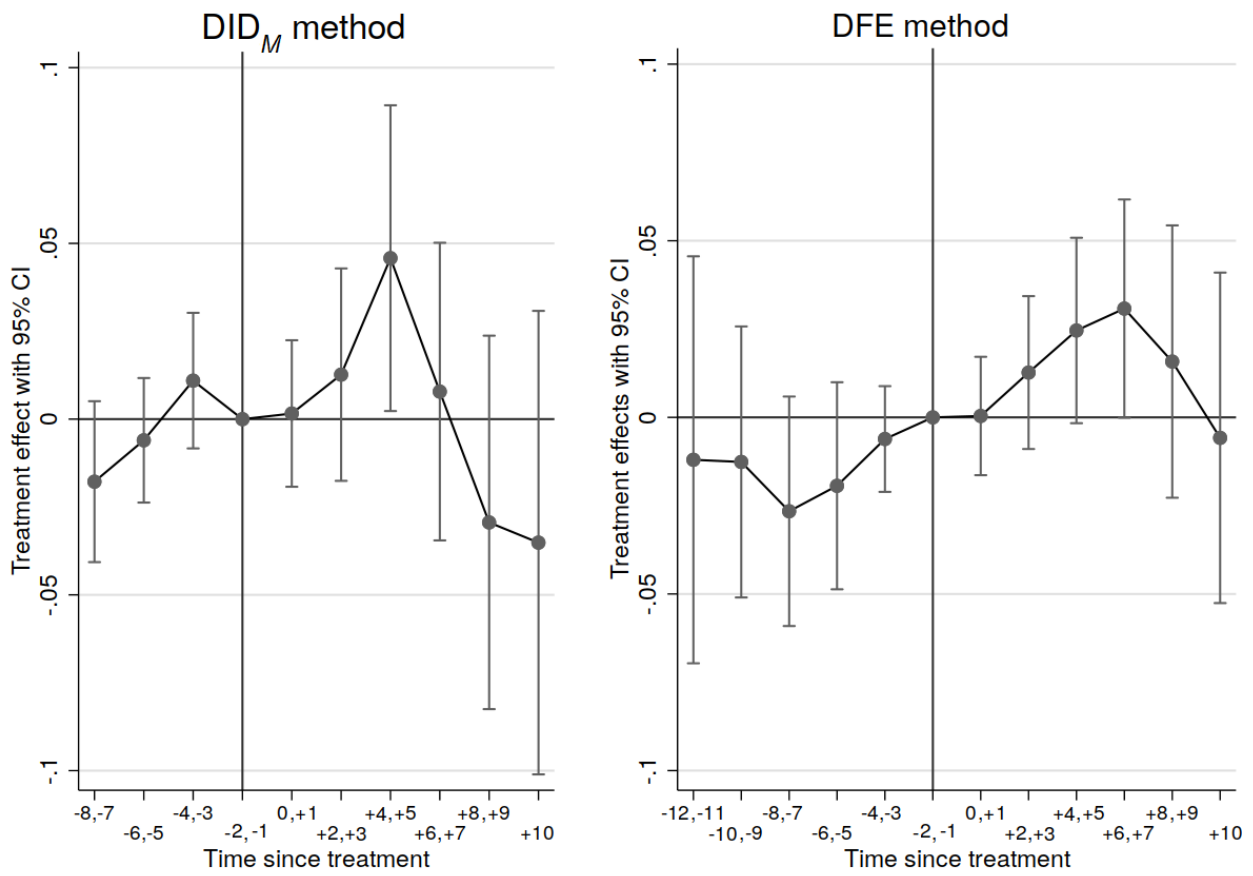


Figure 3.3 – Estimated time-varying impacts of the PNRU program on housing prices, and placebo or pre-trend coefficients

Table 3.3 – Impact of the PNRU program on housing prices - Different sets of controls

	Fixed effects (1)	+ Housing controls (2)	+ Distance (3)	+ Urb. unit trends (4)
<hr/>				
DID <sub>M</sub> estimator				
$\beta_T^{(a)}$	-0.0646 (0.0503)	-0.0044 (0.0213)	-0.0027 (0.0213)	0.0030 (0.0162)
Total observations <sup>(b)</sup>		100,693		
Total switchers <sup>(c)</sup>		38,600		
<hr/>				
DFE estimator				
$\beta_T^{(a)}$	-0.0594 (0.0356)	-0.0352 (0.0226)	-0.0348 (0.0227)	0.0105 (0.0096)
R-squared	0.513	0.824	0.824	0.847
Observations		72,193		
<hr/>				
Controls				
Years and neigh. fixed eff.	X	X	X	X
Housing unit characteristics		X	X	X
Distance to urb. unit center			X	X
Urban unit time trends				X
<hr/>				

Notes: The dependent variable is the log price of the housing transaction. Estimation method is OLS. (a)  $\beta_T$  is the estimated average effect of renovation computed over the years following the start of renovation. For the DFE method, it corresponds to  $\beta_T$  in Equation (3.1). For the DID<sub>M</sub> method, it is computed as a weighted average of time-varying effects, with weights proportional to number of switchers used in each time-varying effect estimation (`prop_number_switchers` option in the `did_multipligt` Stata package) (b) The total number of observations is the sum over time of the numbers of transactions used to estimate each effect. (c) The total number of switchers is the sum over time of the numbers of transactions in neighborhoods entering the treatment. Housing unit characteristics are described in the data section. Urban unit time trends are quadratic for the DFE estimator and linear for the DID<sub>M</sub> estimator. A trend specific to the municipality of Paris is included. Robust standard errors clustered at the neighborhood level in parentheses. \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

the placebo effects, and, for the DFE method (right panel), the pre-trend coefficients.<sup>21, 22</sup> It

21. For an easier comparison with DFE results, the graphs presented here for DID<sub>M</sub> placebo tests differ from those produced by the `did_multipligt` Stata package, in two ways. First, the placebo coefficients plotted in our graphs represent evolutions during the  $i$  periods preceding the start of renovation instead of one-year evolutions. Second, the DID<sub>M</sub> placebo coefficients consider the evolution of the outcome between  $T(n) - i - 1$  and  $T(n) - i$ , so that a positive coefficient is associated with an increase in the outcome over time, whereas the opposite holds for DFE pre-trends, where a positive coefficients means that the outcome at time  $-i$  is higher than at time 0. We therefore take the opposite of placebo coefficients produced by the `did_multipligt` Stata package. In practice, we compute the relevant sum of opposites of `did_multipligt` placebo coefficients (i.e. for the  $i$  periods preceding renovation for coefficient  $-i$ ), weighted by the number of transactions associated with each estimated coefficient. The standard deviations are computed using the covariance matrix of estimated placebo coefficients. We also include in the graph a non-estimated 0 coefficient at time 0, although the DID<sub>M</sub> estimator does not involve any normalization. In summary, the  $-i$  coefficient presented on the graphs refers to the difference  $Y_{T(n)-i} - Y_{T(n)}$  with  $Y$  the outcome and  $T(n)$  the starting year of renovation. Although the two types of graphs are presented in parallel, we bear in mind that the two estimators are based on different identification methods and that the plotted coefficients have different interpretations.

22. Whatever the estimator, we do not show coefficients estimated on 20 or less renovated neighborhoods. This is why there are only 6 coefficients for pre-trends and 3 coefficients for placebos. The difference between these two numbers is explained by the stronger data requirements of the DID<sub>M</sub> estimator, as exposed in subsection 3.3.2.

is clear that all pre-trend and placebo coefficients are small and not significantly different from 0, which suggests that treated and control groups indeed experienced similar housing price trends before the start of renovation.

**Heterogeneities.** Taking advantage of the unusually large scale of this urban renewal program, we examine in this subsection whether the non-significant global impact of the program hides some heterogeneous effects that may countervail each other. We focus on three different heterogeneity dimensions: the size of the urban unit the neighborhood is located in, the amount of funding per housing unit received by the neighborhood for its renovation, and the initial share of public housing in the neighborhood.<sup>23</sup> The size of urban unit is likely to be correlated to tension on the housing market, hence a source of treatment effect heterogeneity. The other two dimensions are likely to be linked to treatment intensity, therefore also a potential source of differentiation in our sample.

First, we divide the sample into two categories of transactions, those located in the four most populous urban units of France (i.e the four with more than one million inhabitants: Paris, Lyon, Marseille and Lille), and those located in the rest of metropolitan France. In Table 3.4, Column 1 shows the mean impact of the program in the four largest urban units, and Column 2 the mean impact of the program in the rest of France. These two impacts are not significantly different from zero, irrespective of the method. Their standard errors also indicate that they are not statistically different from each other.

Then, we investigate whether the amount of funding per housing unit received by the neighborhood for its renovation modifies the impact of the program. To this aim, we divide the sample of treated transactions into two categories, those located in neighborhoods that received more than the median funding per housing unit, i.e. more than €24,268 per housing unit, and those located in neighborhoods that received less than this median funding.<sup>24</sup> In Table 3.4, Column 3 and Column 4 show that the mean impacts of the program estimated on the two subsamples are not statistically different from zero in both methods and they are clearly not statistically different from one another.

To finish with, we examine whether the initial share of public housing in the neighborhood affects the impact of the program. Indeed, the share of public housing could be an indicator

23. The level of funding considered is the ratio of total funding over the number of housing units existing in 1999 as observed in Census data and not the number of housing units involved in the renovation. For the sake of simplicity, we only speak of "funding per housing unit" in the following.

24. The median funding per neighborhood in the ANRU data is €55.4 millions. The median funding per neighborhood in our sample of neighborhoods is higher with €65.6 millions, due to the selection of neighborhoods where transactions occurred, which are likely to be larger. Moreover, the weight of large neighborhoods is increased in the transaction sample, which explains the higher median funding per neighborhood observed in our final data: €109 millions. This finally explains the rather high median funding per housing unit observed here. Our analysis therefore concerns higher than average funding levels, which gives even more weight to the result of absence of any impact of the program, if one assumes that higher funding should lead to higher impacts.

of the treatment intensity, given that renovation operations are focused on public housing; it could also be that this share is an indicator of the initial level of deprivation, hence of potential for improvement. We divide the neighborhoods into two categories: above and below the median share of public housing in 1999 (i.e. 45.2 %). Column 5 and Column 6 show that the impacts estimated on the two subsamples are, once more, not significantly different from zero in the DID<sub>M</sub> method. The effect of the program in neighborhoods with more than the median initial share of public housing, when estimated with the DFE method, is however significantly positive at the 5% level with a point estimate of 1.8%. The point estimate with the DID<sub>M</sub> method is very close (1.6%), but statistically not significant. Still, the impacts measured in the two subsamples are clearly not statistically different from each other in both methods.

From this study of heterogeneities, it appears that the non-significant or hardly sizable effects of the program do hold on subsamples defined along the three investigated dimensions.

Table 3.4 – Heterogeneities in the program’s impacts depending on urban unit size, amount of renovation funding and initial share of public housing

	City size		Funding level		% pub. housing in 1999	
	Four largest (1)	Others (2)	High (3)	Low (4)	High (5)	Low (6)
DID <sub>M</sub> estimator						
$\beta_T$	0.0302 (0.0188)	-0.0091 (0.0274)	0.0254 (0.0212)	-0.0201 (0.0208)	0.0159 (0.0222)	-0.0078 (0.0343)
Observations <sup>(a)</sup>	57,418	43,274	74,121	77,595	43,068	56,565
DFE estimator						
$\beta_T$	0.0096 (0.0129)	0.0118 (0.0134)	0.0209 (0.0146)	0.0099 (0.0113)	0.0181** (0.0090)	0.0159 (0.0164)
R-squared	0.856	0.814	0.858	0.852	0.846	0.851
Observations	38,780	33,413	46,525	46,519	36,637	35,505

Notes: Dependent variable is the log price of the housing transaction. Estimation method is OLS.  $\beta_T$  is the estimated average effect of renovation over the years after renovation started. Column 1 corresponds to France’s four largest urban units (Paris, Lyon, Marseille, Lille). Column 2 corresponds to the other urban units. Column 3 restricts the treated group to renovated neighborhoods that received more than €24,268 of funding per dwelling in the neighborhood. Column 4 restricts the treated group to renovated neighborhoods that received less than €24,268 of funding per dwelling in the neighborhood. Column 5 is for a subsample of neighborhoods with more than 45.2 % public housing in 1999. Column 6 is for a subsample of neighborhoods with less than 45.2 % public housing in 1999. Explanatory variables included are housing unit characteristics, distance, urban unit time trends and year and neighborhood fixed effects. Robust standard errors in parentheses are clustered at the neighborhood level. \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

### 3.5.3 Robustness checks

In order to assess the robustness of these results, we first experiment alternative clustering levels and geographical fixed effects levels. We then use matching and weighting procedures



combined with the DFE estimator to see whether improving the comparability between the treatment and control groups alters the results. Eventually, we verify that restricting our dataset to obtain a balanced panel of neighborhoods does not change the results for the time-varying effects.

**Varying fixed effects and cluster levels.** Table A2 shows estimates of the program’s effect obtained with the DFE method, when varying both clustering and fixed effects levels. Column 1 repeats the baseline estimate shown in Column 4 of Table 3.3. In Column 2, the clustering is shifted to the urban unit level, and to the infra-communal IRIS level in Column 3. In Column 4, both fixed effects and clustering are set at the infra-communal IRIS level.<sup>25</sup> It is clear from this table that variations in the clustering and fixed effects geographical level do not drastically affect the results, the estimated impact of the program remaining insignificant in all of these alternative estimations. Nonetheless, clustering at the urban unit level shows a very slight positive impact of renovation on housing prices, significant at the 10% but not the 5% level.

**Matching and weighting methods.** In Table A3 in Appendix, we experiment alternative control groups with the DFE estimator, by using matching and weighting techniques in order to reduce the differences between the treated and control groups. We first estimate a propensity score corresponding to the probability for each transaction to be located in a renovated neighborhood. This score is estimated based on housing unit characteristics and neighborhood characteristics, the latter measured in relative value with respect to all deprived neighborhoods in the same urban unit and introduced with a quadratic form.<sup>26</sup> Using this propensity score, a control observation corresponding to a weighted average of transactions located in a non-renovated neighborhood is built for each transaction located in a renovated neighborhood.<sup>27</sup> In the first two columns of Table A3, we use a traditional kernel weighting. In the third and fourth columns, we use Lechner, Miquel and Wunsch (2011)’s procedure of weighted radius matching that consists in including in the control group of a treated transaction only transactions of which propensity score is within a given radius from that of the treated transaction, the radius being chosen depending on the density of control observations around each treated observation. In Column 1, the bandwidth chosen for the kernel matching is 0.001. In Column 2, it is 0.06. In Column 3, the maximum weight given to control transactions with respect to total weights is fixed to 0.1 and, in Column 4, to 0.025. After the implementation of these

25. We do not perform the same robustness check with the  $DID_M$  estimator because it is valid only on data aggregated at the neighborhood  $\times$  period level.

26. The propensity score estimation results are presented in Table A4.

27. Whatever the matching method, the region of common support is very large, in line with the idea that, although non-renovated and renovated neighborhoods slightly differ, they still have close profiles.

weighting procedures, we run the same difference-in-difference regression as previously.<sup>28</sup>

For Columns 5 to 7 of Table A3, we use another weighting technique, at the level of neighborhoods rather than transactions.<sup>29</sup> More precisely, we estimate the probability for each urban policy neighborhood to be renovated, based on its characteristics. Then, we weight each neighborhood (renovated and non-renovated ones) depending on the difference between their estimated probability to be renovated and the observed proportion of renovated neighborhoods.<sup>30, 31</sup> The smaller this difference, the larger the weight associated to the neighborhood. We then run a DFE regression, using these weights. In Column 5, the optimal bandwidth is used (Silverman, 1986). In Column 6, the bandwidth is twice the optimal bandwidth. In Column 7, the 25% of non-renovated neighborhoods that are the most distant from the threshold are suppressed while all the remaining neighborhoods are given a weight of 1. It is clear from Table A3 that improving the comparability between the treated and control groups does not alter the results, as none of the estimated coefficients are significantly different from 0.<sup>32</sup>

**Using a balanced panel of neighborhoods.** As a last robustness check, we restrict the panel of neighborhoods so as to obtain a balanced panel. Indeed, given the timing of renovation and the observation period in our data, the temporal effects of the program are not all estimated on the same sets of neighborhoods. For example, the impact of the program after 2 years is estimated on neighborhoods where renovation started in any year between 2004 and 2012, while the impact after 10 years is computed only on neighborhoods where renovation started in 2004. It is also the case for the estimation of pre-trends. This pattern leads to composition effects in the estimation of time-varying treatment effects. Consequently, as a last robustness check, we estimate again  $DID_M$  time-varying effects, keeping only neighborhoods in which renovation started in 2004 or 2005 and restricting the sample to time-varying effects comprised between (-4,-3) and (+8,+9), so that each effect is estimated on exactly the same sample of neighborhoods. The results, depicted in Figure A5, suggest that the program may have had a limited and barely significant short term impact on housing prices, consistent with the effects depicted in Figure 3.3, but that this effect disappeared in the longer run. The corresponding effect averaged over the whole treatment period is non-significant. This last robustness check hence substantiates also our global result of an absence of effect of the PNRU program on

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28. The comparison of the treated and control groups before and after matching corresponding to Column 4 of Table A3 (Lechner's procedure with maximum weight 0.025) is presented in Table A5. Although numerous explanatory variables exhibit a substantial level of bias before matching, this bias becomes smaller than 10% for most of them after. The matching procedure can thus be considered to satisfactorily reduce the difference in characteristics between treated and control transactions.

29. This technique is also used by Ahlfeldt, Maennig and Richter (2017).

30. The following neighborhood-level weights are used:  $w_s = \frac{1}{\lambda\sqrt{2\pi}} \exp\left(-\frac{1}{2}\left(\frac{s_s - \bar{s}}{\lambda}\right)^2\right)$  with  $\lambda$  the bandwidth.

31. This procedure is, in spirit, close to a regression-discontinuity design, in a setting where there is however no explicit eligibility criteria.

32. We also verified the absence of any pre-trend by estimating Equation (3.2).

housing prices at the aggregate level.

### 3.5.4 Impacts of renovation on volumes of transactions and housing buyers and sellers social profile

In this subsection, to obtain a broader picture of the effects of the PNRU program on housing markets in renovated neighborhoods, we complement the study of housing prices by an investigation of housing transaction volumes and buyers' and sellers' social profiles.

**Volume of transacted housing units.** To investigate the impacts of the program on the volume of housing transactions, we apply the same methodologies as for housing prices, considering the volume of transactions aggregated at the neighborhood  $\times$  pair of years level. More precisely, the explained variable is the ratio between the number of housing transactions and the number of housing units in 1999, so that it represents the percentage of housing units that have been transacted in each observed year. For obvious reasons, only distance to the center and urban unit trends are included as control variables. The estimated impacts of the program on the volume of transactions based on DID<sub>M</sub> and DFE estimators are presented in Table 3.5, with the global impact in Column 1 and then impacts depending on city size, level of funding for renovation and initial share of public housing. We observe that the global estimated impact and the impacts depending on city size and level of funding are not significantly different from zero, irrespective of the estimator considered. However, neighborhoods with an initial share of public housing above the median have experienced a significant decrease in (private) housing transactions due to the renovation program. This decrease could translate a lower willingness to sell on the part of owners located in neighborhoods with more public housing because more substantial changes may be expected from the program in these neighborhoods, or reflect an increased uncertainty leading to fewer transactions. However, the difference in effects between neighborhoods with a high or a low share of public housing is clearly not significant at the 95% level so that, taken together, Columns (6) and (7) only mildly suggest an heterogeneity in the program's effects depending on the initial share of public housing.

**Sellers' and buyers' social profile.** Beside prices of transacted housing units and their volume, our dataset also allows us to investigate a rarely available dimension of housing transactions, namely the socio-professional categories of housing sellers and buyers. To do so, we rely on the same DID<sub>M</sub> and DFE methods as described in Section 3.3. The variable of interest is a dummy indicating the socio-professional category of the seller or buyer. A linear probability model is estimated, with explanatory variables including urban unit time trends and distance to the city center only, as housing characteristics are likely to be endogenous with respect to the social category of sellers and buyers. In Table 3.6's Column 1, the variable of interest is a

Table 3.5 – Impact of the PNRU on the ratio of number of housing transactions/number of housing units in 1999

	Whole France (1)	City size		Funding level		Initial % pub. housing	
		4 largest (2)	Others (3)	High (4)	Low (5)	High (6)	Low (7)
DID <sub>M</sub> method							
$\beta_T$	-0.00127 (0.00084)	-0.00134 (0.00159)	-0.00111 (0.00083)	-0.00162 (0.00131)	-0.00062 (0.00082)	-0.00231 (0.00086)	0.00113 (0.00163)
# obs.	5,162	1,858	3,304	3,771	4,401	3,123	1,945
DFE method							
$\beta_T$	-0.00051 (0.00073)	-0.00125 (0.00139)	-0.0000084 (0.00063)	-0.00089 (0.00143)	-0.00048 (0.00060)	-0.00094 (0.00070)	0.00065 (0.00188)
# obs.	4,241	1,434	2,807	2,488	3,232	2,918	1,323
R-squared	0.904	0.906	0.883	0.908	0.910	0.861	0.925

Notes: Transactions are counted at the level of urban policy neighborhoods. Dependent variable is the ratio of number of transactions in year  $t$  over existing dwellings in 1999 in the urban policy neighborhood. Estimation method is OLS.  $\beta_T$  is the estimated average effect of renovation over the years after renovation started. Column 1 is estimated on the whole sample. In Column 2, the sample is restricted to France’s four largest urban units (Paris, Lyon, Marseille and Lille). In Column 3, the sample is restricted to the other urban units with at least one ZUS. Column 4 restricts the treated group to renovated neighborhoods that received more than the median level of funding. Column 5 restricts the treated group to renovated neighborhoods that received less than the median level of funding. Column 6 is for a subsample of neighborhoods with more than 45.2 % public housing in 1999. Column 7 is for a subsample of neighborhoods with less than 45.2 % public housing in 1999. Explanatory variables included are year, distance, urban unit trend, and neighborhood fixed effects. Robust standard errors clustered at the neighborhood level in parentheses. \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$ .

dummy equal to 1 if the seller belongs to the “executive” category and 0 if not. In Column 2, the variable of interest is the same, but for buyers. Columns 3 and 4 (resp. 5 and 6) are similar to Columns 1 and 2, for “intermediate” socio-professional category (resp. “blue-collar” category). The estimates obtained for the whole sample are presented first (top panel), followed by estimates in the four largest urban units (middle panel) and in the other urban units (bottom panel).

Table 3.6 suggests that the PNRU program had indeed some impacts on the profiles of sellers and buyers, although these impacts’ level of significance sometimes varies depending on the estimator. Note that the signs of the estimated effects nearly always coincide in the two methods (except in two cases with the “other cities” subsample) so that, when only the DFE estimate is significantly different from zero but the DID<sub>M</sub> point estimate is close to it, one may think that the program led to a significant effect that cannot be captured with the DID<sub>M</sub> method because of its larger standard errors.

At the aggregate level of France, the only effect that is significant both in the DID<sub>M</sub> and the DFE estimations concerns the share of intermediate category buyers, which appears to have increased due to the program (Table 3.6, column 4, top panel). Yet, this effect is only

significant at the 10% (resp. 5%) level in the  $DID_M$  (resp. DFE) estimation. When restricting the sample to the four largest urban units, this same effect becomes larger and more significant. The program is estimated to have increased the share of intermediate category buyers in the renovated neighborhoods of these cities by between 0.4% and 6.9% (resp. 1.1% and 4.8%) according to the 95% confidence interval of the  $DID_M$  (resp. DFE) estimate. However, the program does not appear to have had a similar effect in the other urban units.

Considering now the other estimates that are significantly different from zero in the DFE method at the aggregate level (but not in the  $DID_M$  method), we can observe that the program appears to have reduced the share of executive buyers (at the 10% significance level) and increased the share of blue-collar sellers (at the 5% significance level). The corresponding point estimates obtained with the  $DID_M$  method, though not significant, are greater than in the DFE method, which yields some support to both effects. Eventually, the  $DID_M$  method suggests that the share of executive sellers could have been reduced by the program (at a 10% significance level). When looking at large versus smaller cities, it further appears that the share of sellers from the intermediate category decreased in the cities outside the four largest, while the share of blue-collar as sellers increased (although this result is only supported by the DFE estimate). This would mean that in the medium and small cities, intermediate categories tended to stay more in the renovated neighborhoods, contrary to lower-income categories.

In order to shed further light on those results, we investigate the time-varying effects of the program on the transition probabilities of housing units from a given initial socio-professional category (the buyer's) to a given final socio-professional category (the seller's), focusing on the four largest cities, where the effects of the program are the strongest. To this aim, we use the  $DID_M$  method and change the explained variable to a dummy equal to 1 if the transaction took place between a given initial socio-professional category and a given final one. Using this approach, we obtain nine graphs corresponding to the nine possible transitions between the executive, intermediate and blue-collar categories. We show in Figure 3.4 the three ones exhibiting the larger effects. First, the top-left graph shows that the program seems to have reduced the probability of transactions between executives. The bottom graph may suggest that the probability of transactions from an intermediate category seller to an executive buyer slightly increased, although none of the coefficients is significant at the 5% level. Eventually, the top-right graph indicates a clear increase in the probability of transactions from a blue-collar seller to an intermediate category buyer. These three effects are also obtained with the DFE method (see Figure A6 in Appendix).

Together, these results may be interpreted in the following way. The program led to a reduction in the share of executive buyers and sellers, to a reduction in the share of transactions between executives and, at the same time, to a slight increase in transactions between intermediate category sellers and executive buyers. Thus, the reduction in transactions between exec-

utives does not seem to translate in a reduction in the attractiveness of renovated neighborhoods for executives, but rather an increased willingness of executives to stay in these neighborhoods and not sell their housing unit. This, in turn, encourages executives who cannot acquire a housing unit from their own socio-professional category to increasingly buy from a lower socio-professional category (the intermediate category). Additionally, the share of buyers from the intermediate category and the share of blue-collar sellers increased, and the probability of an upward transition from a blue-collar seller to an intermediate category buyer increased. These effects corroborate each other, suggesting an increase in the attractiveness of renovated neighborhoods and shifts of housing units in these neighborhoods from lower-income to higher-income categories. These upward transitions seem to correspond more to transitions from executives to medium-income households in the four largest cities, and to transitions from blue-collar to medium-income categories in small and medium cities.

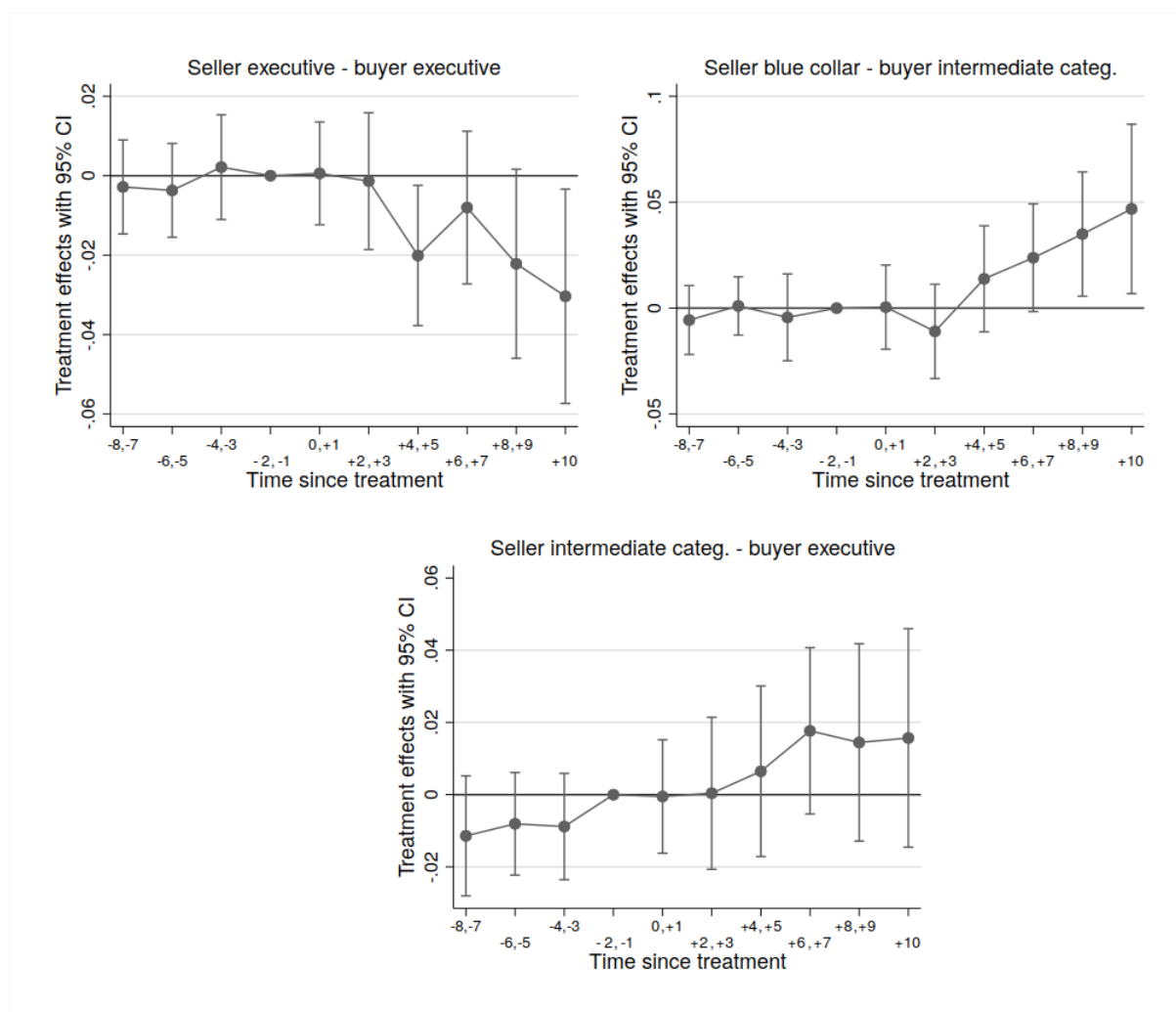


Figure 3.4 – DID<sub>M</sub> placebo and time-varying treatment effects on transitions probabilities in the four largest cities. Robust standard errors clustered at the neighborhood level

Table 3.6 – Impact of the PNRU on the socio-professional category of housing sellers and buyers

	Executive		Interm. cat.		Blue-collar	
	sellers (1)	buyers (2)	sellers (3)	buyers (4)	sellers (5)	buyers (6)
Whole sample						
DID <sub>M</sub> estim.	-0.0169*	-0.0131	-0.0158	0.0224*	0.0193	-0.0140
	(0.0102)	(0.0102)	(0.0118)	(0.0136)	(0.0123)	(0.0134)
# obs.	100,009	100,009	100,009	100,009	100,009	100,009
DFE estim.	-0.00228	-0.0119*	-0.0103	0.0180**	0.0151**	-0.000570
	(0.00606)	(0.00609)	(0.00719)	(0.00704)	(0.00741)	(0.00734)
# obs.	61,904	65,678	61,904	65,678	61,904	65,678
Four largest cities						
DID <sub>M</sub> estim.	-0.0232*	-0.0145	0.0080	0.0365**	0.0232	-0.0158
	(0.0128)	(0.0137)	(0.0149)	(0.0164)	(0.0150)	(0.0178)
# obs.	57,284	57,356	57,284	57,356	57,284	57,356
DFE estim.	-0.0070	-0.0133	0.00057	0.0295***	0.0062	-0.0032
	(0.0082)	(0.0086)	(0.00875)	(0.0093)	(0.0092)	(0.0091)
# obs.	33,707	35,630	33,707	35,630	33,707	35,630
Other cities						
DID <sub>M</sub> estim.	0.00014	0.0027	-0.0420**	0.0099	0.0050	-0.0206
	(0.01566)	(0.0141)	(0.0185)	(0.0233)	(0.0209)	(0.0212)
# obs.	42,724	42844	42,724	42844	42,724	42844
DFE estim.	0.00538	-0.00841	-0.0302**	0.00113	0.0300**	0.00237
	(0.00816)	(0.00790)	(0.0124)	(0.0106)	(0.0121)	(0.0124)
# obs.	28,197	30,048	28,197	30,048	28,197	30,048

Notes: Dependent variable is a dummy equal to 1 if (1) the housing seller is an executive, (2) the housing buyer is an executive, (3) the housing seller belongs to an intermediate category, (4) the housing buyer belongs to an intermediate category, (5) the housing seller is a blue-collar, (6) the housing buyer is a blue-collar, and 0 if not. Estimation method is OLS.  $\beta_T$  is the estimated average effect of renovation over the years after renovation started. Explanatory variables included are distance to the urban unit center and linear urban unit time trends for DID<sub>M</sub> and quadratic urban unit time trends for DFE method. Robust standard errors clustered at the neighborhood level in parentheses. \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

### 3.6 Conclusion

In a context of urban segregation and concentration of poverty in deteriorating neighborhoods, urban renewal programs have been implemented in a number of countries, like France, Germany, Spain, the Netherlands and the US. A few attempts at measuring their impacts have been proposed in the literature, leading to contrasted results depending on the context and leaving open the question of efficiency of this type of intervention in changing the attractiveness of these neighborhoods. Existing studies analyzed limited scale renovation programs or considered renovation’s impacts at the city level. In this article, we analyze the effects of the

French *Programme National de Rénovation Urbaine*, an ambitious urban renewal program led in around six hundreds of deprived neighborhoods and targeting large public housing developments and their environment. Using the  $DID_M$  estimator proposed by DCDH and complementing it by the potentially biased but also more precise traditional double fixed effect difference-in-differences estimator, we analyze the impact of this program on housing prices, volumes of transactions and buyers and sellers social profiles.

We do not find any significant impact of the French renovation program on local housing prices, even when studying separately neighborhoods that received a high amount of funding per housing unit, neighborhoods where the initial share of public housing was particularly large and neighborhoods located in the largest urban units of France where tension on the housing market is high. Our results indicate that the program had, in any case, an impact of less than 3.5% on housing prices. These results contrast with most studies on the impacts of urban renewal projects in the United States that find significant impacts of renovation on housing prices (Ding, Simons and Baku, 2000; Rossi-Hansberg, Sarte and Owens III, 2010; Collins and Shester, 2013), but it is consistent with a number of studies led more recently in the U.S. (Chen, Glaeser and Wessel, 2019) or in other contexts (Aarland, Osland and Gjestland, 2017; Ahlfeldt, Maennig and Richter, 2017) that obtain small or insignificant effects of renovation. We do not find any significant impact of renovation on the volume of transactions either, apart from a decrease in neighborhoods likely to have experienced the most numerous demolitions. However, we do find sizable effects on the socio-professional characteristics of buyers and sellers. Indeed, we find evidence that the program led to an increased number of upward transitions of housing units (from a blue-collar seller to an intermediate category buyer or from an intermediate category seller to an executive buyer) and to a reduction of housing transactions among executives, suggesting an increased interest of upper socio-professional categories to invest in the renovated neighborhoods or to remain in them.

We interpret our results as evidence that, despite its non-significant effect on housing prices, the program was successful, in some measure, in driving renovated neighborhoods up on the social ladder. By looking at flows through the lens of housing units transactions instead of stocks of population, our analysis complements Guyon (2016) and González-Pampillón, Jofre-Monseny and Viladecans-Marsal (2019)'s studies of urban renewal impacts on poverty rates and population social composition. It allows indeed for a finer view on the social changes induced by urban renewal and exemplifies the fact that the absence of a sizable aggregate impact on housing prices may hide some non negligible effects on the social profile of new homeowners, that could be a signal of further changes in these neighborhoods.

The attraction of more intermediate category and executive buyers evidenced in our results may have all kinds of effects on the long-term trajectories of renovated neighborhoods, which are difficult to anticipate. One may expect positive impacts at school and on the labor market



for members of poorer households, for example through network effects. However, it is difficult to predict whether these effects will be sizable. To finish with, in view of the amounts invested in the PNRU program and of the limited impacts estimated in the present article, our results appear to corroborate the idea that place-based policies may not be the most efficient mean to durably alter deprived neighborhoods' trajectories and to solve social ills.

### 3.7 Appendix

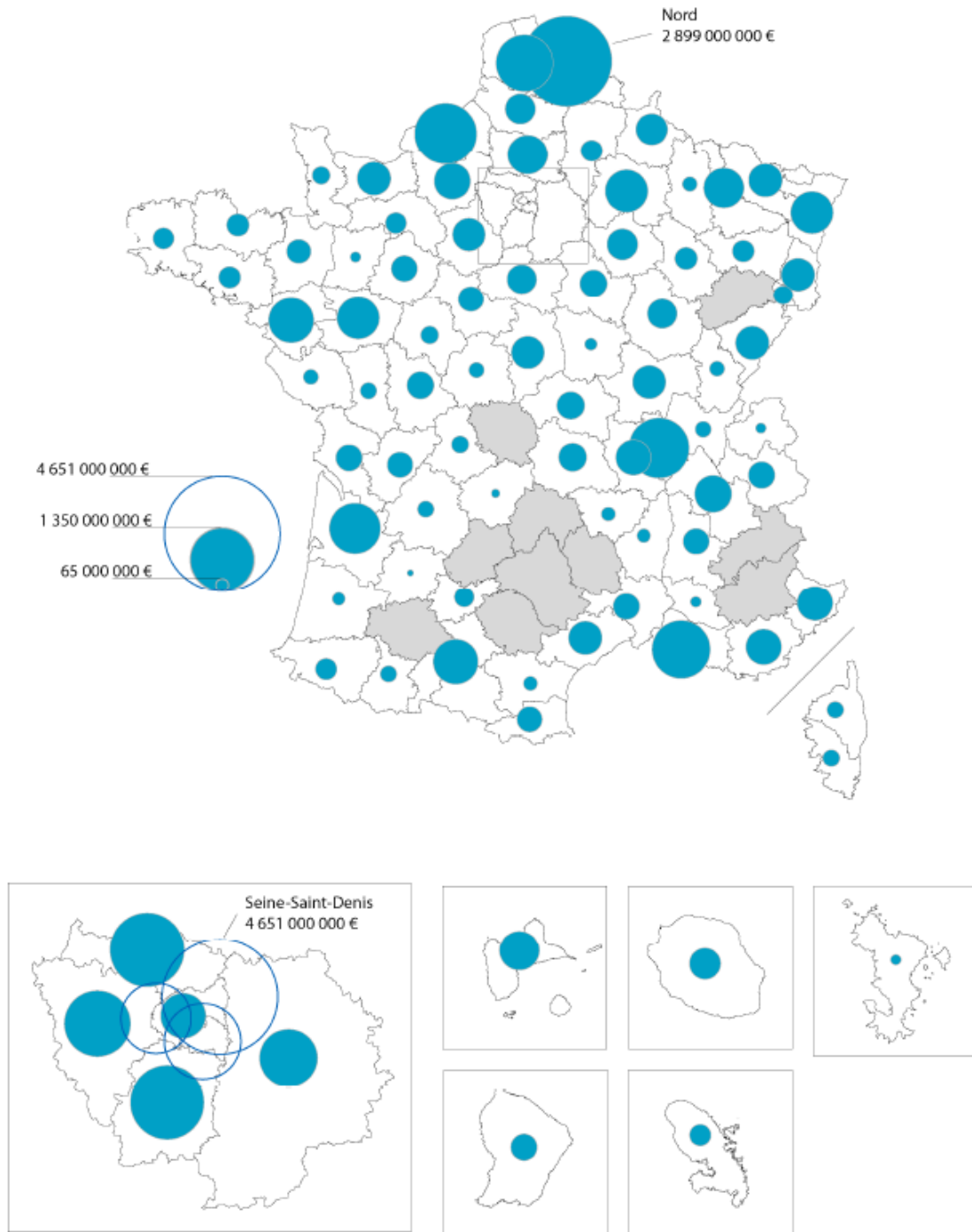


Figure A1 – Geographical distribution of PNRU funding at the departmental level

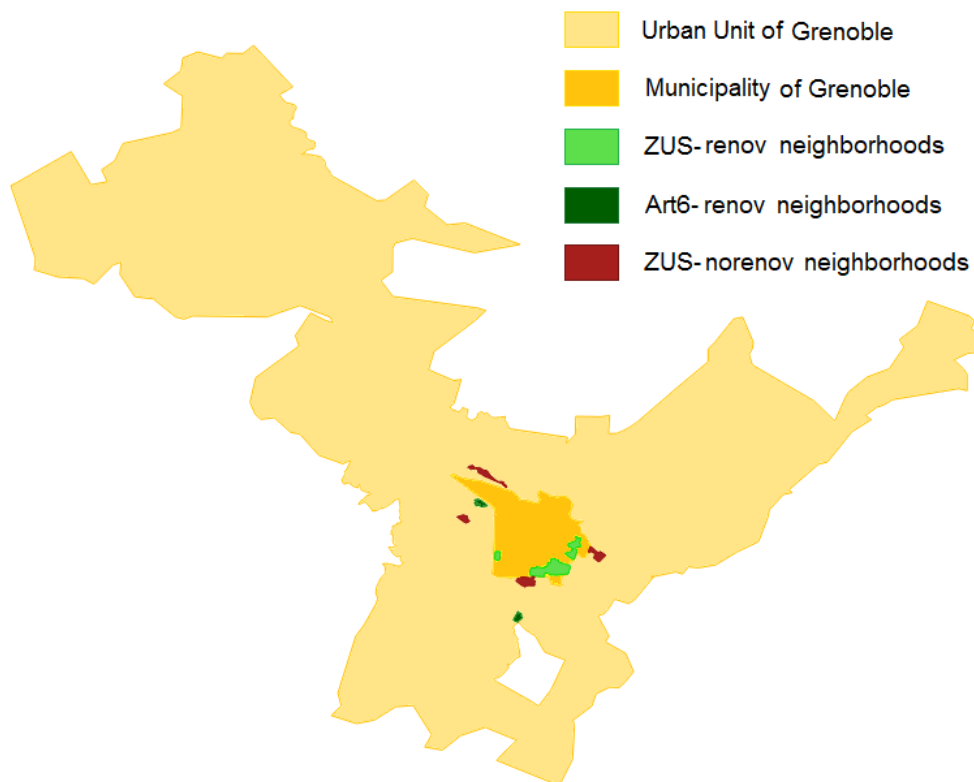


Figure A2 – The urban unit of the city of Grenoble and its urban policy neighborhoods

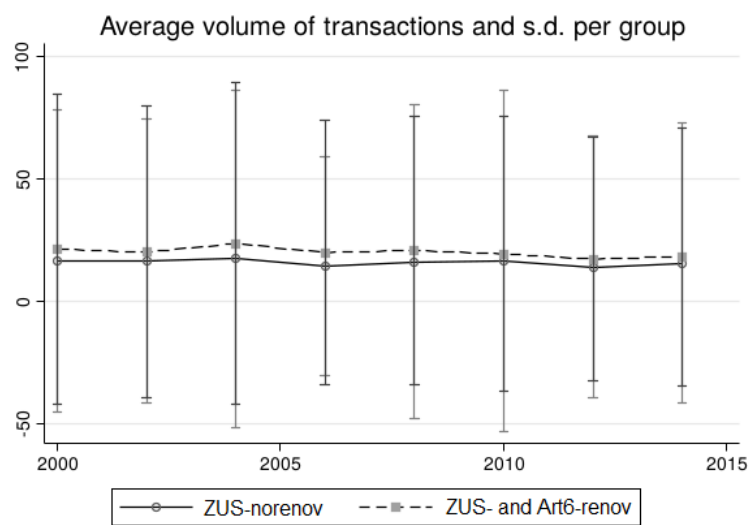


Figure A3 – Evolution of the average number of transactions per neighborhood in renovated and non renovated urban policy neighborhoods

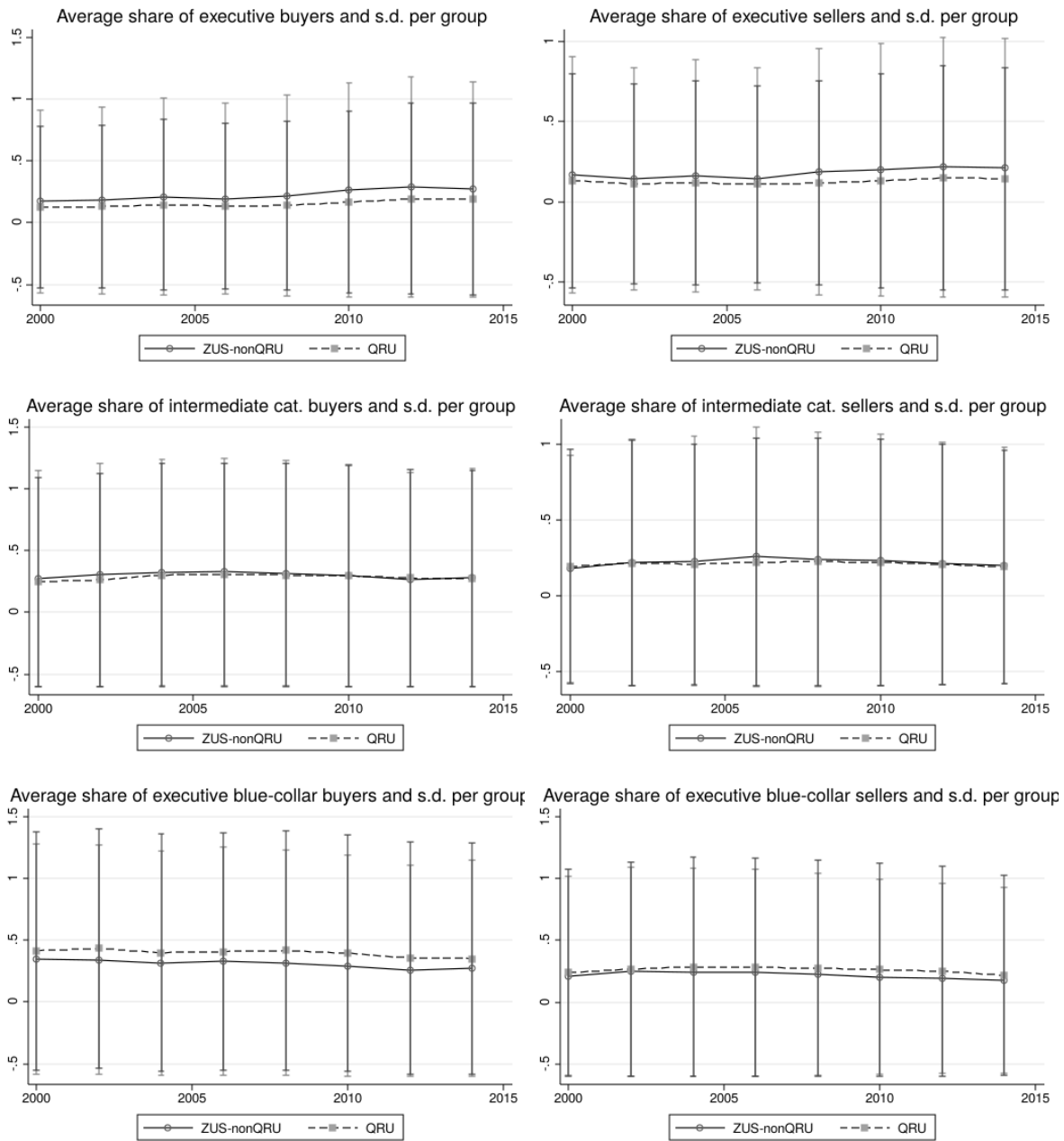


Figure A4 – Evolution of the average share of executive buyers (resp. executive sellers, intermediate category buyers and intermediate category sellers, blue-collar buyers, blue-collar sellers, retired buyers, retired sellers) per neighborhood in renovated and non renovated urban policy neighborhoods

Table A1 – Baseline results - Impact of the PNRU program on housing prices (From the left to the right: Progressive introduction of additional explanatory variables)

	(1) Neigh.& yr FE	(2) + Hsg char.	(3) + dist.	(4) + UU trends
$\beta_T$	-0.0594*	-0.0352	-0.0348	0.00866
2002	0.156***	0.165***	0.165***	0.145***
2004	0.501***	0.482***	0.482***	0.419***
2006	0.828***	0.810***	0.810***	0.712***
2008	0.914***	0.892***	0.892***	0.768***
2010	0.910***	0.882***	0.881***	0.723***
2012	0.934***	0.908***	0.908***	0.724***
2014	0.913***	0.846***	0.846***	0.643***
Apart.#1 room		-1.697***	-1.700***	-1.695***
House#1 room		-1.763***	-1.767***	-1.798***
Apart.#2 rooms		-1.078***	-1.080***	-1.082***
House#2 rooms		-0.886***	-0.886***	-0.888***
Apart.#3 rooms		-0.721***	-0.724***	-0.725***
House#3 rooms		-0.499***	-0.500***	-0.498***
Apart.#4 rooms		-0.501***	-0.504***	-0.504***
House#4 rooms		-0.217***	-0.218***	-0.216***
Apart.#5 rooms		-0.312***	-0.314***	-0.318***
Less than 5 years old		0.0462	0.0468	0.0616**
Floor area per room		0.0341***	0.0341***	0.0341***
0 bathroom		-0.230***	-0.230***	-0.172***
2 bathrooms		0.102***	0.102***	0.103***
3 bathrooms		-0.0858***	-0.0852***	-0.0908***
Const 0-1850		-0.141***	-0.141***	-0.114***
Const 1851-1913		-0.206***	-0.207***	-0.170***
Const 1914-1947		-0.149***	-0.150***	-0.144***
Const 1948-1969		-0.109***	-0.110***	-0.109***
Const 1970-1980		-0.0765***	-0.0762***	-0.0762***
Const 1992-2000		0.0886***	0.0882***	0.0875***
Const 2001-2010		0.144***	0.145***	0.138***
Const 2011-2020		0.292***	0.297***	0.288***
Const unknown		-0.0831***	-0.0835***	-0.0832***
Dist transaction-center UU			-2.69e-05***	-2.66e-05***
Constant	11.54***	11.94***	12.08***	11.77***
Observations	72,193	72,193	72,193	72,193
R-squared	0.513	0.824	0.824	0.844

Notes: Dependent variable is the log price of the housing transaction. Estimation method is OLS.  $\beta_T$  is the estimated average effect of renovation over the years after renovation started. Explanatory variables are: year and neighborhood fixed effects in Column 1, housing characteristics (interaction term between housing type (apartment or house) and number of rooms, dummy equal to one if the housing unit was constructed less than 5 years before the transaction, dummies for the construction period (Const t1-t2 is equal to 1 if the housing unit was constructed between year t1 and year t2) are added in Column 2, distance to the center of the urban unit is added in Column 3. Quadratic trends at the urban unit level are included in Column 4 but their coefficients are omitted from the table for lack of space. Robust standard errors clustered at the neighborhood level in parentheses. \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

Table A2 – Robustness checks: Alternative clustering and fixed effects’ geographical levels - DFE estimator

DFE estimator	FE neigh. cluster neigh.	FE neigh. cluster UU	FE neigh. cluster IRIS	FE IRIS cluster IRIS
	(1)	(2)	(3)	(4)
$\beta_T$	0.0105 (0.0096)	0.0105* (0.0057)	0.0105 (0.0067)	0.0094 (0.0065)
Observations	72,193	72,193	72,193	72,193
R-squared	0.847	0.847	0.847	0.867

Notes: Dependent variable is the log price of the housing transaction. Estimation method is OLS.  $\beta_T$  is the estimated average effect of renovation over the years after renovation started. In Column 1, fixed effects and standard error clustering are at the neighborhood level. In Column 2, fixed effects are at the neighborhood level and standard error clustering at the urban unit level. In Column 3, fixed effects are at neighborhood level and standard error clustering is at the infra-communal IRIS level. In Column 4, fixed effects and standard error clustering are at the infra-communal IRIS level. Explanatory variables included are housing unit characteristics, distance, urban unit time trends and year and neighborhood fixed effects. Robust standard errors clustered at the level indicated in column title in parentheses. \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

Table A3 – Robustness checks: Difference-in-differences with propensity score matching or neighborhood weighting - DFE estimator

	Propensity score matching				Weighting procedure		
	Kernel matching		Lechner rad. matching		w/o 25%		
	Bandwidth value		Max weight in %		Bandwidth value	2*opt.	most distant ZUS
	.001	.06	.1	.025	Optimal	2*opt.	Optimal
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$\beta_T$	0.0148 (0.0115)	0.0128 (0.0113)	0.0145 (0.0126)	0.0138 (0.0129)	-0.00919 (0.0167)	-0.00450 (0.0133)	0.00485 (0.00953)
Obs.	71,785	71,936	69,937	59,988	71,868	72,141	70,758
R-squared	0.850	0.846	0.844	0.851	0.844	0.849	0.846

Notes: Dependent variable is the log price of the housing transaction. Estimation method is OLS.  $\beta_T$  is the estimated average effect of renovation over the years after renovation started. In Columns 1 and 2, kernel propensity score matching is used in a preliminary step before the OLS regression, with a bandwidth of 0.001 in Column 1 and 0.06 in Column 2. In Columns 3 and 4 Lechner’s radius matching method is used in a preliminary step, with a maximum weight per transaction of 0.1% of the sample size in Column 3 and of 0.025% of the sample size in Column 4. In Columns 5 to 7, neighborhoods are weighted in a preliminary step, using Silverman (1986)’s methodology, with a bandwidth set at the optimal level in Column 5 and at twice the optimal level in Column 6. In Column 7, the 25% of non renovated neighborhoods, which estimated probability to be renovated is the most distant from the proportion of renovated urban policy neighborhoods, are suppressed from the sample. All the remaining transactions are given a weight equal to 1. Explanatory variables included are housing unit characteristics, distance, urban unit time trends and year and neighborhood fixed effects. Robust standard errors clustered at the neighborhood level in parentheses. \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.

Table A4 – Robustness checks - Propensity score estimation

Logit model	Explained variable: Proba to be in a renovated neighborhood
Relative share of social housing	1.096***
Relative share of owners	2.917***
Relative share of unemployed	9.912***
Relative revenue	-12.75***
Squared relative share of social housing	-0.210***
Squared relative share of owners	-1.180***
Squared relative share of unemployed	-3.939***
Squared relative revenue	4.044***
House	0.0908***
Floor area per room	0.0144***
1 room	-0.455***
2 rooms	-0.218***
4 rooms	-0.0413
≥ 5 rooms	0.0324
0 bathroom	-0.0907
2 bathrooms	-0.0647
Nb of bathrooms unknown	0.0507
Const 0-1850	-0.692***
Const 1851-1913	-0.980***
Const 1914-1947	0.0227
Const 1948-1969	0.117***
Const 1970-1980	0.403***
Const 1992-2000	0.176**
Const 2001-2010	0.369***
Const 2011-2020	0.928***
Const unknown	0.140***
Constant	1.142***
Observations	72,142

Notes: Propensity score estimation used for propensity score matching in Table A3. Dependent variable is a dummy equal to 1 if the transaction is located in a renovated neighborhood and 0 if it is not. The estimation method is a logit model. The “relative share of social housing” corresponds to the share of social housing in the neighborhood, as compared to the average share of social housing in the urban policy neighborhoods of the urban unit. The other “relative” variables are computed in a similar fashion. “House” is a dummy equal to 1 if the transacted housing unit is a house (instead of an apartment). “X rooms” is a dummy equal to 1 if the transacted housing unit has X rooms (the effect on price is estimated in comparison to a 3-room housing unit). “X bathrooms” is a dummy equal to 1 if the transacted housing unit has X bathrooms (the effect on price is estimated in comparison to a 1-bathroom housing unit). “Const t1-t2” is a dummy equal to 1 if the housing unit was built between year t1 and year t2 (the effect on price is estimated in comparison to the period of construction 1981-1991). \*\*\* p<0.01, \*\* p<0.05, \* p<0.1.



Table A5 – Robustness checks - Propensity score - Comparison of treated and control group transactions before and after matching

Variable	Unmatched			Matched		
	Mean		%bias	Mean		%bias
	Treated	Control		Treated	Control	
<b>Housing unit characteristics</b>						
House	16178	.12644	10.1	.17176	.23567	-18.2
Floor space per room	21.069	21.159	-1.6	21.03	21.485	-8.4
1 room	.08054	.11962	-13.0	.08177	.06788	4.6
2 rooms	.18266	.22942	-11.6	.18551	.15461	7.7
3 rooms	.28573	.26486	4.7	.28085	.26642	3.2
4 rooms	.28304	.24986	7.5	.28287	.29857	-3.6
5 rooms	.16803	.13625	8.9	.169	.21252	-12.1
1 bathroom	.02178	.02957	-4.9	.02216	.02117	0.6
2 bathrooms	.88666	.87707	3.0	.88615	.86806	5.6
3 bathrooms	.0431	.04163	0.7	.04212	.05471	-6.3
4 bathrooms	.04846	.05173	-1.5	.04957	.05606	-3.0
<b>Building period</b>						
< 1850	.00522	.01827	-12.1	.00595	.00513	0.8
1850-1913	.0491	.11563	-24.4	.05759	.03482	8.3
1914-1947	.10261	.09356	3.0	.10911	.09794	3.8
1948-1969	.23386	.22548	2.0	.23766	.20686	7.3
1970-1980	.27443	.2012	17.3	.25307	.26782	-3.5
1981-1991	.05424	.0624	-3.5	.05408	.07771	-10.1
1992-2000	.02078	.02606	-3.5	.02186	.02646	-3.0
2001-2010	.01469	.01442	0.2	.01503	.02187	-5.7
2011-2020	.00467	.00226	4.1	.00476	.00685	-3.6
Unknown	.24039	.24072	-0.1	.24089	.25455	-3.2
<b>Neighborhood characteristics in 1999</b>						
rel. % social housing	1.0595	0.85316	39.5	1.0295	1.1407	-21.3
(rel. % social housing) <sup>2</sup>	1.3798	1.0161	22.8	1.3131	1.5905	-17.4
rel. % homeowners	.96856	1.0776	-32.3	.99223	.91777	22.0
(rel. % homeowners) <sup>2</sup>	1.0272	1.3004	-34.4	1.0758	.94209	16.8
rel. % unemployed	1.0482	.88103	90.9	1.0055	.99783	4.2
(rel. % unemployed) <sup>2</sup>	1.1358	.80679	84.3	1.0363	1.0246	3.0
rel. mean income	.94862	1.1268	-102.0	.98667	.99384	-4.1
(rel. mean income) <sup>2</sup>	.92757	1.3031	-101.1	.99314	1.0078	-3.9

Notes: Comparison of treated and control group transactions before and after the matching procedure corresponding to Column 4 of Table A3 (Lechner's procedure with maximum weight 0.025). The mean of each explanatory variable before matching in the treated (resp. in the control) group is reported in Column 2 (resp. 3). A measure of the bias between treated and control group on this variable is displayed in Column 4. The three last columns (5 to 7) are similar to Columns 2 to 4, except that the mean and bias are computed after matching. Among the explanatory variables, "House" is a dummy equal to 1 if the transacted housing unit is a house (instead of an apartment), "X rooms" is a dummy equal to one if the housing unit has exactly X rooms, "rel. % social housing" corresponds to the relative share of social housing in the neighborhood's housing stock as compared to the average share of social housing in the urban policy neighborhoods of the urban unit to which the neighborhood in question belongs. When all bias measures are smaller than 10%, it is generally agreed that treated and control groups are comparable.

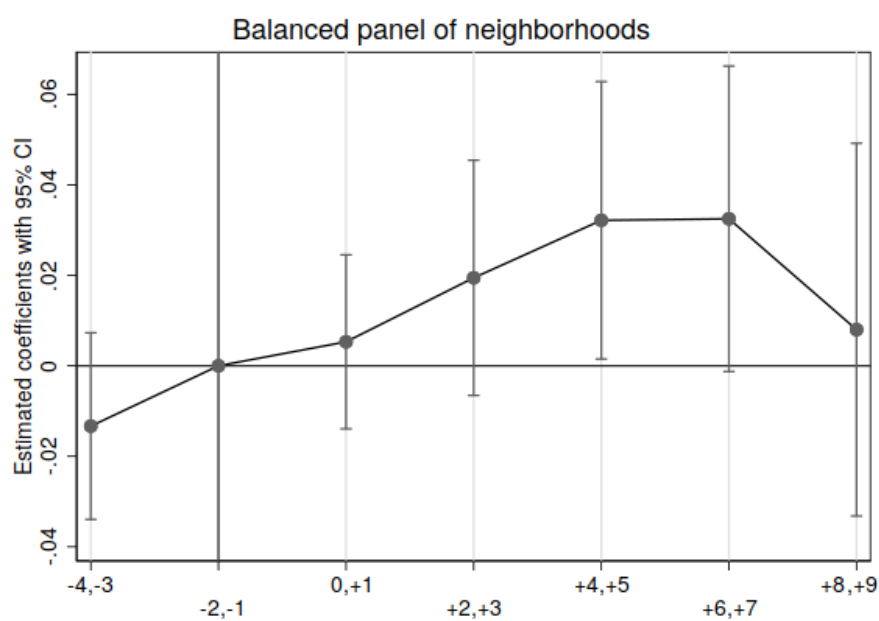


Figure A5 – Robustness checks: Impact of the PNRU program on housing prices estimated with a balanced panel of neighborhoods, i.e. keeping only renovated neighborhoods where renovation started in 2004 or 2005 and restricting the sample to time-varying effects comprised between (-4,-3) and (+8,+9).

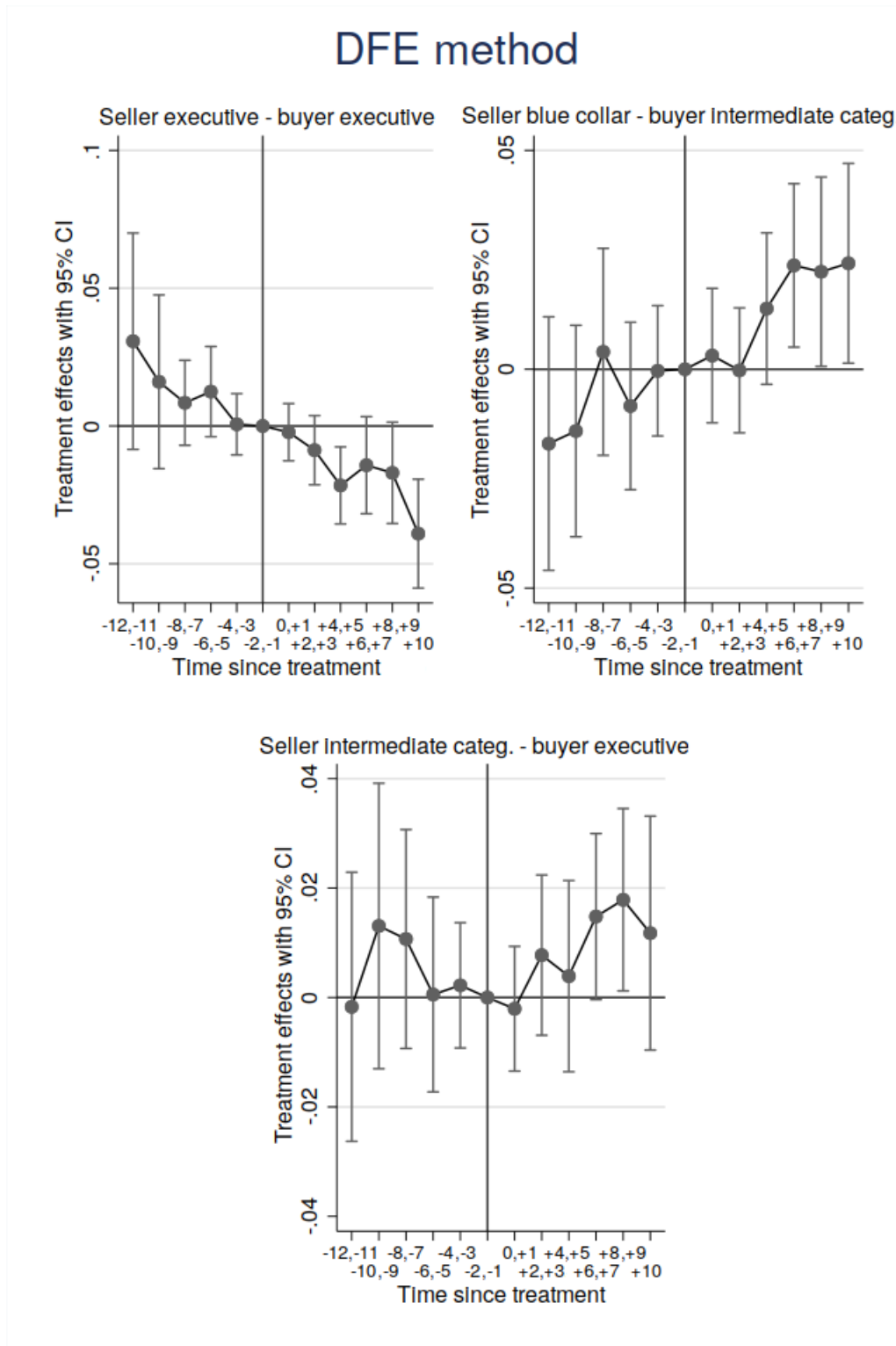


Figure A6 – DFE pre-trends and time-varying treatment effects on transitions probabilities in the four largest cities. Robust standard errors clustered at the neighborhood level.

## General conclusion

This dissertation presents three essays on various aspects of the question of social integration in an urban context. While the first essay analyzes the emergence of ethno-cultural hierarchies in a multi-cultural setting that corresponds to a typical world metropolis context, be it in a developing or developed country, the second essay focuses more specifically on a developing country city context to study the role of social norms in the functioning of land markets and the third essay deals with the evaluation of an urban renewal program in a developed country context.

The first essay proposes a multi-group multi-strategy evolutionary game theory model adapted for the analysis of the emergence of ethno-cultural hierarchies in multi-cultural contexts. It constitutes, to the best of my knowledge, the first to allow for such an analysis in the presence of more than two groups and to account for the reciprocal effects that minorities may have on each others' statuses. This feature is interesting because it yields a possible explanation for the complex relationship between a minority's size and its social status. It is also interesting as it allows to study the theoretical impact of the arrival of a new minority in a society on the status of other minorities and to analyze the existing motivations for minority split. The model shows, in particular, that the arrival of a new minority tends to benefit the other minorities. Eventually, a simple extension of the model allows to study its economic implications. It shows that, if group sizes differ sufficiently, which is the case in most developed country cities, then the ethno-cultural hierarchy favored by such an evolutionary process is inegalitarian and economically inefficient. The model thus suggests that inefficient inegalitarian hierarchy views emerge spontaneously in a context where several ethno-cultural groups of different sizes coexist, thereby advocating for some governmental action aimed at counterbalancing inegalitarian hierarchy views. It also suggests that immigration tends to favor the emergence of more egalitarian (and more efficient) hierarchy views, which pushes for policies favoring immigration.

Among the dimensions that are left aside in this model, an important one is the existence of differing cultural distances between the various ethno-cultural groups that coexist in real-world societies and the possible evolution of these cultural distances through time, due to

identity shifts. A second one is the possibility for individuals to choose, in some cases, the group to which they are assimilated, notably through clothes and behavioral choices. Allowing for these dimensions in another model could possibly yield interesting predictions regarding cultural convergence between ethno-cultural groups in a multi-cultural context.

The second essay presents an urban economics model integrating several specificities of West African cities: informal land markets, land conflict risks, information asymmetries between buyers and sellers in land transactions and the existence of trust relationships between certain groups. To the best of my knowledge, this model is the first land use model with interpersonal transactions, a key feature that was largely missing in the theoretical literature on land markets in developing countries. The framework presented allows to compare the effects of two institutions aimed at reducing information asymmetries in land transactions: a land registration system and a trust norm. An important prediction of the model is that although matching along ethnic lines reduces information asymmetry, it also lowers overall market participation. Alternatively, when owners are offered the possibility to make plots secure by paying to register them in a cadaster, both information asymmetry and tenure insecurity disappear, but the cost of registration limits transactions at the periphery of the city. Our framework allows to understand the prevalence of ethnic matching in land markets where registration is very costly, the substitutability between trusted relationships and registration, and the probable gradual evolution of developing country economies towards more efficient cities with full cadastral coverage and weakened trust norms. It therefore motivates policies aimed at reducing registration costs, but also, to a lesser extent, policies aimed at promoting trust links as a second best option.

It would be interesting, in the future, to complement this second essay with an experiment aimed at measuring the effect of trust links on information asymmetry alleviation, on perceived risk and on the efficiency of informal land markets, as well as the reduced role of trust links when land registration is possible.

Eventually, the third essay consists in the evaluation of a very large-scaled urban renewal program, the *Programme National pour la Rénovation Urbaine*, launched in 2004 in France for the renovation of 600 deprived neighborhoods. It is, to the best of my knowledge, the first to apply in the context of urban renewal evaluation the very novel method developed by De Chaisemartin and D'Haultfœuille (forthcoming) to avoid certain biases in difference-in-differences estimations. The large scale of the program and the availability of data concerning the social profile of housing buyers and sellers also constitute rare advantages for this analysis. Our results indicate that renovation did not lead to a significant increase in housing values in renovated neighborhoods at the aggregate level of France between 2004 and 2014 and that its impact was, in any case, smaller than 3.5%. Furthermore, we find no substantial differences in estimated impacts, neither with respect to the level of funding per housing unit received by

the neighborhood, nor with respect to the initial share of public housing in the neighborhood or the size of the urban unit in which the renovated neighborhood is located. We also find no impact on the volume of transactions in renovated neighborhoods. However, we do find that the program led to a positive shift in the socio-professional categories of housing buyers with respect to sellers, suggesting a sensible increase in renovated neighborhoods' attractiveness. This empirical study suggests that urban renewal may not be the most efficient way to revitalize deprived neighborhoods, as the estimated effects are very limited in comparison to the amounts invested.

The third essay possesses several limitations. First, due to the urban renewal program's features, no instrument or regression discontinuity design can be used for the evaluation of its effects. Second, the time period under study is limited in scope so that it may be interesting, in a few years, to complement this study by focusing on longer term effects of the program. Another complementary analysis could focus on the trajectories of renovated neighborhoods' initial inhabitants after the start of the program, provided adequate data can be obtained.

# Conclusion générale

Cette dissertation de thèse se compose de trois essais portant sur divers aspects de la question de l'intégration sociale en contexte urbain. Tandis que le premier essai analyse l'émergence de hiérarchies ethno-culturelles dans un contexte multi-culturel typique des grandes métropoles actuelles, tant dans les pays développés qu'en développement, le deuxième essai se concentre plus spécifiquement sur le contexte des villes d'Afrique de l'Ouest pour analyser le rôle des normes sociales dans le fonctionnement des marchés fonciers. Le troisième essai s'intéresse, au contraire, aux villes d'un pays développé, la France, pour analyser les effets d'un grand programme de rénovation urbaine.

Le premier essai propose un modèle de théorie des jeux évolutionnaires multi-groupes et multi-stratégies adapté pour l'analyse de l'émergence de hiérarchies ethno-culturelles dans le contexte de sociétés multi-culturelles. Il constitue, à ma connaissance, le premier modèle à permettre une analyse de ce type en présence de plus de deux groupes et le premier à analyser les effets réciproques que les minorités peuvent avoir sur les statuts des autres minorités. Cette caractéristique est intéressante car elle permet d'obtenir une explication du lien complexe entre la taille d'une minorité et son statut social. Elle est aussi intéressante en ce qu'elle permet d'analyser l'impact de l'arrivée d'une nouvelle minorité sur le statut des anciennes minorités ainsi que les forces poussant à la division des minorités en plusieurs groupes culturels distincts. Le modèle montre, en particulier, que l'arrivée d'une nouvelle minorité tend à bénéficier aux minorités déjà présentes dans une société. Pour finir, une extension simple du modèle permet d'étudier ses implications économiques. Elle montre que, si les groupes ethno-culturels ont des tailles suffisamment différentes, ce qui est le cas dans la plupart des villes des pays développés, alors la hiérarchie ethno-culturelle qui émerge au terme du processus évolutionnaire étudié est inégalitaire et économiquement inefficace. Le modèle suggère ainsi qu'une politique publique visant à contrecarrer les conceptions hiérarchiques inégalitaires serait économiquement souhaitable mais aussi qu'elle irait à l'encontre d'une tendance naturelle des sociétés multi-culturelles à adopter des hiérarchies inégalitaires, ce qui pourrait limiter son efficacité. Le modèle suggère aussi que l'immigration (i.e. l'arrivée de nouvelles minorités) tend à favoriser l'émergence de conceptions hiérarchiques plus égalitaires et plus

efficaces, ce qui constitue un argument en faveur des politiques propices à l'immigration.

Parmi les dimensions laissées de côté dans ce modèle, on peut citer l'existence de distances culturelles différentes entre les divers groupes ethno-culturels au sein des sociétés et la possible évolution de ces distances culturelles avec le temps, par le biais de glissements identitaires. Par ailleurs, il arrive que les individus puissent, dans une certaine mesure, choisir le groupe ethno-culturel auquel ils sont assimilés, par leur choix vestimentaires et comportementaux notamment. Introduire ces dimensions dans un futur modèle pourrait conduire à une analyse intéressante des dynamiques de convergence culturelle entre groupes ethno-culturels dans un contexte multi-culturel.

Le deuxième essai présente un modèle d'économie urbaine intégrant plusieurs spécificités des villes d'Afrique de l'Ouest : marchés fonciers informels, risques de conflits fonciers, asymétries d'information entre acheteurs et vendeurs lors des transactions foncières et existence de relations de confiance entre certains groupes, en particulier ethniques. A ma connaissance, ce modèle est le premier modèle d'occupation des sols avec des transactions interpersonnelles, un élément clé qui faisait largement défaut dans la littérature théorique sur les marchés fonciers des pays en développement. Le cadre théorique proposé dans cet essai permet de comparer les effets de deux institutions visant à réduire les asymétries d'information dans les transactions foncières et les failles de marché associées : un système d'enregistrement des terrains et une norme de confiance. Une prédiction importante du modèle est que, même si l'appariement entre acheteurs et vendeurs selon des liens de confiance réduit l'asymétrie d'information, il réduit aussi le niveau de participation global au marché. Si, au contraire, les propriétaires fonciers ont la possibilité de sécuriser leur propriété en l'enregistrant dans un cadastre, l'asymétrie d'information et l'insécurité de la propriété disparaissent, mais le coût d'enregistrement limite les transactions à la périphérie de la ville. Notre cadre théorique permet de comprendre la prévalence de l'appariement ethnique sur les marchés fonciers où les coûts d'enregistrement sont élevés, la substituabilité entre relations de confiance et enregistrement des terrains, et la probable évolution graduelle des économies en développement vers des villes plus efficaces avec un enregistrement de tous les terrains et des normes de confiance affaiblies. Ce modèle souligne donc l'intérêt des politiques publiques visant à réduire les coûts d'enregistrement, mais aussi, dans une moindre mesure, des politiques visant à favoriser la perpétuation des liens de confiance, comme solution de second rang au problème d'insécurité foncière.

Il serait intéressant, à l'avenir, de compléter ce deuxième essai par une expérience mesurant les effets des liens de confiance sur les asymétries d'information, les risques perçus et l'efficacité des marchés fonciers informels, ainsi que le rôle réduit des liens de confiance quand les terrains sont enregistrés dans un cadastre.



Pour finir, le troisième essai consiste en l'évaluation d'un programme de renouvellement urbain de très grande ampleur, le PNRU (Programme National pour la Rénovation Urbaine), lancé en France en 2004 pour la rénovation de 600 quartiers défavorisés. Il s'agit, à ma connaissance, de la première évaluation d'un programme de rénovation urbaine s'appuyant sur la toute nouvelle méthode développée par De Chaisemartin and D'Haultfœuille (à paraître dans l'AER) pour éviter certains biais liés aux estimations fondées sur les méthodes de différences-de-différences. La grande ampleur de ce programme et l'existence de données concernant le profil socio-professionnel des acheteurs et vendeurs de logements constituent aussi des spécificités intéressantes de cette évaluation. Nos résultats indiquent que le programme n'a pas mené à un accroissement significatif des valeurs immobilières dans les quartiers rénovés au niveau agrégé de la France pendant la période 2004-2014 et que cet accroissement a été, avec 95% de certitude, inférieur à 3.5%. De plus, nous ne mesurons pas de différences d'effets estimés en fonction du niveau de financement par unité de logement perçu par les quartiers, de la proportion initiale de logements sociaux dans les quartiers ou de la taille de l'unité urbaine dans laquelle les quartiers sont situés. Nous ne trouvons pas non plus d'effet significatif sur le volume de transactions. Cependant, nos résultats indiquent que le programme a mené à un glissement vers le haut des catégories socio-professionnelles des acheteurs de logements par rapport aux vendeurs, ce qui semble traduire une amélioration sensible de l'attractivité des quartiers rénovés. Cette étude empirique suggère que la rénovation urbaine pourrait ne pas être la politique la plus efficace pour revaloriser les quartiers défavorisés, car les effets estimés du programme apparaissent très limités par rapport aux montants investis.

Ce troisième essai empirique a plusieurs limitations. Tout d'abord, en raison des caractéristiques propres au programme, il n'est a priori pas possible de s'appuyer sur des variables instrumentales ou une méthode de régression sur discontinuité pour mesurer ses effets. Ensuite, la période temporelle d'étude, entre 2000 et 2014, est relativement limitée. Il pourrait donc être intéressant, dans quelques années, de compléter cette étude par une analyse des effets du programme à plus long terme. Une autre analyse complémentaire à ce troisième essai pourrait porter sur les trajectoires individuelles des habitants des quartiers rénovés après le début du programme, mais celle-ci nécessiterait des données additionnelles très détaillées.



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