THE MULTIFACETED NATURE OF IDENTITY: SOCIAL NETWORKS, COGNITIVE CONSTRAINTS, AND ECONOMIC DEVELOPMENT

by

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DISSERTATION ABSTRACT

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This dissertation provides a deep exploration of identity. Three chapters present studies of the interplay between identity and various social, cultural, and economic factors from different angles. The first chapter develops a theoretical framework for expressing cultural identity within social networks, taking into account individuals' desire to conform and be unique. This leads to diverse expressions of cultural identity influenced by social structures. The second chapter proposes a model to explain the emergence of dominance hierarchies, where agents with limited cognitive abilities optimize their strategies in a social interaction game. This results in different types of hierarchical structures, providing insight into societal order. The final investigation focuses on ethnicity choice in mixed-ethnic families in modern China, highlighting the impact of economic development and education quality. It presents an intra-household bargaining model that explains changes in benefits, costs, and bargaining powers within families. The dissertation as a whole characterizes the multifaceted nature of identity, revealing its profound connections with social networks, cognitive processes, and economic development.

This dissertation includes both previously published and co-authored material.

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Lastly, to all my dear family members, your constant encouragement and belief in me were a pillar of strength throughout this journey. I dedicate this work to you.

In loving memory of my grandmother You Wei (1941-2023).

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Chapter 1

Overview

This dissertation studies the multifaceted nature of identity, exploring the interplay between identities and social networks, cognitive constraints, and economic development. It seeks to understand how these factors shape individual identities and are influenced by identity decisions. The central objective is to understand on the complex mechanisms underlying identity formation and its consequences.

Identity is a fundamental aspect of human existence, influencing our behaviors, beliefs, and interactions with others. However, understanding the intricacies of identity construction requires a comprehensive examination of its social, cultural, and economic dimensions. This dissertation addresses this need by employing a multidisciplinary approach, drawing upon theories from sociology, psychology, and economics. The specific objectives include investigating how social networks impact the expression of cultural identity and the emergence of diverse cultural phenomena within societies, examining the role of cognitive constraints in the formation of dominance hierarchies and their implications for societal order, and exploring the influence of economic development and education on ethnicity choice in mixed-ethnic families, with a focus on understanding the decision-making processes involved.

This dissertation is organized into three main chapters, each addressing a specific aspect of identity and its relationship with social networks, cognitive constraints, and economic development.

Chapter 2, Cultural Identity Expression in Social Networks, develops a theoretical framework for understanding the expression of cultural identity within social networks. It explores how individuals navigate the tension between conformity and uniqueness, leading to diverse manifestations of cultural identity. The analysis employs network-based metrics and investigates the relationship between social structures and the equilibrium of cultural phenomena.

Chapter 3, Limited Cognitive Abilities and Dominance Hierarchy, investigates the formation of dominance hierarchies. It proposes a model that incorporates cognitive constraints and examines how agents optimize their strategies in a social interaction game. The study elucidates the emergence of hierarchical structures observed in various social contexts. This chapter is a co-authored work with Prof. Jiabin Wu, and was published in volume 70 of the journal Acta Biotheoretica in September 2022 (Huang and Wu [2022]).

Focusing on the impact of economic development and education, Chapter 4, Economic Development, Education, and Ethnicity Choice in China, explores the factors influencing ethnicity choice in mixed-ethnic families in China. It develops an intra-household bargaining model to explain the decision-making processes involved. The empirical analysis examines the relationship between economic development, educational quality, and the propensity of mixed-ethnic families to choose minority ethnicity for their children.

As the conclusion Chapter 5 summarizes the key findings, discusses implications, and offers avenues for future research in the field of identity studies.

Chapter 2

Cultural Identity Expression and Social Networks

2.1 Introduction

In today's increasingly globalized world, the interaction and co-existence among different cultures have reached an unprecedented level. This has been facilitated by factors such as economic development, population migration, and the evolution of political ideologies, leading individuals to develop and express multiple cultural identities in their daily lives. The literature on cultural identity expression has grown in recent years, with researchers examining the complexities of cultural identity expression in a globalized world (Nagel [1994]; Vertovec [2009]) and the emergence of multicultural societies (Berry [2005]). This body of work has shed light on the diverse ways in which individuals navigate their cultural affiliations and negotiate their identities in various social environments. The concept of polyculturalism, introduced by Morris [2015], highlights the fluidity and interconnections of cultures in shaping individual identities. Building on this idea, the present research proposes a game theoretical framework to model how individuals express their identities in multicultural social environments and how different social structures affect their identity expression decisions. The proposed framework is grounded in game theory and considers factors that measure the level of decentralization and the level of heterogeneity of an equilibrium, as well as the limitations of agents' interactions through a network approach. By examining the interplay between individual motives and social structures, this research seeks to provide insights into the behaviors of identity expression and the potential implications of social policies designed to promote cultural integration and harmony.

In the proposed framework, individuals express their cultural identities based on a balance between the motives to conform, which involves aligning with the social norm, and the motives of uniqueness, which involve expressing an identity that is different from others. Scholars in the field of psychology have asserted that the motive to conform fundamentally originates from the desire to integrate within a social group (Asch [1955]). Individuals can experience discomfort when contemplating, maintaining, or voicing beliefs that diverge from the prevalent societal viewpoints, or when engaging in unconventional behavior that could potentially label them as outsiders to their social group (Golman et al. [2016]). In theoretical economics, researchers often use "choosing a value" to model the behavior of identity expression, and they have conceptualized the motive to conform as "choosing their person value that is close to the social norm", where the social norm is generally calculated according to the social average value (Akerlof and Kranton [2000]; Michaeli and Spiro [2015]; Wu [2021]).

The theory of the conformity motive could lead one to anticipate a societal convergence towards a uniform equilibrium. However, contrary to the hypothesis of an entirely homogeneous societal state, the enduring presence of diversity within a society suggests that we should look at another contrasting motive. There exists a universally inherent human yearning for uniqueness (Sutton [1981]). Evidently, the aspiration for individual distinction is at odds with the impulse to merge into the social fabric (Imhoff and Erb [2009]). However, research conducted by Chan et al. [2012] illustrates that individuals concurrently strive for assimilation and differentiation, aspiring to be recognizable yet not exact replicas. Preferences for unique behavioral patterns may contribute to the maintenance of diversity (Smaldino et al. [2015]). Collectively, these dual motives guide individuals towards establishing an equilibrium in behavioral patterns, where everyone achieves a balance between uniqueness and conformity. In the examination of the model, we examine how the comparative potency of the two motives influences the resulting equilibria.

The network framework employed in this research builds upon the work of Jackson and Zenou [2015], who proposed a framework for social interaction that models the limitations of agents' interactions through local neighborhoods on social networks[1]. In our network model, agents can only interact with their "neighbors", defined as other players with whom they share a connection within the network. As such, when agents, restricted by limited interactions, formulate their motives, they consider only the strategies of those players to whom they are connected within the network. Given varying network structures and distinct positions within these networks, agents may exhibit different identity expression behaviors, thereby yielding diverse types of equilibria.

[1] More specific researches on network modelling including Granovetter's 'strength of weak ties' theory highlights how even loose social connections can significantly influence the spread of information and behaviors within a network, contributing to cultural assimilation, conformity, and polarization (Granovetter [1973]; Centola [2010]). Network models and community detection help identify groups with shared cultural identities and offer insights into the interplay between these communities within the larger social network (Fortunato [2010]). Structural properties of these networks, like "hubs" or individuals with extensive connections, can significantly impact cultural identity expression (Borgatti et al. [2009]).

In this study, we introduce and employ novel metrics to evaluate the Nash equilibria (NEs) in terms of their cultural properties arising from the interactions among agents[2]. This research employs metrics including dispersion, number of traits, and maximum links. The dispersion metric quantifies the extent to which individual strategies diverge from the societal average, providing a quantitative measure of the decentralization of identity expression within a strategy profile around the social norm. The number of traits metric accounts for the total number of identity expressions within a strategy profile, offering a qualitative measure of the heterogeneity of a strategy profile. The maximum links metric quantifies the number of paired neighbors within the network structure of a strategy profile, serving as a measure of intensity of interactions. The application of these metrics in evaluating the equilibria of the model will facilitate our understanding of the relationship between network structures and equilibria. Furthermore, it will enable us to assess different equilibria from societal perspectives including centralization, heterogeneity, and interactional intensity.

The analysis of our models yields insights into how varying relative strengths between the motives and diverse network structures can engender distinct equilibria, characterized by differing levels of centralization, heterogeneity, and interactional intensity. The main finding is that in general, a stronger motive for uniqueness appears to facilitate the formation of equilibria that are less centralized and more heterogeneous. Additionally, networks with a larger number of links or a higher number of maximum links per node tend to be associated with equilibria that are less centralized and exhibit greater heterogeneity. Nevertheless, these relationships are not monotonic and can be highly network-specific, contingent on the inherent structure of the network. To elucidate our findings, we provide a comprehensive analysis of an identity expression game involving two identity types within a four-player network.

In addition to the baseline model, this paper explores an extension to further enrich our understanding of cultural identity expression within social networks: the self-esteem motive. The self-esteem motive introduces an additional factor that drives individuals to express their identity in a way that boosts their self-esteem, taking into account their own self-evaluation of their cultural traits. This extension allows us to examine how self-perception influences the dynamics of identity expression and the resulting equilibria. By incorporating this extension, we aim to offer a more comprehensive and nuanced understanding of the factors influencing individual motives in cultural identity expression and their implications for social cohesion and intergroup relations.

The rest of the paper organizes as follows. Section 2 introduces the baseline model and newly-defined terms. Section 3 provides a detailed analysis of the model, discussing the implications of various network structures on identity expression strategies. Section 4 extends the framework with additional variations,

[2] The introduction of new metrics for assessing frameworks has been widely adopted in the literature across various disciplines, such as economics, political science, and social psychology, to examine the behavior of NEs in different contexts (Marsden [1987]; Easley and Kleinberg [2010]; Ballester et al. [2006]).

exploring the impact of these changes on the equilibria of cultural identity expression. Section 5 discusses the results, examining the broader implications for social policies and interventions aimed at fostering cultural integration and harmony, and concludes the paper by highlighting the contributions of this research to the understanding of cultural identity expression in multicultural societies.

2.2 Model

2.2.1 Expressing Cultural Identity

The game of expressing cultural identity involves a population of N individuals, where there are m distinct identity types. Each agent i chooses to express their identity $e_i \in \{0,1\}^m$ (an ordered list of m numbers between 0 and 1). For instance, if an individual opts to express solely the first identity type out of three types, their e_i would be represented as $(1, 0, 0)$.

There are two factors that contribute to an individual's utility in this game: conformity and uniqueness. The level of conformity expresses the agents' incentive to be close to the social norm. We determine this with the euclidean distance between an individual's expressed identity and the average identity in the population, represented by $\|e_i - \overline{e}\|$. The level of uniqueness represents agents' incentive to be the same as nobody (Chan et al. [2012]), which is calculated by the number of other agents who share the same expression of identity as them, denoted by s_i.

The utility function for agent i is as follows:

$$u_i = -\|e_i - \overline{e}\| - ks_i \tag{2.1}$$

Note that both two component are negative because both "being away from the social average" and "being the same as others" are negative payoffs in each motive. $k > 0$ is a positive parameter that describes the relative strength of uniqueness over conformity. For simplicity, we assume every agent has the same relative strength. Each individual strives to maximize their utility by balancing the conformity and the uniqueness factors when choosing how to express their identity in the society. Intuitively when conformity is a stronger force ($k < 1$), individuals may opt for expressions that are closer to the average identity of the population, resulting in a more homogeneous population. Conversely, when uniqueness is a significant factor ($k > 1$), individuals will be more inclined to adopt identity expressions that are distinct from those of others, which leads to a greater variety of identity expressions.

In what follows we analyse the possible equilibria in a simple 2-player game to gain a better understanding of the impact of the parameter k on the game's outcomes and the behavior of the individuals involved.

Example 1 *There are two individuals, A and B, living in a society with two types of identities which are perpendicular to each other. Each player i has four pure strategies available: $e_i \in \{(0,0), (0,1), (1,0), (1,1)\}$, with a payoff function $u_i = -\|e_i - \bar{e}\| - ks_i$. The game can be described by the following table:*

Table 2.1: Game of cultural identity expression, with two players and two identities

		Player B			
		(0,0)	(0,1)	(1,0)	(1,1)
Player A	(0,0)	$-k, -k$	$-\frac{1}{2}, -\frac{1}{2}$	$-\frac{1}{2}, -\frac{1}{2}$	$-\frac{\sqrt{2}}{2}, -\frac{\sqrt{2}}{2}$
	(0,1)	$-\frac{1}{2}, -\frac{1}{2}$	$-k, -k$	$-\frac{\sqrt{2}}{2}, -\frac{\sqrt{2}}{2}$	$-\frac{1}{2}, -\frac{1}{2}$
	(1,0)	$-\frac{1}{2}, -\frac{1}{2}$	$-\frac{\sqrt{2}}{2}, -\frac{\sqrt{2}}{2}$	$-k, -k$	$-\frac{1}{2}, -\frac{1}{2}$
	(1,1)	$-\frac{\sqrt{2}}{2}, -\frac{\sqrt{2}}{2}$	$-\frac{1}{2}, -\frac{1}{2}$	$-\frac{1}{2}, -\frac{1}{2}$	$-k, -k$

It is straightforward to identify the pure Nash equilibria in the game[3]*:*

1. *If $k \leq \frac{1}{2}$, then ((0,0),(0,0)), ((0,1),(0,1)), ((1,0),(1,0)) and ((1,1),(1,1)) are NEs. In such equilibria, both players are expressing the same identity, and getting a payoff of $-k$. This type of equilibria represent a homogeneous population.*

2. *If $k \geq \frac{1}{2}$, then ((1,0),(0,0)), ((1,0),(1,1)),((0,0),(0,1)), ((0,0),(1,0)), ((0,1),(0,0)), ((0,1),(1,1)), ((1,1),(1,0)) and ((1,1),(0,1)) are NEs. In such equilibria, one player's expression contains one and only one type of identity, and the other player's expression either contain both types of identity or neither type of identity. Both players receive a payoff of $-\frac{1}{2}$. This type of equilibrium reflects a heterogeneous society with a social average that favors one type of identity.*

3. *Players expressing completely opposite identities (((1,0),(0,1)),((0,0),(1,1)),((0,1),(1,0)), and ((1,1),(0,0))) cannot be NEs. Because in these strategy profiles players are receiving a payoff of $-\frac{\sqrt{2}}{2}$, and they always have incentives to deviate to reach a strategy profile in case 2, which give them a payoff of $-\frac{1}{2}$. The intuition is that they do so to "move closer" to the social average, which increases their level of conformity, while still maintaining a maximum possible level of uniqueness since no one is playing the same strategy as their opponent's.*

Level of Decentralization: Dispersion

In the previous example, the key difference between the heterogeneous equilibria and non-equilibrium strategy profiles is that the distance between the players' strategies and the social average is larger in the non-equilibria ($\frac{\sqrt{2}}{2}$) than in the heterogeneous equilibria ($\frac{1}{2}$), although both can be described as "two players

[3]See Appendix for details on identifying the pure Nash Equilibria of game of cultural identity expression with two players.

playing different strategies". We see the need of a new index to evaluate the degree of which individual strategies deviate from the social average, or the level of decentralization of a strategy profile. The new term we define, is called the *dispersion* of a strategy profile which measures the average level of individual strategies' deviation from the social average (Morris [2000]).

Formally, let e_i be the strategy of player i, and let $\bar{e}$ be the social average strategy, computed as the average of all players' strategies. The dispersion D of a strategy profile can be calculated as follows:

$$D = \frac{1}{N} \sum_{i=1}^{N} \|e_i - \bar{e}\| \tag{2.2}$$

A lower dispersion indicates that the strategies are closer to the social average, whereas a higher dispersion suggests that the strategies are more spread out from the social average. In the context of cultural identity expression, understanding the dispersion of strategy profiles, or more importantly, strategy profiles that are NEs, can offer valuable insights into the distribution of identity expression strategies within a given society. A high dispersion of NEs might suggest that the society is characterized by a diverse array of identity expression strategies, with individuals adopting a wide range of approaches to express their cultural affiliations. This diversity might be indicative of a more inclusive and tolerant social environment, where individuals are free to express their cultural identities without fear of marginalization or discrimination. On the other hand, a low dispersion of NEs might imply that individuals' identity expression strategies are more tightly clustered around the social average, suggesting a higher degree of conformity to prevailing cultural norms.

Level of Heterogeneity: Number of traits

The second term we introduce to evaluate strategy profiles in the game of cultural identity expression is the "number of traits", which represents the number of distinct strategies in a strategy profile. This metric provides insights into the variety and complexity of identity expression strategies adopted by individuals within a given society.

In a game of cultural identity expression where there are m distinct identity types, there is 2^m possible identity expressions as agents' strategy, which we refer as "traits". To see why it is necessary to introduce the number of traits as another measurement of the strategy profiles, consider two strategy profiles in a 2-identity 4-player game of cultural identity expression, where one is $((0,0),(0,0),(1,1),(1,1)$, and the other one is $((0,0),(0,1),(1,0),(1,1)$. If we use the previously introduced metric, dispersion, to evaluate them, they both have a dispersion of $\frac{\sqrt{2}}{2}$. However it is a natural argument that the second profile is more "diverse" in the sense that it carries more traits than the first profile, which can be an indicator individuals within the society adopt a broad range of approaches to express their cultural affiliations in describing cultural phenomena in real life. More specifically, strategy profile with relative high number of traits might suggest an inclusive and tolerant social environment, where individuals feel free to explore and express various aspects of their cultural identity without fear of marginalization or discrimination. Conversely, a low number of traits suggests that individuals within the society employ a more limited set of identity expression strategies.

The introduced measurements allow us to perceive the social environment characterized by a greater degree of conformity to prevailing cultural norms, particularly in situations where individuals feel pressured to assimilate into the dominant culture. One interpretation is that these conditions may limit opportunities for developing and expressing multiple cultural identities. This constraint could result in increased tension and conflict among cultural groups. It could also lead to less exposure to diverse cultural influences and stronger pressures to assimilate into the dominant culture, not to mention the potential presence of discriminatory practices that discourage the expression of minority identities.

2.2.2 Expressing Cultural Identity in a Social Network

When the number of agents in a society is large or the interaction is costly, it is unrealistic to assume that every agent would have the same level of interactions with every other agent. Therefore, we extend the model to incorporate network structure (Jackson and Zenou [2015]) into our analysis. The game of cultural identity expression in a social network is described as follows:

In a population of N individuals, a social network is represented by an adjacency matrix A where $a_{ij} = 1$ if the expressed identity of person j is observed by person i. If person i cannot observe the identity of person j, then $a_{ij} = 0$. Let $n_i = \{j : a_{ij} = 1\}$ be the set of people whose expressed identities can be observed by player i. In this social network A, player i's level of conformity and uniqueness is influenced only by the expressed identities of their neighbors (Granovetter [1973]):

$$u_i = -\|e_i - \bar{e}_{n_i}\| - ks_i(n_i) \tag{2.3}$$

Given a social network , we introduce our last measure, the maximum link. The maximum link $l \in [0, N]$ is used to describe *level of social interaction* that captures the limitations of agents' ability to observe the expressed identities of others (Wasserman and Faust [1994]). l is an integer from 0 to N representing the maximum number of agents whose identity an agent can observe. In graphs of networks, this is equivalent to the maximum number of links that a node can have. It should be noted that being different from dispersion and the number of traits, which are endogenous (determined by agents' strategies), maximum link, as well as the total number of links in a network, is an exogenous measure to each specific network, which are not affected by agents' strategies. In the following analysis we will examine how agents' behavior affected by maximum link and total number of links.

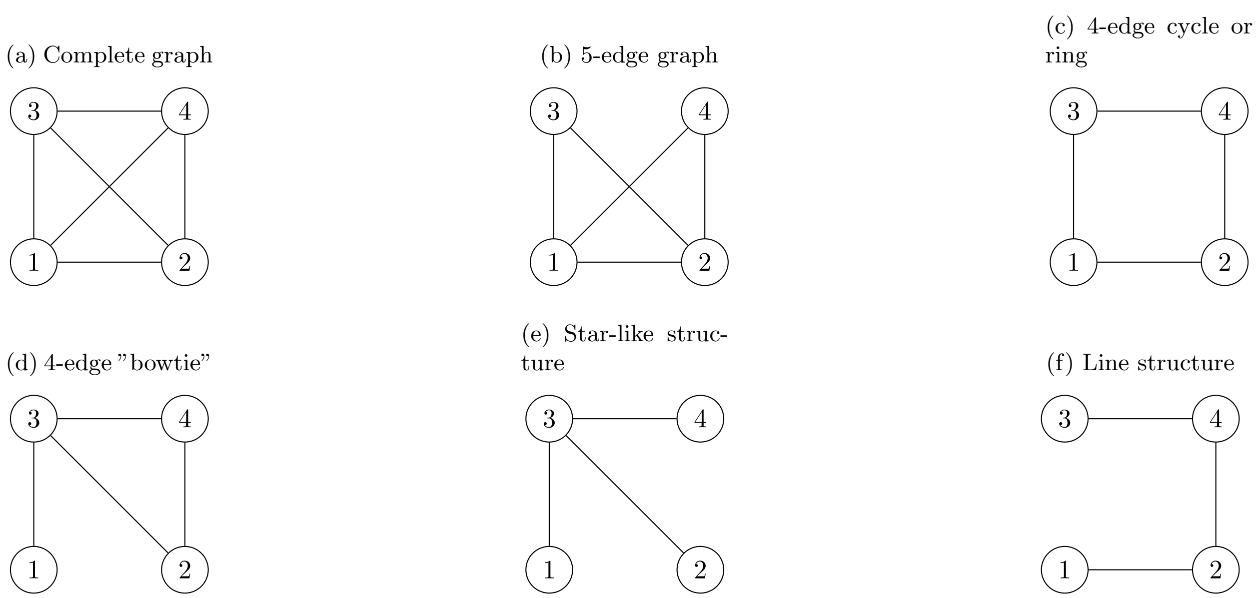
2.3 Analysis

2.3.1 Two-Identity Four-Player Networks

In this section, we provide a detailed analysis on two-identity ($e_i \in \{0,1\}^2$) four-player ($i \in \{1,2,3,4\}$) networks with three possible values for k: 0, 0.5, 1 ($k \in \{0, 0.5, 1\}$). This allows us to thoroughly investigate the interplay between network structure and game mechanics in shaping the cultural identity expression[4].

There are six types of four-player networks where there exists at least one path from any player to any other player:

Figure 2.1: Types of Four-player Networks



By deriving Nash equilibria[5] in these different networks with various k values ($k = 0$, $k = 0.5$ and $k = 1$), we can compare the number of traits and dispersion in different NEs:

As discussed, the motive to conform is the driving force for the convergence towards a uniform equilibrium. This is reflected in the table that when the motive to conform is the dominant motive (k=0), a uniform equilibrium where there is only one trait appears in every network structure. However, when we increase

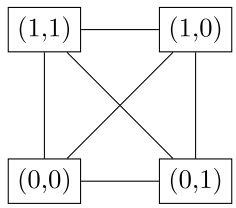
[4] Due to the significant increase in complexity associated with larger networks, analyzing games of cultural identity expression with general settings in arbitrary networks can be both analytically and computationally challenging.

[5] See Appendix 5.2 for a full list of Nash Equlibria in two-identity four-player networks.

Table 2.2: Number of Traits and Dispersion at Equilibria

Type of Graph	Total links	Max links per node	Number of Traits (Dispersion) k=0	k=0.5	k=1
Complete	6	3	1(0)	4(0.7071)	4(0.7071)
5-edge	5	3	1(0)	No Equilibrium	3(0.3), 4(0.7071)
Ring	4	2	1(0),2(0.5), 2(0.7071)	2(0.5)	2(0.5), 3(0.3), 4(0.7071)
Bowtie	4	3	1(0)	3(0.6583),4(0.7071)	3(0.3),3(0.6583),4(0.7071)
Star	3	3	1(0)	2(0.375),3(0.6583)	2(0.375), 3(0.6583)
Line	3	2	1(0),2(0.5), 2(0.7071)	2(0.375),2(0.5)	2(0.5),3(0.3),4(0.7071)

Figure 2.2: Equilibrium of the complete graph when k=1



the relative strength of the motive of uniqueness (k), different networks can yield different results:

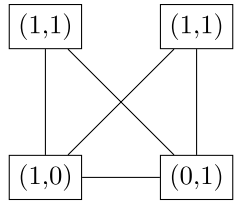
In the complete graph (Figure 1(a)), with an increase in k, both the number of traits and dispersion escalate to 4(0.7071), implying that the salience of uniqueness stimulates increased diversity in cultural identity expression. Given that each agent in a complete graph is connected to all others (so everyone is a "central player" with three links), the uniqueness motive impels agents to opt for an expression that differs from everyone else[6]. There are four (2^2) possible traits for four agents, each agent selecting a distinct identity expression in any equilibrium (Figure 2).

The 5-edge graph (Figure 1(b)) is a derivative of the complete graph wherein one link is removed. Within this 5-edge graph, as k nears 1, the equilibrium number of traits can either be 3 or 4, corresponding to dispersion values of 0.3 and 0.7071, respectively. The emergence of a new 3-trait equilibrium (Figure 3) is attributable to the absence of the link. Given that there are two players who are not interconnected in the network (Player 3 and 4 in Figure 1(b)), they can select identical identity expressions without incurring any cost from the uniqueness motive. Furthermore, the 5-edge graph yields a captivating result wherein no pure equilibrium exists at $k = 0.5$. This phenomenon arises because when $k = 0.5$, there is always at least one player with an incentive to alter their expression in any given strategy profile, thereby preventing the network from attaining a steady pure strategy equilibrium. This absence of an equilibrium at $k = 0.5$ also indicates a non-monotonic effect of k on the equilibrium number of traits and dispersion in the 5-edge graph.

The ring graph (Figure 1(c)), characterized by each agent being connected to two other players, forms a cyclic or ring-like network structure. A unique aspect of the ring graph is that it allows for a certain degree

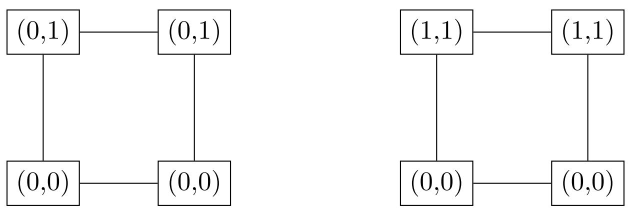
[6] It is straightforward to calculate that this is true as long as $k > 0.7071/4$.

Figure 2.3: 3-trait equilibria of a 5-edge graph when $k = 1$



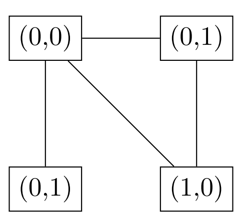
of heterogeneity in expression even in the absence of considering the importance of uniqueness. As depicted in Figure 4, when $k = 0$, equilibria with 2 traits also exist. This phenomenon can be explained by the fact that if an agent is connected with two other agents who exhibit different expressions, the conformity motive permits the agent to align with either of their neighbors' strategies. If no agent is connected to more than two others, then two distinct traits can coexist in an equilibrium where no agent has an incentive to deviate.

Figure 2.4: 2-trait equilibria of a ring graph when $k = 0$



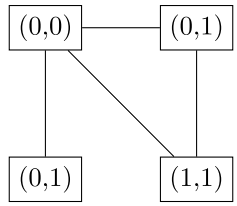
A "bowtie" graph (Figure 1(d)) is characterized by a central player who is connected to three neighbors, with two of these neighbors connected to each other. A key distinction between the equilibria in bowtie graphs and those in the previously discussed graphs is a new type of 3-trait equilibrium (Figure 5). In the new 3-trait equilibrium in a bowtie graph, the dispersion value is now 0.6583, compared to $D = 0.3$ in the 3-trait equilibrium in a 5-edge graph. The $D = 0.3$ 3-trait equilibrium is still possible in the bowtie graph (Figure 6)

Figure 2.5: 3-trait equilibrium of bowtie with D=0.6583 graph when k=1



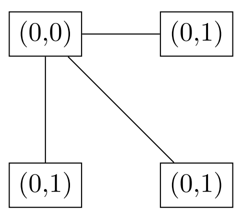
A star-like structure (Figure 1(e)) is characterized by a central player who is connected to all other

Figure 2.6: 3-trait equilibrium of bowtie with D=0.3 graph when k=1



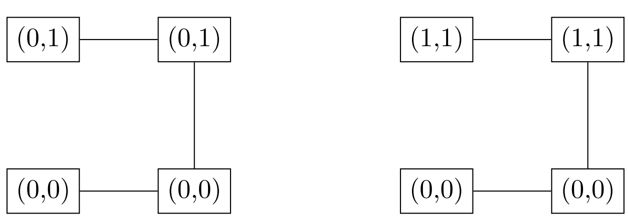
players. All links in a star-like network are from the central player to another player. Given that all non-central players are not connected, a 2-trait equilibrium in a star-like structure is feasible when k values are high (Figure 7). In such a scenario, the central player selects one strategy, while the other non-central players collectively choose a strategy that shares at least one common identity with the central player's strategy. A 4-trait equilibrium is now impossible in star-like graphs, even when k values are high. Because for any given strategy of the central player,(for example (0,0)), all three non-central player will not have incentive to play the strategy that shares no common cultural identity trait with the central player's strategy ((1,1) in the example).

Figure 2.7: 2-trait equilibrium in star-like graph when k=1



The last possible network is the line graph (Figure 1(f)), where two players at the ends have only one neighbor while the middle two players have two neighbors. Again, similar to the ring graph, the lack of a central player allows for a heterogeneity in expression even when k is small. Two types of equilibria with two traits can exists when k=0 (Figure 8).

Figure 2.8: 2-trait equilibria of line structure when k=0



We also examine the relationship between dispersion, the number of traits in equilibria, and the k-value (Figure 9 to Figure 14) and found it is complex and heavily depends on the specific network structure. Generally, as k augments, the dispersion as well as the number of traits tends to increase, thereby underscoring the significance of uniqueness in fostering diversity within a multicultural social group. However, this relation does not hold universally for all network structures or for every range of k values. For instance, in the bowtie structure, the dispersion of equilibria when k=1 is actually smaller than those when k=0.5 (Figure 12). In certain cases, such as the 5-edge graph when $k = 0.5$, no pure equilibrium exists, hinting that specific network structures and k-values may not permit a stable social state. Hence, we conclude that the relationship between the dispersion and k value and the relationship between the number of traits and k value as non-monotonic and network-specific. Fixing the maximum links per node, increasing total links generally leads to an increase in the number of traits and dispersion, particularly when k is large. The range bars depicted in Figures 9 to 14 represent the maximum and minimum potential values of dispersion at a specific k value within each network. Our analysis revealed that these range values have no significant correlation with either the k value or the number of links. This demonstrates that the relationship between the variation of dispersion and total number of links is also non-monotonic and specific to the network structure.

Figure 2.9: Dispension vs. k-value, Complete graph

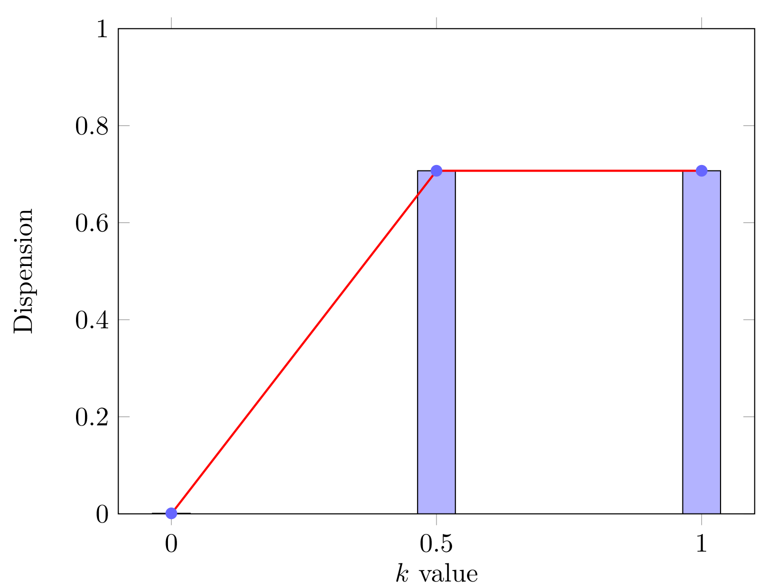


Figure 2.10: Dispension vs. k-value, 5-edge graph

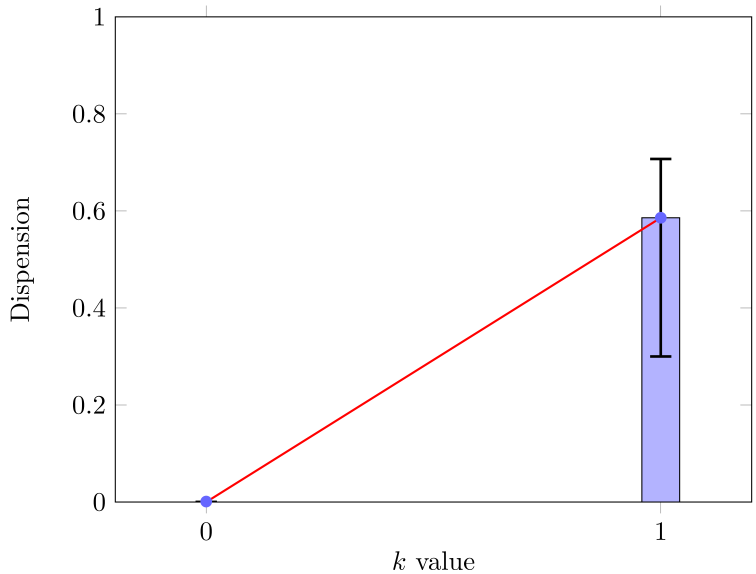


Figure 2.11: Dispension vs. k-value, 4-edge ring

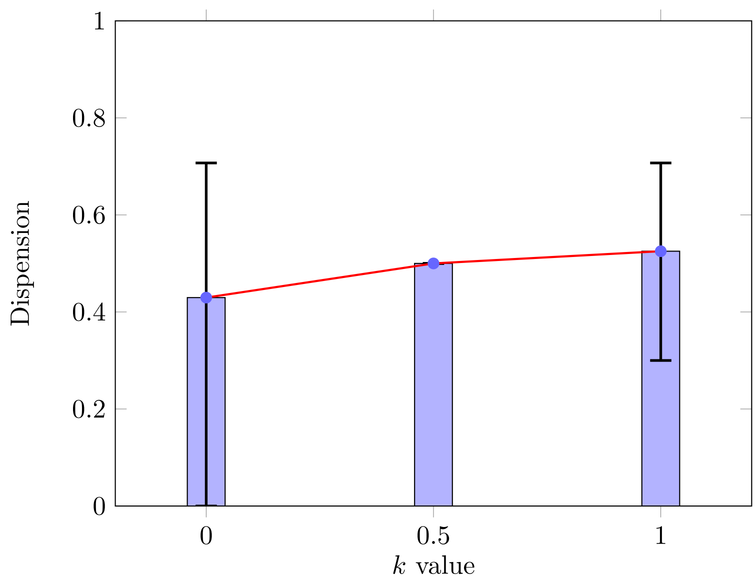


Figure 2.12: Dispension vs. k-value, bowtie structure

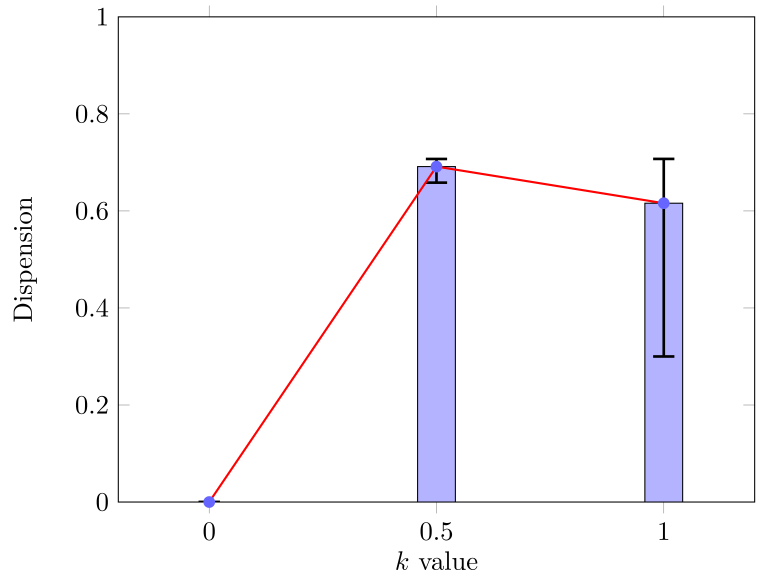


Figure 2.13: Dispension vs. k-value, star-like structure

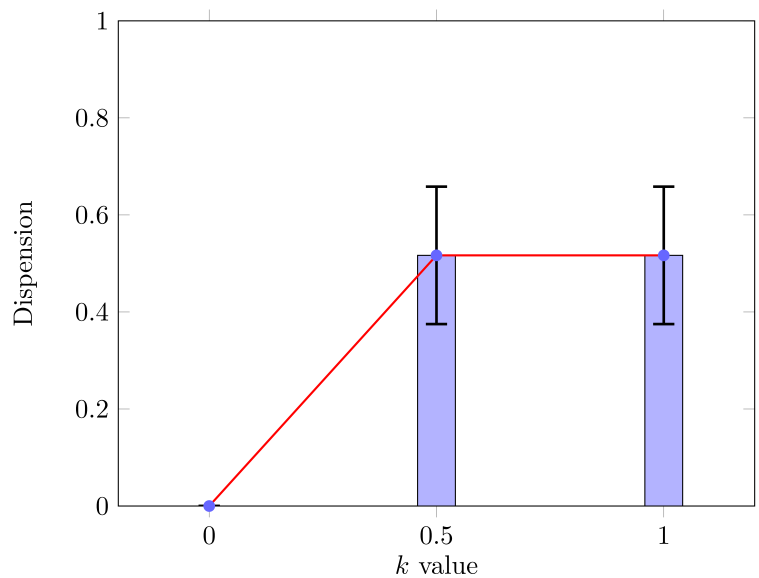
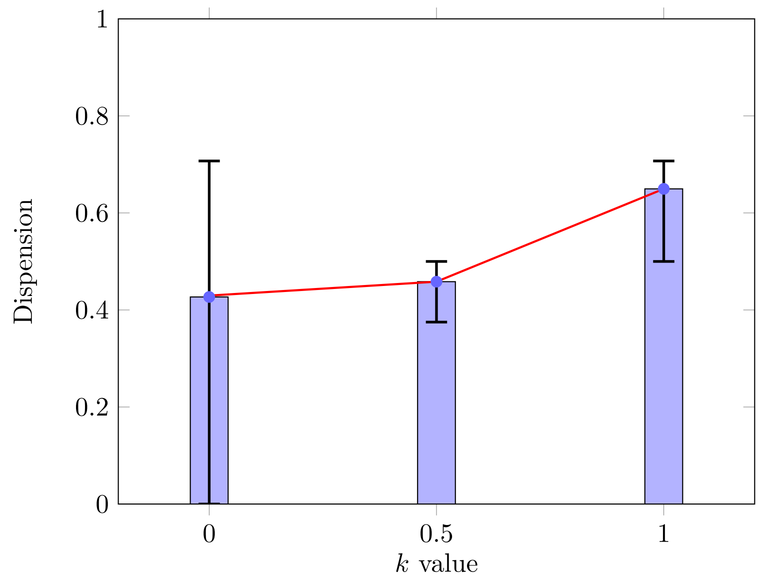


Figure 2.14: Dispension vs. k-value, line structure



2.4 Extension

2.4.1 Self-Esteem Motive

Previous model assumes that agents are identical and have no predetermined intrinsic values that represent their cultural identities. In other words, agents do not have cultural identities until they play the game of cultural identity expression. However in model cultural interactions across different cultures, such as the behavior of immigrants or international students, assuming agents having an ex ante "actual identity", which may or may not be the same as their expressed identity is essential. In this extension of the game of cultural identity expression, we introduce a third motive: the self-esteem motive. The self-esteem motive is driven by the desire of an individual to maintain a positive self-image by expressing an identity that closely aligns with their actual identity (Crocker and Wolfe [2001]).

Incorporating the self-esteem motive into the analysis provides a more comprehensive understanding of the factors that influence an individual's choice of identity expression strategies (Swann [1987]). This additional motive highlights the importance of authenticity and consistency between one's expressed and actual identity, which may be particularly relevant in societies where individuals are encouraged to explore and embrace their true cultural affiliations (Vignoles et al. [2006]). When considering the self-esteem motive, individuals face a trade-off between conformity, uniqueness, and authenticity (Brewer [1991]). They must balance the desire to align with the prevailing cultural norms and expectations of their social environment, maintain a unique identity among their peers, and express an identity that reflects their true self (Sedikides and Gregg [2008]). This complex interplay of motives can lead to a diverse range of identity expression strategies, with different individuals prioritizing different aspects based on their personal preferences and cultural backgrounds (Markus and Kitayama [1991]).

Examining the role of the self-esteem motive in different multicultural social environments can shed light on the factors that shape the distribution of identity expression strategies and their consequences for intergroup relations (Tajfel and Turner [1986]; Berry [1997]). Initiatives that encourage self-reflection, self-awareness, and open dialogue about cultural differences, such as diversity training, mentoring programs, or inclusive educational curricula, might be particularly effective in fostering a more diverse array of identity expression strategies that are consistent with individuals' true cultural identities (Banks [2008]).

The extended model assumes that agents have pre-determined multi-dimension intrinsic values that represent their cultural identities. While these values are fixed and cannot be updated, agents can choose to express a value that differ from their intrinsic values when interacting with others[7]. The level of self-esteem for an agent is calculated by the distance between their expressed identity and their actual identity, denoted by $\|e_i - v_i\|$. The level of conformity and uniqueness are defined the same as in the previous model.

The utility function for person i is as follows:

$$u_i = -\alpha\|e_i - v_i\| - \beta\|e_i - \bar{e}\| - \gamma s_i \tag{2.4}$$

In this utility function, α, β, and γ are positive parameters that describe the relative importance of self-esteem, conformity, and uniqueness, respectively. Intuitively when self-esteem (α) is a dominant factor, individuals are more likely to choose identity expressions that closely align with their personal identities. In the following example, we will present a 2-player game to illustrate the additional insights generated by the self-esteem motive.

Example 2 *There are two individuals, A and B, living in a society with two types of identities which are perpendicular to each other. The personal identity (i.e. their personal values) for A is* $(1, 0)$ *and for B is* $(0, 1)$*, then* $v_A = (1, 0)$ *and* $v_B = (0, 1)$*. Each player has four pure strategies available:* $(0, 0)$*,* $(0, 1)$*,* $(1, 0)$ *and* $(1, 1)$*, with a payoff function* $u_i = -\alpha\|e_i - v_i\| - \beta\|e_i - \bar{e}\| - \gamma s_i$*. The game can be described by the following table:*

[7]One even further extension to this is that we can allow the intrinsic values of agents to be updated during periods. This can be explained a preference change shaped by socialization and self-persuasion (Kuran and Sandholm [2008] and Wu [2021]).

Table 2.3: Game of expressing of cultural identity, two players and two identities with self-esteem motives

		Player B			
		(0,0)	(0,1)	(1,0)	(1,1)
Player A	(0,0)	$-\alpha-\gamma,-\alpha-\gamma$	$-\alpha-\frac{1}{2}\beta,-\frac{1}{2}\beta$	$-\alpha-\frac{1}{2}\beta,-\sqrt{2}\alpha-\frac{1}{2}\beta$	$-\alpha-\frac{\sqrt{2}}{2}\beta,-\alpha-\frac{\sqrt{2}}{2}\beta$
	(0,1)	$-\sqrt{2}\alpha-\frac{1}{2}\beta,-\alpha-\frac{1}{2}\beta$	$-\sqrt{2}\alpha-\gamma,-\gamma$	$-\sqrt{2}\alpha-\frac{\sqrt{2}}{2}\beta,-\sqrt{2}\alpha-\frac{\sqrt{2}}{2}\beta$	$-\sqrt{2}\alpha-\frac{1}{2}\beta,-\alpha-\frac{1}{2}\beta$
	(1,0)	$-\frac{1}{2}\beta,-\alpha-\frac{1}{2}\beta$	$-\frac{\sqrt{2}}{2}\beta,-\frac{\sqrt{2}}{2}\beta$	$-\gamma,-\sqrt{2}\alpha-\gamma$	$-\frac{1}{2}\beta,-\alpha-\frac{1}{2}\beta$
	(1,1)	$-\alpha-\frac{\sqrt{2}}{2}\beta,-\alpha-\frac{\sqrt{2}}{2}\beta$	$-\alpha-\frac{1}{2}\beta,-\frac{1}{2}\beta$	$-\alpha-\frac{1}{2}\beta,-\sqrt{2}\alpha-\frac{1}{2}\beta$	$-\alpha-\gamma,-\alpha-\gamma$

We can identify pure Nash equilibria in the game[8]*:*

1. *If* $\alpha+\gamma \leq \frac{1}{2}\beta$*, then ((0,0),(0,0)) and ((1,1),(1,1)) are NEs. In such equilibria both players are expressing the same identity that is the midpoint of players' personal values, and get a payoff of* $-\alpha-\gamma$*.*

2. *If* $\alpha \leq \frac{\sqrt{2}-1}{2}\beta$*,* $\alpha+\gamma \geq \frac{1}{2}\beta$ *and* $(\sqrt{2}-1)\alpha \geq \frac{1}{2}\beta-\gamma$*, then ((1,0),(0,0)), ((1,0),(1,1)),((0,0),(0,1)) and ((1,1),(0,1)) are NEs. In such equilibria one player is expressing their personal value, and the other player is expressing an identity that is a midpoint of both players' personal values. Player who is expressing their personal value gets a relative higher payoff (*$-\frac{1}{2}\beta$*), and player who is expressing the midpoint value gets a relative lower payoff (*$-\alpha-\frac{1}{2}\beta$*).*

3. *If* $\alpha \geq \frac{\sqrt{2}-1}{2}\beta$ *and* $\sqrt{2}\alpha+\gamma \geq \frac{\sqrt{2}}{2}\beta$*, then ((1,0),(0,1)) is a NE. Both players are expressing their personal values and get a payoff of* $-\frac{\sqrt{2}}{2}\beta$*.*

4. *If* $\alpha+\frac{1}{2}\beta>\gamma$*,* $\alpha>\frac{\sqrt{2}-1}{2}\beta$ *and* $\sqrt{2}\alpha+\gamma<\frac{\sqrt{2}}{2}\beta$ *then* $((0,1),(0,1))$ *and* $(1,0),(1,0)$ *are NEs. In these NEs one player is playing their person value, and the other player is following by also playing their opponent's value.*

We can see that different values of the parameters of motives can result in different types of equilibria in the context of cultural identity expression. Particularly the strategy profiles where players expressing the opposite identity expression ((1,0),(0,1)), which was not a possible NE in the baseline model is now supported as a NE. In these equilibria, both players strictly express their personal values, and both receive a payoff of $-\frac{\sqrt{2}}{2}\beta$.

2.5 Conclusion

We employ game theory to model the motives underlying cultural identity expression in social networks, considering agents driven by conformity and uniqueness. We proposed a network framework to capture the limitations of agents' interactions within the society, which plays a crucial role in shaping the patterns of

[8]See Appendix for details on identifying the pure Nash equilibria of the game of expressing of cultural identity of two players and two identities with self-esteem motive.

cultural identity expression. Through the lens of game theory, we were able to analyze the behavior of agents and their strategic choices in expressing their cultural identities.

To evaluate the Nash equilibria (NEs) in the context of cultural identity expression, we introduced new metrics such as dispersion, number of traits, and maximum links. Dispersion measures the average deviation of individual strategies from the social average. The number of traits reflects the diversity of strategies in a strategy profile, and maximum links capture the extent to which agents can interact with others in the network.

Our analysis revealed that the influence of the relative strength between conformity and uniqueness motives differs among different networks. Depending on the network structure and the social environment, the balance between these motives may lead to distinct patterns of cultural identity expression. This finding highlights the importance of understanding the interplay between individual motives and social network structures in shaping cultural identity expression strategies.

Future research can build upon our proposed framework to explore the impact of additional motives, such as the self-esteem motive, which we briefly discussed earlier. Moreover, incorporating more complex network structures and considering continuous or infinite player settings[9] could provide further insights into the dynamics of cultural identity expression. We also see a need for a more rigorous analysis of social networks using network theory: the formal exploration of the relationship between different max links per nodes and total links, using precise values such as eigenvalues to understand the mathematical implications of these links and metrics in network theory. This approach can bring a higher level of rigor to the study of the cultural identity expression and offer a more precise understanding of how social networks operate and evolve with more advanced analytical methods. Finally. our work also constitute a great foundation to study empirical implications social network analysis. In particular, the examination of real-life social networks, such as online networks versus face-to-face interactions, with methods and metrics introduced in this research can offer valuable insights.

[9] Representative researches include Blume [1993], Brock and Durlauf [2001]), and Sandholm [2010].

Chapter 3

Limited Cognitive Abilities and Dominance Hierarchy

This chapter is co-authored by Hanyuan Huang[1] and Jiabin Wu[2]. The research was previously published as: Huang, H., Wu, J. Limited Cognitive Abilities and Dominance Hierarchies. Acta Biotheor 70, 17 (2022)

3.1 Introduction

Dominance hierarchy is a social hierarchical structure in which a ranking system among the agents in a population can be induced based on their interactions. Introduced by Schjelderup-Ebbe [1935] in describing the social organization of chickens, dominance hierarchy has been found to be very common as a function of regulating animal societies, especially in situations where there are potential costs and risks of conflict during interactions. More specifically, in a society with dominance hierarchy, pairwise interactions are regulated by a ranking system, where the higher-ranked agent in a pair acts dominantly, and the lower-ranked agent acts submissively. Linear hierarchy, known as pecking order, is a common social structure in various species including sheep, birds and crayfish (Addison and Simmel [1980]; Barkan et al. [1986]; Goessmann et al. [2000]; Hausfater et al. [1982]; Heinze [1990]; Nelissen [1985]; Savin-Williams [1980]; Vannini and Sardini [1971]; Wang et al. [2011]). In this hierarchy, every agent is dominated by the higher-ranked members and in turn dominates the lower-ranked agents. Other nonlinear hierarchical structures have also been observed in nature. A typical nonlinear hierarchy is despotism, which can be found in hamsters, gorillas, and African

[1] Author Contributions by Hanyuan Huang: Conceptualization; Formal analysis; Investigation; Methodology; Software; Visualization; Original draft; Review & editing.

[2] Author Contributions by Jiabin Wu: Conceptualization; Methodology; Supervision; Review & editing.

wild dogs (Alcock [2013]). It is a social order in which one agent dominates all others, with no dominance relations among subordinates. In addition, more complex nonlinear hierarchical social structures have been observed in dolphins, chimpanzees, baboons, and macaques (Holekamp and Smale [1993]; Kummer [1984]; Surbeck et al. [2011]). It is worth noting that if a hierarchical structure is not linear, then it must have at least one of the following properties: (1) there are two agents with equal hierarchical status, that is, they behave in an equal manner upon interaction; (2) there are two agents with an unknown or undefined relationship; and (3) there is a non-transitive relationship in a triad (A dominates B, B dominates C,and C dominates A) (de Vries [1995]). The commonality of the linear hierarchical structure in nature suggests that transitivity may be a desired property of the dominance hierarchy (Appleby [1983]).

Many studies have been conducted to explain how social hierarchies can be achieved and sustained. Two major approaches have been proposed in the literature. The first approach proposes that the social hierarchical structure is an external attribute and an expression of intrinsic physical or physiological differences among the agents, which can be directly (e.g., greater fighting abilities and larger bodies) or indirectly (e.g., better reproductive abilities and higher social status) related to the dominance behavior. This is also known as the prior attribute hypothesis (Drews [1993]; Chase et al. [2002]). However, evidence has shown that it is difficult to predict the outcomes of dominance encounters for animals in small groups using these differences (Chase and Seitz [2011]). The second approach suggests that social hierarchies result from the dynamics of social interactions. The most representative case is the winner-and-loser effect, where individuals who win (lose) a contest have higher (lower) probability winning the next contest (Dugatkin and Earley [2004]; Kura et al. [2016]; Goessmann et al. [2000]). Although it is the most representative explanation for hierarchy formation, the theory of winner-and-loser effect has been criticized for its arbitrary set-up values and lack of independence with regard to personality traits (Favati et al. [2017]).

The two existing approaches are not mutually exclusive (Chase and Seitz [2011]), yet they have rarely been studied jointly (Favati et al. [2017]). The aim of this research is to develop a model to explain some typical social hierarchical structures considering the pre-existed differences in the individual characteristics of the agents and the social interactions among them. Our model is built on the classical Hawk-Dove (HD) game. A population of agents is randomly matched to play the HD game, and each agent carries a unique identity. Thus, agents are able to condition their strategies on their opponents' identities. We then assume that the identities of the agents can be ranked linearly to capture the external differences in attributes, such as their biological characteristics. We also introduce a social convention to the game that provides "suggestions" to the agents on their actions in the HD game according to their relative ranks. The purpose of this social convention can be seen as nature acting like a principal, who aims to maximize the fitness of a population of agents by indirectly influencing their behavior (Binmore [1994]).

Another important feature of the model is that we assume that the agents can only memorize some agents' identities, but not the rest. The restriction imposed on the agents' memories can be viewed as a case of bounded rationality framed as a costly computation (Halpern and Pass [2015]). It captures the fact that it usually requires a certain level of cognitive ability for the agents to understand the characteristics of their opponents, to realize the useful information revealed by those characteristics, and to act accordingly. This limited ability to acquire others' identities, also referred as memory size, helps the agents in choosing their strategies, which include whose identities they choose to memorize and their corresponding actions in the HD game. The agents can condition their actions in the HD game on their opponents' identities only when the identities of these opponents are memorized.

We analyze the hierarchical social structures that emerge as equilibria in the model and consider those that follow the suggestion of the social convention and maximize the total fitness of the population. We find that different hierarchical social structures, including linear hierarchy and despotism, maximize total fitness in populations with different levels of cognitive abilities. Specifically, when the memory size of the agents is sufficiently large, the linear hierarchy is optimal. When the memory size is singular, despotism is optimal for small populations. We also conjecture that when cognitive ability is at a medium level, a three-layer dominance hierarchy structure, that divides the population into three classes, may be optimal. We confirm this conjecture through simulation. Hence, our model provides a mechanism that links cognitive ability with social hierarchy.

A closely related paper by Doi and Nakamaru [2018] studies the coevolution of transitive inference and memory capacity in the Hawk–Dove game. They find that when the cost of fighting is low, transitive inference with limited memory capacity has an evolutionary advantage because the agents can avoid costly fights via prompt formation of the dominance hierarchy which does not necessarily reflect the actual rank of the agents' resource-holding potential[3] While both we and Doi and Nakamaru [2018] consider the dominance hierarchy and limited memory capacity, their approach is different from ours in several ways. First, in the model of Doi and Nakamaru [2018], agents engage in repeated interactions with one another, and their memories allow them to count a certain number of past wins and losses of the contests between two agents, which helps them determine the ranking of the two agents in terms of resource-holding potential. Instead, we consider that agents memorize the identities of some other agents. Second, Doi and Nakamaru [2018] consider agents with different resource-holding potential, whereas the agents in our model are identical except for their identities. Hence, the agents in our model do not need to access who are stronger (weaker) than them. Third, Doi and Nakamaru [2018] examine the evolutionary stability of different combinations of inference procedures and memory capacity. In contrast, we investigate what equilibrium social structure can arise given different

[3]See also Nakamaru and Sasaki [2003] for a study on the evolution of transitive inference.

memory capacities and find those that maximize population fitness.

The remainder of this paper is organized as follows. In Section 2, the proposed model is presented. Section 3 analyzes the equilibria of the game from our model under various levels of limited cognitive abilities. Section 4 discusses a possible relaxation of restrictions imposed on the model. Section 5 consists of the conclusion.

3.2 Model

3.2.1 The Hawk-Dove game

Consider a population of N agents who are randomly matched in pairs to play the Hawk-Dove (HD) game. The HD game has been widely used to model pairwise interactions where individuals contest a beneficial resource with a possibility of an escalated fight at a large cost, which constructs a simple situation where players have a choice to either being harsh (play Hawk) or soft (play Dove) on their opponents. The earliest illustration of the HD game is presented by Smith and Price [1973] in their analysis of animal behavioral strategies in contest situations. In this paper, we adopt the game form provided by Smith and Parker [1976] as shown in Figure 1.

In this game, V is the value of the contested resource and C is the cost of an escalated fight. It is assumed that the value of the resource is less than the cost of a fight, that is, $C > V > 0$. Players split the beneficial resource equally if they both play Dove. They equally split the difference between the resource and fighting cost if they both play Hawk. The player who plays Hawk exclusively wins the resource if the other player plays Dove.

Figure 3.1: The Hawk-Dove Game

		Player 2	
		Hawk	Dove
Player 1	Hawk	$(V-C)/2, (V-C)/2$	$V, 0$
	Dove	$0, V$	$V/2, V/2$

The HD game carries three Nash equilibria (NEs), with two in pure strategy, $(Hawk, Dove)$ and $(Dove, Hawk)$, and one in mixed strategy, where each player plays *Hawk* with a probability of V/C. The expected fitness from playing the mixed NE strategy is $(1 - V/C)(V/2)$.

3.2.2 Identity and Social Convention

We assume that each agent is assigned with an identity. Identity plays the role of a name tag and it is unique for each agent. With this information, it is possible for the agents to condition their strategies on their opponents' identities. The difference in identities between two agents can be interpreted on the basis of differences in some of their biological characteristics, such as body size and reproductive ability, whereas in a social interpretation, it can be a label (e.g., representing different social classes in human societies) attached to the agents.

A linear social rank over the agents' identities is assumed. With this assumption, identities can be written as numbers such that their values reflect the relative ranks. Without loss of generality, we say agents with smaller-valued identities are ranked higher.

There is also a social convention that gives favor to those who rank higher. This is done by imposing a suggestive rule on the agents, regulating their actions in the HD game in accordance with the predetermined social rank. Specifically, it suggests that agents play $Hawk$ against opponents with lower ranks, and play $Dove$ against opponents with higher ranks. Since everyone is assumed to have a unique identity, if the social convention is followed, in any equilibrium, one player plays $Hawk$ and the other plays $Dove$ in each pairwise interaction.

Importantly, a linear social rank is assumed for the purpose of designing the social convention. The numerical values of the numbers are meaningless to the agents, and they do not need to know the social rank. For example, if an agent's assigned number is 5 and it knows the identity of the agent whose assigned number is 1, then given the suggestion of the social convention, the number 5 agent should play Dove to the number 1 agent.

A pertinent question is, who design the social convention? We assume nature acts as the principal, trying to maximize the fitness of the population by indirectly influencing agents' behavior [Binmore, 1994]. The social convention based on the linear social rank can guide agents to avoid playing $(Hawk, Hawk)$, which is the only strategy profile that generates fitness loss (C) on the scale of the full population in the HD game (Figure 1).

3.2.3 Memory

In a complete information environment, each agent's identity is common knowledge to all agents; therefore the agents can condition their strategies on their opponents' identities for every possible opponent. However, given their limited cognitive abilities, it seems unrealistic to assume that all agents can access all others' identities any time at no cost, especially in a large population. We use the concept of memory to model the limitations of the cognitive ability of the agents. The limitation is the maximum number of agents that an agent can have memory of, which we refer to as the individual memory size (m). In other words, the agents can memorize the identities of at most m other agents, but not those of the rest. Once encountered, agents can recognize the identities of those who they remember. Therefore, on the one hand, the agents can prepare a corresponding strategy for each of the agents that they have a memory of, conditioned on the basis of their identities. On the other hand, they can have only one universal strategy of responding to the rest of the agents, whom they do not have a memory of, because they have no way to distinguish these opponents.

With limited memory, the predetermined social rank and the social convention will be effective for the agents only in situations when they are facing opponents with identities that they memorize. This is because social convention provides agents with suggestions on their actions according to their relative ranks to their opponents. If an agent does not know the identity of its opponent, it cannot act accordingly as suggested by the social convention.[4]

To summarize, in our model, a population of agents is randomly matched in pairs to play the HD game, as shown in Figure 1. Each agent in the population carries a unique number as its identity. The numbers provide a natural linear social rank among the agents. There is a social convention suggesting that agents play *Hawk* against opponents with lower ranks, and play *Dove* against opponents with higher ranks. Each agent can memorize the identities of a limited number of agents. We assume that all the agents in the population have the same memory capacity. Note that an agent is not required to use all of its memory. In addition, we do not explicitly model the cost of memorizing an agent's identity. Nevertheless, if we encounter two equilibria that induce the same level of total fitness of the population and one equilibrium requires fewer memory slots than the other, we consider that the former is favored by natural selection.

3.2.4 Equilibrium

Memory table, Strategy table and Social Structure graph

To discuss the potential equilibria of the model, we first need to clarify how we describe the agents' strategies. At the beginning of the game, the agents must decide: (1) who they memorize, and (2) what their corresponding strategies are against each possible opponent. They can have a separate strategy for each opponent that they memorize (because once encountered, they are able to tell which opponent they are playing against if they have the opponent in their memory), but only one universal strategy for all other opponents that they do not have a memory of. As a result, the strategy profiles of the game should contain every agents' choices on memories and the corresponding strategies.

We use two tables, a memory table and a strategy table to represent a particular strategy profile. Figure 2 shows an example of the memory and strategy tables of a particular strategy profile in a population with

[4] It is still possible for the agents to infer the relative ranks between themselves and their opponents without having the identities of their opponents in memory. For example, the top ranked agent can infer that all its opponents have lower ranks; the bottom ranked agent can infer that all its opponents have higher ranks; the second top ranked agent who has the top ranked agent in its memory can infer that all other opponents have lower ranks. Nevertheless, inferring about the ranks of those agents that an agent has no memory of arguably requires strong cognitive ability, which cannot simply be modeled as memory. Hence, we do not consider such a possibility in this paper.

five agents. In the example, Player 1 (P_1) memorizes P_2 and P_3 and, always plays $Hawk(H)$. P_2 and P_3 memorize P_1 and P_5, and play $Dove(D)$ to P_1 and the mixed strategy in the mixed NE of the original HD game (*plays Hawk with a probability of* V/C), which we refer to as M, to others. $P4$ memorizes P_1 and P_5, and plays D to P_1, H to P_5, and M to others. P_5 memorizes P_1 and P_4, and plays D to P_1 and P_4, and M to others.

The memory and strategy tables combined can be used to describe any strategy profile in the game. The two tables need to be consistent in describing the same strategy profile of the game, meaning that agents have to be able to perform the strategy they choose in the strategy table, given their memories as shown in the memory table. Specifically, every agent should have the same strategy in the strategy table for all opponents that they do not have a memory of. The strategy table lists every agent's strategies in the HD game, which can be H, D or any mix of H and D. However, if a strategy table describes a strategy profile that is an equilibrium, then its only possible entries are H, D and M, and any pair that is on the symmetric positions relative to the diagonal (e.g., (1,2) and (2,1), or (3,5) and (5,3)) must be (H, D), (D, H) or (M, M), reflecting only three NEs in the original HD game.

In addition, if the agents' strategies do not violate the social convention (that is, the upper-right entries in the strategy table must be H if their corresponding entries in the memory table are 1, and the lower left entries in the strategy table must be D if their corresponding entries in the memory table are 1), then the strategy profile is an equilibrium that follows social convention.

Figure 3.2: Example of the memory and strategy tables of a strategy profile

A: Memory Table

	P_1	P_2	P_3	P_4	P_5
P_1	*	1	1	0	0
P_2	1	*	0	0	1
P_3	1	0	*	0	1
P_4	1	0	0	*	1
P_5	1	0	0	1	*

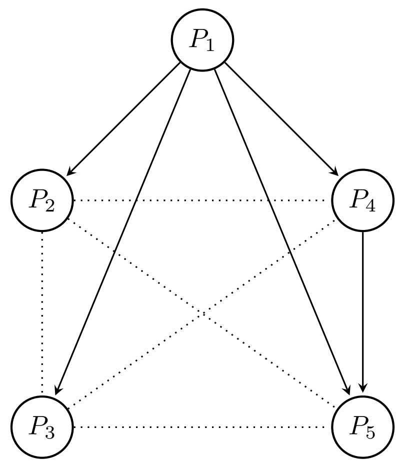
B: Strategy Table

	P_1	P_2	P_3	P_4	P_5
P_1	*	H	H	H	H
P_2	D	*	M	M	M
P_3	D	M	*	M	M
P_4	D	M	M	*	H
P_5	D	M	M	D	*

Since in any equilibrium, the only strategy pairs between any two agents are (H, D), (D, H) or (M, M), there are only two possible relations between any two agents as the result of an equilibrium: one (who plays H) dominates the other (who plays D) or an equal status (play M against each other). Therefore, a network graph can be used to show the underlying social structure based on the equilibrium of the game. Figure 3 shows the social structure graph based on the example in Figure 2. In the graph, players are represented by circles with names, and a solid arrow between two circles indicates the dominant-submissive relation, where its direction shows the direction of domination. Two players are connected by a dotted line if they have an equal status in which they play M when facing each other. Note that the strategy profile shown in Figure

2 is an equilibrium. However, it does not follow social convention because P_2 and P_3 both have memory of P_5 but do not play *Hawk* against it. The social convention requires that an agent will always play *Hawk* against any agent that they recognize who is lower in the social order.

Figure 3.3: The social structure graph of the society in Figure 2



3.2.5 Equilibrium Selection Based on Total Fitness

Each equilibrium constructs a hierarchical social structure in the sense that it assigns each agent a hierarchical position resulting in some agents enjoying a higher fitness than the others. The assignment is purely based on the agents' identities, which have nothing to do with superior rationality, information, or contribution.

However, the benefit of forming a hierarchical social structure may be more significant at the population level than at the individual level. Indeed, at the individual level, some agents (those with dominant roles in the hierarchies) may benefit and the rest (those with submissive roles) may suffer from a hierarchical social structure compared to an anarchical state where the only equilibrium is everyone always playing M. However, at the population level, a hierarchical social structure may increase the total fitness of the entire population (the sum of individual fitness), which helps the population stand out in the competition with other populations, if there are multiple populations. Hence, a population with a hierarchical social structure may be favored by natural selection.

We seek a social structure that maximizes the total fitness of the population. Recall that, $(Hawk, Hawk)$ is the only strategy profile that generates fitness loss, and under our potential equilibrium social structures, this only happens when two players have equal status and they play (M, M) (then $(Hawk, Hawk)$ occurs at a probability of V^2/C^2). Therefore, an optimal social structure must have the fewest pairs of agents with the same social status.

A secondary evaluation of the total fitness of the population is performed to examine the total memory usage among all agents. Memorizing an agent's identity is potentially costly, although the cost may be minimal compared with the fitness loss from the $Hawk - Hawk$ clash in the game. Hence, we only use such an evaluation as a tie-breaker for social structures that provide the same level of total fitness.

3.3 Analysis

In this section, we study the model with a focus on the hierarchical social structure that maximizes total fitness under various levels of limited cognitive abilities. As described above, the limitation on cognitive abilities is modelled as a memory constraint (m), that is, the maximum number of other agents that an agent can remember the identities of.

3.3.1 Fully Restricted Memory: $m < 1$

First, we consider the case in which memory size is smaller than one. This occurs when agents' cognitive ability is sufficiently low. Since the memory size is not sufficient for the agents to memorize the identity of any single agent, the only possible memory table for this population is as shown in Figure 4(A) (we use a population of five agents for illustration). Then, the only equilibrium strategy table can be supported in this case, is where everyone plays the mix strategy in the mix NE in the original HD game (M) to all others, as shown in Figure 4 (B). Thus, the corresponding social structure gives an anarchical (or some refer to it as egalitarian) social structure, as shown in Figure 5.

When evaluating the total fitness, because every pair in the population plays (M, M), the probability of having a $Hawk - Hawk$ clash, the major source of fitness loss in the game, is V^2/C^2. Therefore, the expected fitness loss for each pair is $(V^2/C^2)(C) = V^2/C$ and all agents have an identical average fitness value of $(1 - V/C)(V/2)$. Note that in this case, the social convention is not followed as the agents cannot access others' identities.

Figure 3.4: Fully restricted memory

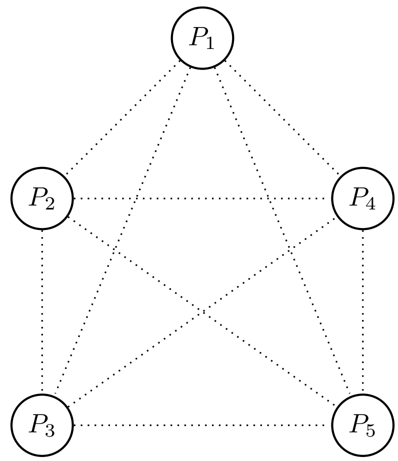
A: Memory Table

	P_1	P_2	P_3	P_4	P_5
P_1	*	0	0	0	0
P_2	0	*	0	0	0
P_3	0	0	*	0	0
P_4	0	0	0	*	0
P_5	0	0	0	0	*

B: Strategy Table

	P_1	P_2	P_3	P_4	P_5
P_1	*	M	M	M	M
P_2	M	*	M	M	M
P_3	M	M	*	M	M
P_4	M	M	M	*	M
P_5	M	M	M	M	*

Figure 3.5: Social structure, $m < 1$



3.3.2 Unlimited Memory: $m \geq N - 1$

The agents are able to memorize all other agents' identities if their memory size equals the population size minus 1 ($N - 1$). In this case, with everyone's identity in memory, each agent can condition its strategy for every possible opponent, making ($Hawk, Dove$) and ($Dove, Hawk$), in addition to (M, M), possible equilibria in meetings between any two agents. Thus, in the population, there are $2^{\frac{N(N-1)}{2}}$ different ways to form a social structure in which each pair of agents is playing (H, D) or (D, H). Under such a social structure, every pair of agents is arranged with a dominant-submissive relation. Hence, there is no fitness loss in the population from the $Hawk - Hawk$ clash. We refer to these fitness-loss-free social structures as ordered social structures.

With the presence of linear rank in their identities and the fact that agents memorize the identities of all other agents, a linear social hierarchical structure (Figure 7) is the only ordered social structure that follows social convention. Figures 6 (A) and 6(B) show the corresponding memory table and strategy stable. Again, we use a population of five agents for illustration purposes.

Figure 3.6: Unlimited Memory ($m \geq N - 1$), linear hierarchy

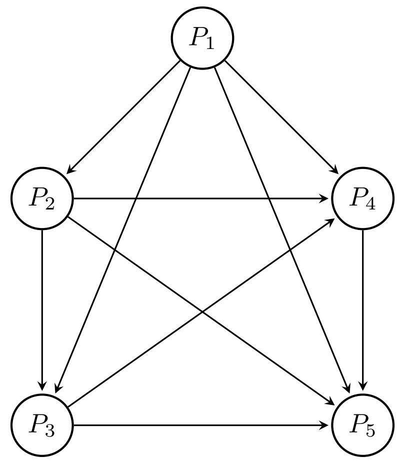
A: Memory Table

	P_1	P_2	P_3	P_4	P_5
P_1	*	1	1	1	1
P_2	1	*	1	1	1
P_3	1	1	*	1	1
P_4	1	1	1	*	1
P_5	1	1	1	1	*

B: Strategy Table

	P_1	P_2	P_3	P_4	P_5
P_1	*	H	H	H	H
P_2	D	*	H	H	H
P_3	D	D	*	H	H
P_4	D	D	D	*	H
P_5	D	D	D	D	*

Figure 3.7: Linear Hierarchy



3.3.3 Sufficient Memory: $\lceil N/2 - 1 \rceil \leq m < N - 1$

We consider agents as having sufficient memory if they are able to memorize at least half minus one ($\lceil N/2 - 1 \rceil$), but not all the identities of the other agents.[5] We demonstrate that sufficient memory is sufficient for a population to form an ordered social structure. In particular, we show that a linear hierarchy can be formed.

Proposition 1 *A linear hierarchy social structure can be an equilibrium if the memory size (m) satisfies* $m \geq \lceil N/2 - 1 \rceil$.

Proof. Under a linear hierarchical social structure, each agent plays either *Hawk* (H) or *Dove* (D) to its opponents. To successfully implement these strategies, the agents can choose to memorize the fewer between all agents that they need to play H to and all agents that they need to play D to. Then, they play H (or D) to the agents in their memory and D (or H) to those who are not in their memory. The required memory level for the agents depends on their positions in the linear social rank. When N is odd, the agent who needs the largest memory size is the one who is positioned in the middle, and it needs to memorize $(N-1)/2$ other agents to play H (or D) to, and D (or H) to the rest. If N is even, the two agents in the middle need to memorize $N/2 - 1$ other agents. Hence, if everyone has a memory size no less than $\lceil N/2 - 1 \rceil$, then the linear hierarchical social structure can be supported as an equilibrium. ■

Note that if we treat the use of memory as a minor source of fitness loss, the optimal memory size that gives rise to the linear structure is $\lceil N/2 - 1 \rceil$. Moreover, only the agent(s) situated in the middle of the linear social rank require(s) the use of its entire memory, while others can use less. Figure 8 (A) illustrates the optimal memory table for a population of five agents. We call this form of memory usage as a "triangular memory structure" because the usage of memory gradually increases as we move from either the top or the

[5] $\lceil x \rceil$ is the ceiling function, which gives the least integer greater than or equal to x.

bottom toward the middle of the rank of agents, and the agents who need the largest memory size are those who are situated in the middle. The total memory usage is $\lceil N(N-2)/4 \rceil$ for a triangular memory structure in a population of N agents. When compared with Figure 6 (A), one can observe that the memory cost is greatly reduced in Figure 8 (A), and it is sufficient to ensure that the strategy table in Figure 8 (B) (identical to Figure 6 (B)) constitutes an equilibrium that follows social convention.

Figure 3.8: Sufficient Memory, $\lceil N/2-1 \rceil \leq m < N-1$

A: Memory Table

	P_1	P_2	P_3	P_4	P_5
P_1	*	0	0	0	0
P_2	1	*	0	0	0
P_3	1	1	*	0	0
P_4	0	0	0	*	1
P_5	0	0	0	0	*

B: Strategy Table

	P_1	P_2	P_3	P_4	P_5
P_1	*	H	H	H	H
P_2	D	*	H	H	H
P_3	D	D	*	H	H
P_4	D	D	D	*	H
P_5	D	D	D	D	*

3.3.4 Insufficient Memory: $1 \leq m < \lceil N/2-1 \rceil$

When the memory size is smaller than $\lceil N/2-1 \rceil$, it is impossible for the population to form a linear hierarchical structure that follows social convention. Any equilibrium formed with agents' memory size smaller than $\lceil N/2-1 \rceil$ will involve some pairs of agents playing M to each other, causing a fitness loss from the $Hawk - Hawk$ clash. Therefore, the optimal structures are those that induce the fewest pairs of agents playing (M, M) as their equilibrium strategies.

We first examine the case in which the agents can memorize at the most one other agent's identity, which we refer as the singular memory. We use a computational method[6] to find all equilibrium social structures by examining all possible strategy tables that can be supported by at least one memory table (i.e., the agents must be able to perform the strategy they choose in the strategy table given the memory table). The results show that the despotic social system, where one agent dominates all others ($Hawk - Dove$ relation), is an equilibrium social structure that follows social convention and maximizes the total fitness in a population of five agents (Figures 10 and 11) and in a population of six agents as well.[7] Note that in a population with five agents, there exists another equilibrium social structure, which we refer as the "proxy despotism," where the top-ranked (in the linear social rank) agent only dominates (plays H to) the second top-ranked agent and plays M with the rest. The second top-ranked agent dominates (plays H to) all agents besides the top-ranked agent but plays D to the top.[8] It is equally as good as the despotic structure in terms of

[6]See the appendix for a description of the computation method. The code can be found at https://github.com/harrisonhhy/optimal_social_structure.

[7]Symmetrically, a social system in which one agent is dominated by all others is also an equilibrium social structure that follows social convention and maximizes the total fitness.

[8]Symmetrically, a social system in which the bottom ranked agent is dominated by the second bottom ranked and the second top ranked agent is dominated by all agents beside the bottomed ranked agent is also an equilibrium social structure

total fitness. As shown in Figure 13, proxy despotism has the same probability of having $Hawk - Hawk$ clash as the despotic social structure (4 out of 10 pairs do not have clash). However, their difference is that the proxy despotism requires full use of all agents' singular memory size, while under the despotic structure, the use of memory for the top-ranked agent can be waived. Consequently, the despotic social structure has a fitness advantage over the proxy despotic structure. This may explain their relative frequencies (Sasaki et al. [2016]).

The intuition behind the optimality of the despotic social structure is that when the top-ranked agent is memorized by all others, each usage of memory creates a non-clash ($Hawk - Dove$) pairwise interaction between the top-ranked agent and the agent who uses the memory (in the example of a population with five agents, there are four memories used and four corresponding non-clash relations).

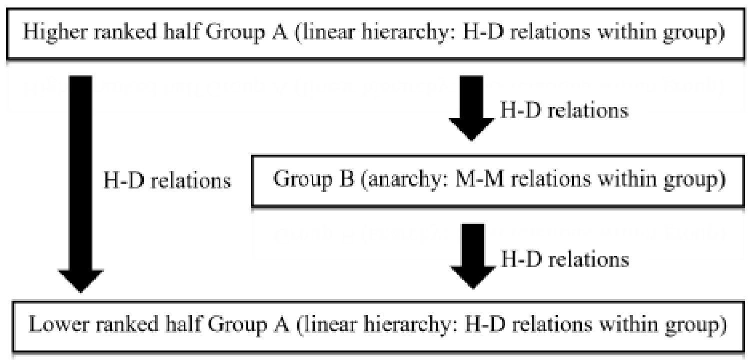
More generally, we conjecture that with insufficient memory ($1 \leq m < \lceil N/2 - 1 \rceil$), the optimal way for agents to use their memories in terms of social efficiency is described as follows.[9] There are m out of N agents, marked as group A, and other $N - m$ agents, marked as group B. Agents in group A form a clash-free linear hierarchy among themselves, and the most fitness-efficient way to do so is to use the triangular memory structure according to Proposition 1. Under the triangular memory structure, agents in group A will be separated into two halves, where the higher-ranked half (lower-ranked half) agents only memorize agents who have higher (lower) ranks than them, and then they play D (H) to the agents in their memory and H (D) to those who are not in their memory (including those agents in group B). The $N - m$ agents in group B will memorize (and only memorize) all agents in group A, play D to the higher-ranked half in group A, play H to the lower-ranked half in group A, and play M to other agents in group B, whom they do not memorize, forming an anarchical/egalitarian sub-social structure within group B. With this form of memory structure and the corresponding strategies, all $m(N-m)$ pairs between group A and group B agents and $m(m-1)/2$ pairs among group A agents have $Hawk - Dove$ as their strategies in equilibrium. Hence, there are $(m(N - m) + m(m - 1)/2)$ out of $N(N - 1)/2$ clash-free pairs, and every one pairwise clash-free relation is maintained by at most one memory. Specifically, the $H - D$ relationship between a group A agent and a group B agent is maintained by the group B agent's memory of the group A agent. The $H - D$ relation between a pair of agents within the higher-ranked (lower-ranked) half in group A is maintained by the lower-ranked (higher-ranked) agent's memory of the higher-ranked (lower-ranked) agent. The $H - D$ relation between one agent from the higher-ranked half and one agent from the lower-ranked half in group A requires no memory to sustain. We call this social structure the "three-layer dominance hierarchy" because society is separated into three classes, as illustrated in Figure 9. When m is even, the upper class contains

that follows social convention and maximizes the total fitness.

[9] We thank an anonymous reviewer for the suggestion.

the top $m/2$ ranked agents with a linear hierarchy, the middle class contains the middle $N-m$ ranked agents with an egalitarian social structure, and the lower class contains the bottom $m/2$ ranked agents with a linear hierarchy. When m is odd, the upper class contains the top $\lceil m/2 \rceil$ ($\lceil m/2 \rceil - 1$) ranked agents, and the lower class contains the bottom $\lceil m/2 \rceil - 1$ ($\lceil m/2 \rceil$) ranked agents. The total amount of memory required for the three-layer dominance hierarchy is $m(N-m) + \lceil m(m-2)/4 \rceil$. Note that the despotic social system is consistent with the description of the three-layer dominance hierarchy for the special case of $m = 1$.

Figure 3.9: Three-layer Dominance Hierarchy



We confirm our conjecture in a population of seven agents with $m = 2$, using our computation method. The social structure at equilibrium that induces the least fitness loss is that the top-ranked agent dominates all others, the bottom-ranked agent is dominated by all others, and the remaining five agents form an egalitarian social structure among themselves. This is supported by a memory structure where the five middle-ranked agents memorize the top-ranked and the bottom-ranked agents, and the top- and bottom-ranked agents do not memorize any agent (Figures 14 and 15).

Figure 3.10: Singular Memory, Despotic Structure $m = 1$

A: Memory Table

	P_1	P_2	P_3	P_4	P_5
P_1	*	0	0	0	0
P_2	1	*	0	0	0
P_3	1	0	*	0	0
P_4	1	0	0	*	0
P_5	1	0	0	0	*

B: Strategy Table

	P_1	P_2	P_3	P_4	P_5
P_1	*	H	H	H	H
P_2	D	*	M	M	M
P_3	D	M	*	M	M
P_4	D	M	M	*	M
P_5	D	M	M	M	*

Figure 3.11: Despotic social structure, $m = 1$

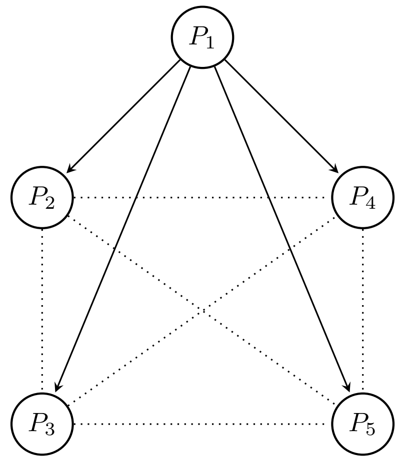


Figure 3.12: Singular Memory, Proxy Despotism $m = 1$

A: Memory Table

	P_1	P_2	P_3	P_4	P_5
P_1	*	1	0	0	0
P_2	1	*	0	0	0
P_3	0	1	*	0	0
P_4	0	1	0	*	0
P_5	0	1	0	0	*

B: Strategy Table

	P_1	P_2	P_3	P_4	P_5
P_1	*	H	M	M	M
P_2	D	*	H	H	H
P_3	M	D	*	M	M
P_4	M	D	M	*	M
P_5	M	D	M	M	*

Figure 3.13: Proxy Despotism $m = 1$

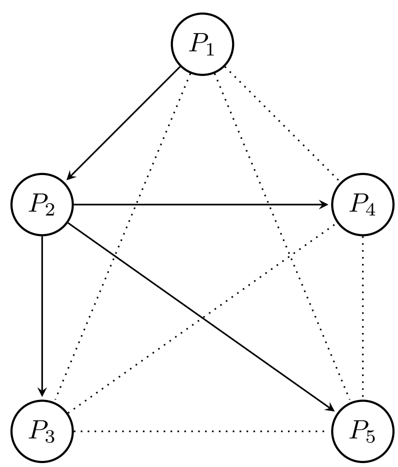


Figure 3.14: Insufficient Memory, $N = 7, m = 2$

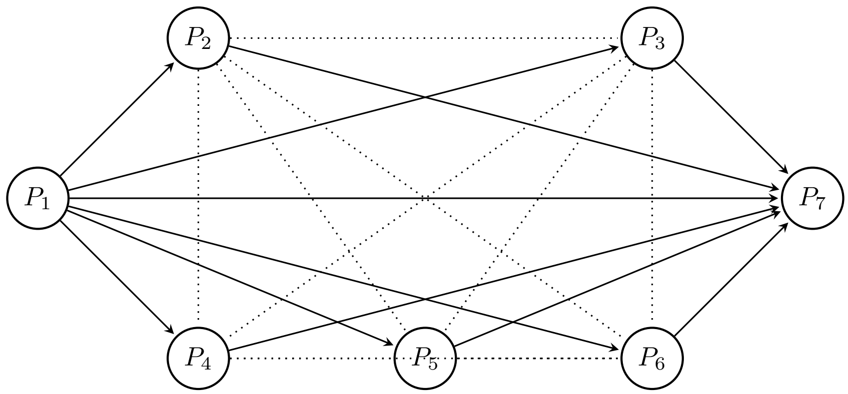
A: Memory Table

	P_1	P_2	P_3	P_4	P_5	P_6	P_7
P_1	*	0	0	0	0	0	0
P_2	1	*	0	0	0	0	1
P_3	1	0	*	0	0	0	1
P_4	1	0	0	*	0	0	1
P_5	1	0	0	0	*	0	1
P_6	1	0	0	0	0	*	1
P_7	0	0	0	0	0	0	*

N: Strategy Table

	P_1	P_2	P_3	P_4	P_5	P_6	P_7
P_1	*	H	H	H	H	H	H
P_2	D	*	M	M	M	M	H
P_3	D	M	*	M	M	M	H
P_4	D	M	M	*	M	M	H
P_5	D	M	M	M	*	M	H
P_6	D	M	M	M	M	*	H
P_7	D	D	D	D	D	D	*

Figure 3.15: Three-layer dominance hierarchy; $m = 2$



3.4 Extension

Thus far, we have analyzed the optimal social hierarchical structures under various levels of cognitive ability limitation, where there exists a predetermined linear social rank and an associated social convention with regard to the identities of the agents. One might wonder what can change in those equilibria if the rank or the social convention does not exist – in which case the agents' identities are identical *ex ante*, although they are still unique tags that others can recognize and condition their strategies on.

Treating identities as arbitrary name tags instead of numbers with rank enables agents to form social hierarchical structures that contain cyclic dominance relations (loop) where A dominates B, B dominates C, and C dominates A. This type of intransitive dominance relation is ruled out if everyone follows social convention, which is based on transitive linear rank. A cyclic loop can sometimes help a population achieve a higher total fitness level with fewer memory usages, especially when the population size is small. Figure 16 and 17 show an example of a population of five agents forming a social structure containing a loop (among P_3, P_4, and P_5). Its individual memory usage is at the same level as that of the despotic social structure (Figure 10), but it achieves a clash-free status as the linear hierarchy does. Apparently, this structure with a loop outraces all structures introduced in the previous section.

Various studies (Banks [1956]; Chase [1982]; Wang et al. [2011]) have pointed out that non-transitive dominance relations are very rare in nature compared to transitive linear dominance structures. This suggests that there are deeper reasons for species not to form non-transitive dominance relations. Besides directly ruling out a structure with loops by assuming that agents just follow the predetermined social convention (as in equilibrium, they do not have reasons not to follow), we do not yet have a feature in our model to explain why non-transitive structures are not favored by agents despite their potential to achieve higher total fitness.

Figure 3.16: Singular Memory, Loop, $m = 1$

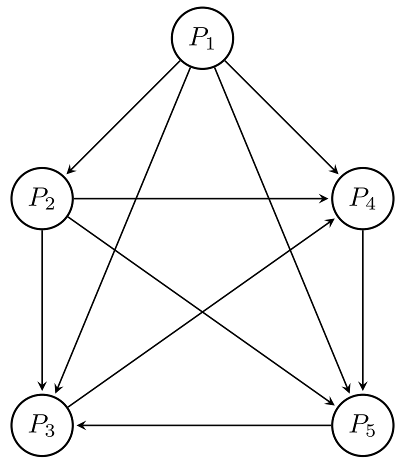
A: Memory Table

	P_1	P_2	P_3	P_4	P_5
P_1	*	0	0	0	0
P_2	1	*	0	0	0
P_3	0	0	*	1	0
P_4	0	0	0	*	1
P_5	0	0	1	0	*

B: Strategy Table

	P_1	P_2	P_3	P_4	P_5
P_1	*	H	H	H	H
P_2	D	*	H	H	H
P_3	D	D	*	H	D
P_4	D	D	D	*	H
P_5	D	D	H	D	*

Figure 3.17: Loop Structure



3.5 Conclusion

We propose a model in which a population of agents is matched to play a Hawk-Dove game. Agents are equipped with unique identities, and there exists a linear social rank over their identities, which is accompanied by a predetermined social convention. Our model suggests that at different levels of cognitive ability limitations, different hierarchical social structures can be supported as equilibria that follow social convention, and they are optimal in terms of the total fitness of the population. Our findings can be supported by the fact that these hierarchies are the most common ones observed in nature. Our model suggests a way to understand how different species utilize their cognitive abilities in social interactions by examining the existing hierarchical social structures in their populations.

Chapter 4

Economic Development, Education and Ethnicity Choice in China

4.1 Introduction

China is a multi-ethnic nation with 56 officially recognized ethnicities, including the dominant Han which makes up 91.11% of the total population, and the other 55 minority ethnicities, which comprise the remaining 8.89%.[1] In China, ethnic identity is assigned to each citizen at birth, following their parents' ethnicity. This creates a decision-making problem for couples with different ethnicities, which we refer to as mixed-ethnicity couples because they are free to choose whichever of their two ethnicities for their children at birth. The choice of ethnicity, however, is beyond the choice that parents make based on their personal preferences of their children's ethnicity, but rather a comprehensive decision affected by various social and cultural features. Jia and Persson [2021] pioneer research on ethnic choice in China, in which they pointed out that social norms and government policies can play essential roles in Chinese parents consideration of their choice of their children's ethnicity. In the 1980s, China began implementing family planning policies and various social policies that favor minority ethnicities in education, employment and family planning.[2] It was also the same period when China stopped the Cultural Revolution and started economic reform, which brought significant economic development and education improvement to the nation and make China the fastest-growing and the second-largest economy in the world, with the largest education system in the world.[3] During this period, Chinese households experienced profound changes in their economic and educational conditions that could

[1] See the seventh national population census of China, 2020.

[2] The most-representative family planning policy was the one-child policy which began in 1979 and phased out in 2015.

[3] In June 2022, there were 11.93 million students taking the College Entrance Examination (Gao Kao) in China. Ministry of Education of China, 2022

significantly impact their family decisions, including the choice of ethnicity for their children. This research aims to analyze the impact of economic development and education quality on parents' ethnic choices for children in mixed-ethnic families in China. Owing to the dominance of the Han population in China, the majority of mixed-ethnic couples are formed by one Han and one minority. Thus when we use the terms "mixed-ethnic" or "mixed-ethnicity", we only refer to Han-minority pairs. We develop an intra-housing bargaining model to study the family decision on choosing ethnicity for children. The framework of the intra-household bargaining model was first introduced by Chiappori [1988] and Chiappori [1992]. Parents derive utilities from the choice of ethnicity for their children at birth; thus they decide on the newborn child's ethnicity to maximize the weighted sum of utilities of the couple (that is, the joint utility of the household), where weights are given by the bargaining power of each individual.[4] The model provides a plausible mechanism of how economic development and education quality affect the parents' decision regarding the newborn child's ethnicity. The model also predicts on changes in parents' choice of ethnicity for their children with different levels of economic development and education quality. We empirically test the model using individual Chinese census data, and the findings confirm the predictions made by the model.

Economic development and educational quality impact on households' decisions has two components: the change in the individual utility of having minority children and the change in the relative intra-household bargaining power of the couple. Jia and Persson [2021] suggests that the individual utility in choosing ethnicity has two interacting motives: material and psychological benefits and costs. Choosing a minority ethnicity for children involves certain future welfare benefits from related government policies that favor minorities. For instance, the Chinese government imposes preferential admission or grants extra points to ethnic minorities in the National College Entrance Exam, making minority students more likely to go to universities or get into better universities than Han students with the same abilities (Sautman [1998]). Minority workers are also more likely to obtain certain jobs because of job quotas for minority ethnicities only (Gustafsson and Shi [2003]). Such institutional arrangements and related government policies are very extensive. These government policies, directly and indirectly, affect the social, economic, and cultural development of various ethnic groups and their relationships at different levels. As it brings special priorities in terms of social mobility opportunities and economic resource allocation that are institutionalized and protected by the government, the ethnic-minority identity is viewed as a heritable social capital for people in China. According to Sautman [1998], Han people express their will or even seek to be reclassified as minorities to gain such benefits from preferential policies. **?** demonstrates the influence of the bonus points policy on the Chinese college entrance examination, which encourages the manipulation of candidates' ethnic

[4]In China, parents (or guardians) must register their new-born children to the public system (Hukou system) within one month after the birth. After registration, the ethnicity of a new-born child becomes official.

identity. On the other hand, despite the preferential policies imposed by the government, minority ethnicities in China can still encounter discrimination in various fields, especially in the labor market (Maurer-Fazio [2012] and Hasmath et al. [2013]), which could generate extra material living costs for them. In addition, due to the differences between the Han culture and their own, living in Han-dominated China may generate extra financial costs for some minority ethnicities when trying to honor their ethnic and cultural habits; we refer to these material costs as social frictions the minority. While the influence from government policies is mainly material, the discrimination and social frictions can also be psychological for minorities, in the sense that minorities can suffer psychological costs, such as pressure, anger and sadness, when they are discriminated against or not able to honor their ethnic, cultural habits. When parents making their decision about their children's ethnicity, they have their expectations of the welfare of their children related to these political and social issues and form their utilities based on their children's welfare; therefore, we refer to such utilities as indirect benefits and costs in the model.

We assume that these indirect benefits of minority children increase with economic development and better education quality with reasons for the following reasons. First, the potential policies that favor minorities are more effective in better economic conditions and cultural environments. For example, the college wage premium in China has greatly increased from 0.4% in the late 1980s to around 50% in the 2000s.[5] This means the relative advantage – a higher probability of going to better universities – that the minority students receive from extra-point policies, is more significant. Second, economic development and better educational quality bring a more civilized and fair working and living environment, reducing social frictions such as living costs and the discrimination against minorities.[6]

Apart from the indirect benefits and costs addressed above, there are also some concerns directly related to their utilities that parents making ethnicity decisions consider. We refer to these as direct benefits and costs. The most salient one is the common social norm in Chinese society to choose the father's ethnicity for the children, which creates stigma among parents, especially fathers who do not follow this social norm. Inter-ethnic marriage also brings about issues of ethnic self-identification, where both parents want to have their ethnic identity inherited by their children. The ethnic choice for children is an opportunity to increase the number of members of certain ethnic groups, especially when the proportion of inter-ethnic marriages in an ethnic group is relatively high. The direct benefits and costs are therefore the intrinsic utility derived by each individual when making the decision, which is a careful consideration of the social norm and the related social stigma, as well as the self-identification problem of their ethnicities. The effect of economic development and educational quality on these direct benefits and costs vary among families according to their

[5]China Health and Nutrition Survey, Carolina Population Center, 2009

[6]For example, in the Xinjiang region, the number of mosques – a necessity for Muslim minorities – increased from 9000 in 1984 to 25000 in 1995. Chinese Youth Daily. 2009-07-17.

ethnicity. The indirect and direct benefits and costs generate the difference between the payoff of choosing Han and choosing a minority for new born children. In a mixed-ethnic household, the husband and the wife will have different preferences over these benefits and costs due to their gender and ethnic differences, which generates different possible equilibria (to choose Han or minority for the child) in the model.

Economic development and educational quality also create changes in intra-household bargaining power. In their field experiment on the personal income and labor participation of Indian women, **?** show that improvement in the financial situation of women has positive effects on promoting women's labor participation and gender equity. Since the bargaining problem we consider is about the choice of ethnicity, which is not merely an economic problem but also involves social and cultural concerns, bargaining power will be a comprehensive evaluation for both household members on their social, economic, and cultural empowerment. The determinants of relative intra-household bargaining power include not only the relative income of household members (the private sphere), but also the relative social and political power - also called institutional power - of household members (the public sphere). The two facets of bargaining power interact and influence each other (Hiller and Touré [2021]). For example, an increase in women's institutional power induces a rise in public spending devoted to human capital formation, including investment in education quality. More human capital increases labor productivity, so the gender wage gap decreases, which, in turn, improves in women's bargaining positions in the private sphere and likely, reinforces their institutional power. Hannum [2005] examines how parental investments in goods and time used in children's human capital production are affected by parental education in rural China, and finds that greater parental education, especially mother's education, generates greater family investments in both goods and time used in children's education. Thus accompanying the economic development is a comprehensive economic, political and cultural improvement of society, which often creates more gender equity. We expect couple's bargaining power to become closer as the economy develops and the educational quality improves.

Our model generates testable predictions. When economic conditions improve, we expect the material benefit of having a minority child in the bargaining model to increase, because these preferential policies will be more effective. Economic development also brings more educational opportunities and cultural communication, which leads to less social friction and discrimination that minority children may encounter. This may also change the psychological benefits of having minority children. For example, in contemporary China, especially in major cities, patriarchy is commonly viewed as out-dated and conservative, a norm not supported by the current social values. Thus, when the economy develops, especially in regions with better educational quality, the social norm of choosing the father's ethnicity for the children and the stigma of not following this social norm to parents will be less followed, especially by new generations. Consequently, the utility difference between having a Han child and a minority child is expected to decrease with economic development. The model yields different predictions for mixed-ethnic families through the family bargaining channel. Having one's ethnicity inherited is considered important in most ethnic groups in China, which reflects the model where each parent wants to assign the new-born child the same ethnicity as themselves. In families with Han fathers and minority mothers (H-M families), the father prefers a Han child and the mother prefers a minority child, while in families with minority fathers and Han mothers (M-H families), the father prefers a minority child and the mother prefers a Han child. This means that when the economy develops, especially in regions with better educational quality, women's bargaining power will increase. As a result H-M families are more likely to have minority children, while M-H families will be less likely to have minority children.

We empirically examine our model using individual Chinese census data from 1982, 1990, 2000, and 2005. The main finding is that economic development is associated with an increased propensity to choose minority ethnicities for children in H-M families. To ensure that the increase in propensity is not due to changes in government policies, we add controls for related policies, including family planning and college entrance exams. We also add the measure of the number of local universities and colleges to test the effect of education quality, and find that the effect of increasing the propensity to choose minority ethnicity for children in H-M families is stronger in regions with better educational qualities. The results also show that such effects are not significant for the M-H families. We further explored the behavior of M-H families by separating the data of based on the gender of the child. The finding is that a significantly negative effect of economic development exists on the decision to assign the new-born girl as the minority for M-H family. A potential explanation is that the meaning of ethnic inheritance is more significant when the child is a boy, so the potential social stigma and incentive of ethnic inheritance is less intensive for the minority father when the child is a girl. Therefore the increased bargaining power of the mother will be more effective.

The closest paper in the literature to our research is Jia and Persson [2021], which focuses on the relationship between social norms and ethnic identity choices in China. However, to the best of our knowledge, the connection between the economy, education, and choice of ethnicity for children has not been systematically investigated. The goal of this study is to fill this gap. This study contributes to the literature by combining the family bargaining model with the problem of choice of ethnicity to study the issues of China's ethnicities, which have rarely been studied in economics. The result explains for the change of the minority ethnic population in the past and also gives potential insights for guiding future policies. The remainder of this study is organized as follows. Section 2 introduces basic background information about China's ethnicities. Section 3 discusses the benefits and costs of having minority children compared to having Han children. Section 4 explains the foundations of the family bargaining model. Section 5 illustrates the interaction between economic development and education quality on the benefits and costs of having minority children compared to having Han children. In Section 6, the proposed model is explained. Section 7 presents measurements and empirical results. Section 8 concludes.

4.2 China's Ethnicities

China has 56 officially recognized ethnicities, including the dominant Han, which makes up 91.11% of the total population and the other 55 minority ethnicities that make up the remaining 8.89%. These minority groups vary in size (from millions to thousands), culture (some have their own languages) and religious beliefs (the two majors are Muslim and Buddhism). Throughout the history of China, many ethnic groups have been absorbed into the Han majority, especially in the south and the west. For example, in many historical literature, the Sichuan and Chongqing regions (Bashu) have been described as places of multi-ethnic groups, but today the large majority is Han Chinese. Today, the majority of ethnic minorities live in the northeast, northwest, and southwest, revealing the expansion of the Han Chinese over centuries.

Owing to historical and geopolitical reasons, the level of development in different regions and provinces in China varies significantly. Such regional development gaps also reflect the development level of different ethnic groups, most ethnic minorities live in remote, under-developed regions. To help the economic development of remote regions, social integration, and the unification of different ethnic groups, the government has implemented preferential policies that favor minority citizens and regions. Such policies differ across provincial regions and over time. They include economic subsidies, priority in choosing schools and hiring, special rules and laws to honor minority cultural habits[7], and waivers from restrictive rules and laws[8]. Therefore, ethnicity as personal information in records is important for Chinese citizens, especially for their education and employment.

Ethnicity information is assigned to each person at birth, and must follow their parents' ethnicities. While this means that ethnicity may not be a choice for the majority of the population (as shown in Tables 1 and 2, about 91% of total households are Han only, and 97% of total households are single-ethnicity), mixed-ethnic couples are free to choose whichever of their two ethnicities for their children at birth[9]. This can be viewed as a joint household decision made at the child's birth, which builds the model's base in this study. Due to the dominance of the Han population, most mixed-ethnic couples (more than 90% nationwide

[7]In China, about ten Muslim-related ethnic minorities have a traditional habit of eating halal food. To properly solve the problem of ethnic minorities eating halal food, the state has set up halal canteens or halal meals in institutions, schools, enterprises and institutions. In large and medium-sized cities where ethnic minorities who eat halal food live in concentrated communities, governments have set up wholesale or retail agencies specializing in beef and lamb with preferential policies and subsidies. (State Council of China, 1999)

[8]Most minority families were waived from the family planning policy, especially the one-child policy during 1979-2015. This is commonly regarded as one reason why the minority population grows faster than Han population. (See Park and Han [1990] and Sautman [1998].

[9]Also it may be changed once at child's own wish before the age of 20.

and more than 99% in non-minority regions) are formed by one Han and one minority. This study thus focuses on the ethnicity choice of children in these families, and when we use the terms mixed-ethnic or mixed-ethnicity, we only refer to Han-minority pairs.

Table 4.1: Household types in China (in millions), 1990, 2000

	1990	2000
Total households	276.91 (100%)	340.49 (100%)
Total population	1097.77 (100%)	1178.27 (100%)
Average population per household	3.96	3.46
Total minority households	15.99 (5.78%)	21.46 (6.30%)
Total minority population	72.72 (6.63%)	82.78 (7.03%)
Average minority population per household	4.54	3.85
Total mixed households	6.75 (2.44%)	9.12 (2.68%)
Total mixed population	29.79 (2.71%)	35.38 (3.00%)
Average mixed population per household	4.41	3.88
Total Han households	254.16 (91.78%)	309.90 (91.02%)
Total Han population	995.25 (90.66%)	1060.09 (89.97%)
Average Han population per household	3.91	3.42

Table 4.2: Household ethnicity types in China (in millions), 2000, 2010

Year	Total	1-ethnicity	2-ethnicity	3-ethnicity	4 or more
2000	340.491	330.405 (97.04%)	9.940 (2.92%)	0.142 (0.04%)	0.003
2010	401.934	390.914 (97.26%)	10.814 (2.69%)	0.201 (0.05%)	0.004

4.3 Benefits and Costs related to Children's Ethnicity

Minority identity brings benefits and costs for the children directly and indirectly for the parents. The decision on a child's ethnicity made by parents at birth is affected by both their expectations and perceptions of the benefits and costs of the child in the future and their intrinsic psychological benefits and costs. As addressed above, we focus on the ethnicity choice for children of mixed-ethnic couples with one Han and one minority. Because their choice is binary between assigning Han or the minority to their children, for convenience in the analysis of this section we will treat Han children as a baseline, and discuss the relative benefits and costs of assigning minority identity to children.

(1) Preferential policies. The Chinese government has introduced policies that favor minorities to help in their development of minorities and promote positive relationships between the Han and minorities. There are three main areas of such policies. (i) *Education:*[10] scores from standardized exams have been the most important and sometimes the only credentials that determine educational entries, especially to high school (zhongkao) and college (gaokao). Minority students are granted extra points or priority admission with the same scores in these exams. Parents regard this potential advantage in educational opportunities for their children as beneficial for themselves. (ii) *Employment:*[11] related policies state that minorities should be given favorable treatment in employment. Governmental institutes, schools, hospitals, and major corporations, especially those that are state-owned or state-controlled, often have explicit job positions or employment quotas for minorities. (iii) *Family planning:*[12] China started family planning policies in the 1970s, which included specific birth quotas (the famous one being the one-child policy) as well as the enforcement of such quotas. The implementation of these policies has been relaxed for minority families. With related rules and laws, most minority families are waived from family planning policies or have special treatment that allows them to have up to three children, which is lenient compared with the nationwide one-child rule. According to Becker [1986], families maximize their payoffs in the decision-making problem of having more children, and relaxation of family planning policies benefits them by increasing their opportunity sets. Parents foresee this benefit for their children and treat it as an indirect benefit for themselves if they choose to assign a minority identity to their children.

(2) Social frictions. Due to the dominance of the Han population and, more importantly, the dominance of Han culture in China, for people of minority ethnicity, there will inevitably be some cost of living in Chinese society stemming from the friction between the Han culture and their own. This cost is greater for those with ethnicities that are more salient and different from the Han culture. The cost can be material or psychological for minorities. For instance, there are approximately ten Muslim minority ethnicities in China. For these minorities, dining in Han-dominant regions in China can be troublesome because it is difficult to find places that do not serve pork as it is the primary protein source for the Han Chinese. Even if they choose to cook by themselves, the price of beef and lamb, the main protein source for Muslim people, is far higher than the price of pork[13], especially in Han-dominant regions such as eastern and southern China. Therefore, the identity of minority ethnicities can incur financial costs. Smith [1985] points out that minority groups in a population can experience various types of life stress and mental health issues resulting from their minority identities. An example of the psychological cost of social friction is that for minorities with their own unique cultural habits or festivals, it will be difficult for them to perform these cultural events if they live in Han-dominant regions. Not being able to honor their own ethnic culture may create psychological

[10] See Sautman [1998], Jia and Persson [2021].

[11] China's preferential policies for minorities on employment vary greatly across regions and over time. See Sautman [1998], Gustafsson and Shi [2003] and Howell [2017] for related discussions.

[12] See Park and Han [1990], Sautman [1998], Attané and Courbage [2000], and Jia and Persson [2021].

[13] National average in April 2021: pork: \$5.59/kg, beef: \$13.40/kg, lamb: \$13.23/kg. Department of Agriculture of China.

costs for minorities.

(3) Discrimination. While enjoying favorable policies from the government, minorities may also face discrimination in Chinese society, particularly in the labor market. The source of discrimination can be the lack of knowledge of or misunderstanding of minorities, Han supremacy, or even dissatisfaction with minority-favored policies. For example, Maurer-Fazio [2012] conducted field experiments to examine the potential discrimination of Chinese firms during their Internet job-hiring procedures. They found significant differences in interview callback rates by ethnicity, where, compared to applicants with typical Han names, applicants with distinctive Mongolian, Tibetan, and Uighur names are discriminated against, mostly by private firms. Although there are no major social instances or public data revealing serious labor discrimination against minorities or the wage gap between Han and minorities, the discussion of the related issues, either discrimination or complaints about discrimination, has greatly increased over the past decades, especially since the occurrence of two major Han-minority conflicts in the 2000s.[14] Hasmath et al. [2013] found that ethnic minorities in China are disadvantaged in the job search process from factors including social network capital and working culture, revealing various labor market discrimination that minorities face other than wage differentials.

(4) Ethnicity Inheriting and Patriarchy. The traditional Chinese culture affects parents' feelings about their children's ethnicities in two essential ways. First, having one's own ethnicity inherited is important in most ethnic groups. Hout and Goldstein [1994] show that for some ethnic groups, especially those who value their ancestors and traditions, interracial marriages provide opportunities for them to expand, because the offspring of mixed marriages often think they are part of that ethnic group. While this sense of responsibility and honor may not be valued too much by the Han people due to their dominance, people of minority groups, especially those who value traditions and inheritance, believe that having their children follow their ethnicity is important. According to the cultural transmission models by Bisin and Verdier [2001], family and social environments act as substitutes for each other in the dynamic process of inter-generational transmission of cultural traits; that is, both families and the social environment can help each other in the transmission of cultural traits from older to younger generations. Therefore, when parents have a cultural trait that is more dominant in the social environment, they will have less incentive to socialize their children with the trait by themselves because they are confident that their children will have enough exposure to the cultural trait once they enter the society. While for parents with a scarce trait in the social environment, this means that they will have strong incentives to socialize their children with the trait.[15] Second, the

[14]Two incidents were a series of unrest or violent riots over several days that broke out in Tibet in 2008 and Xinjiang in 2009. The 2008 Tibetan unrest started with small protests and demonstrations held by local independentists, and the 2009 Xinjiang riot originated from a brawl in southern China several days earlier between the Han and Uyghurs (the dominant minority in Xinjiang). Both incidents quickly transformed into large-scale conflicts and riots.

[15]Bisin et. al. [2004] introduces a model of marriage and child socialization along religious lines with empirical evidence in

unavoidable patriarchal way of thinking in traditional Chinese culture makes a general expectation, even a social norm, to most people that children should follow father's ethnicity. While this traditional patriarchal mind may be diminishing among new generations or in major urban regions, most parents, especially fathers, will still encounter a social stigma if their children have different ethnicities than the father.[16]

It is worth noting that the first three types of benefits and cost are indirect utility for parents derived from the material benefits and costs for the child with the minority ethnicity choice. The last one related to ethnicity inheriting and patriarchal minds for parents is about the direct psychological benefits and costs for parents themselves, which is not related to the well-being of their children. Therefore, we refer to these as indirect and direct benefits and costs. Table 3 shows these benefits and costs (see Section 6 for more details).

Table 4.3: Indirect and direct Benefits and Costs for parents

Indirect	Child is Minority	Child is Han
	Preferential policies (+) Social frictions (-) Discrimination (-)	
Direct	**Child is Minority**	**Child is Han**
Han father	Social stigma(-) and weak not inheriting(-)	Weak inheriting(+)
Minority Mother	Strong inheriting(++)	Strong not inheriting(- -)
Minority Father	Strong inheriting(++)	Strong not inheriting(- -) and social stigma(-)
Han Mother	Weak not inheriting(-)	Weak inheriting(+)

++: major benefit; –: major cost; +: minor benefit; -: minor cost

4.4 Family Bargaining

We assume that, as shown in Table 3, the indirect benefits and costs of having a Han or minority child are identical for each spouse because the indirect payoff is determined by preferential policies and the expectation of future social frictions and discrimination that their children may encounter, which, on average, should create no difference between fathers and mothers. However, two spouses of different ethnicities are likely to have opposing views on the ethnicity of their children in terms of direct psychological benefits and costs. Families face trade-offs between having a minority child and having a Han child. For families with a Han father and a minority mother, compared to having a Han child, having a minority child will generate negative a payoff for the Han father for failing to have their children inherit his ethnicity (Han) and thus suffer the

the United States.

[16] Lee [1999] and Zuo [2009].

social stigma from violating the patriarchal social norm, and a positive payoff for the minority mother to successfully have her minority ethnicity inherited. For families with a minority father and a Han mother, a minority child will create a direct psychological benefit for the minority father by having the child inherit his minority ethnicity and a psychological cost for the Han mother for not having the child inherit her Han ethnicity. A Han child will generate opposite payoffs to the couple, plus social stigma to the minority father. As discussed above we assume that only father in the family will encounter the social stigma from violating the patriarchal social norm, and the benefit of inheriting (and the cost of not inheriting) one's ethnicity is more significant for minority people than for Han people.

When parents choose ethnicity for their children, they engage in a collective decision-making process. Because of the potential differences in preferences due to gender differences, this collective decision-making process may not just be a simple benefit-cost decision-making process, but rather an intra-household bargaining problem, where the utilities of the father and mother are relatively weighted by their intra-household bargaining powers. A typical challenge in empirically examining bargaining power is the lack of a proper measure (**?**). The most commonly used measure for bargaining power in the literature, including Hoddinott and Haddad [1995], Thomas [1990], Schultz [1990] and Chau et al. [2007], is the relative wage income or non-wage income of men and women; many other studies have also used assets controlled by individuals (Thomas et al. [2002]; Quisumbing and Maluccio [2003]; Zhang and Chan [1999]; Brown [2009]). These studies generally focus on bargaining problems related to household consumption patterns and labor force participation. However, as in the bargaining problem considered in this research, choosing the ethnicity of a new born child is a comprehensive family decision that is not just an economic problem but also involves social and cultural concerns. In fact, as described in Table (3), the main difference in the father's and mother's preferences for the child's ethnicity is the psychological concern of ethnicity inheritance and patriarchal social stigma. Therefore, economic variables and indices, such as income and volume of assets, will not be accurate or sufficient to capture bargaining power. An ideal measure of intra-household bargaining power is a set of individual-level variables that capture various influential factors. In the empirical examination of our model, we explicitly assume that the relative bargaining power of women increases with an increase in two key independent variables, economic development (GDP) and level of education (number of colleges), as discussed below.

4.5 Economic Development and Education Quality

China has been the fastest-growing economic power ever since its economic reform, which started in 1978. With an average growth rate of 8 percent for almost 30 years, it has become the second largest economic power in the world, next to the U.S.. The increased GDP numbers not only mean an increase people's material standard of living, but also advances and progress in various social features. Jayachandran [2015] discusses several mechanisms through which gender gaps narrow as societies grow, and argues the importance of society-specific factors and norms in affecting the GDP/gender inequality relationship. Duflo [2012] explains the interaction between women's empowerment and economic development, stating that women's empowerment and development mutually reinforce each other and women eventually become equal partners in richer societies. Such evidence shows that economic development can promote gender equality by giving females more opportunities to acquire human capital, enabling them to be involved in decision-making at the family, social, and governmental levels. The female labor force benefits from economic development due to the shifting focus of the economy of a country from mostly manual labor to more mental labor, which gives females an advantage, as well as the decrease in the fertility rate and the promotion of the use of household electronics, which liberates females from house works. The beginning of the economic reform in the late 1970s mark the end of the Cultural Revolution, a sociopolitical movement that halted Chinese education for over a decade. Since then, led by the adoption of the first Chinese law on education in 1980,[17], Chinese education has dramatically improved with government support. For example, the 9-year compulsory education system was established in 1986, and China's teachers' and education laws were adopted in 1993 and 1995, respectively. Such policies and laws guarantee the basic rights of students and educators, which supports the improvement of education. In 1997, China had around 6.08 million college students and 180 thousands graduate students, which were 2.2 times and 9.6 times those in 1979.[18] Research has shown that better education quality, which is often accompanied by economic development, can improve women's self-awareness and society's perception of gender roles, which makes education a catalyst for economics development on promoting gender equity. Hannum [2005] examined how parental investments in goods and time used in children's human capital production are affected by parental education in rural China and founds that greater parental education, especially greater mother's education, generates greater family investments in both goods and time used in children's education. Based on these facts, we obtain an assumption that in the joint decision-making problem of choosing ethnicity for children, women's relative bargaining power increases with economic development and better educational quality in China.

Economic development and better educational quality have other additional effects on the choice of ethnicity. First, better economic conditions and environments make preferential policies that favor minorities more effective. The benefit for minorities from such policies on education and employment will be amplified in a better economic environment because a better educational opportunity or a higher working class is

[17]Regulations of the People's Republic of China on Academic Degrees, 1980

[18]Ministry of Education of China. http://www.moe.gov.cn/jyb_xwfb/xw_zt/moe_357/s3579/moe_90/tnull_3161.html

valued more. For example, the college wage premium in China has dramactically increased from 0.4% in the late 1980s to around 50% in the mid 2000s. Second, economic development and, more importantly, better educational quality bring in more advanced social services to meet the needs of minorities and a more civilized and fair working and living environment, which reduces social frictions such as living costs and the discrimination against minorities. For example, in the Xinjiang region, mosques – a necessity for Muslim minorities –increased from 9,000 in 1984 to 25,000 in 1995. [19] These results lead to our assumption that the indirect payoff for minority children also increases with the economic development and better educational quality. Finally, economic development and improved educational quality may affect direct benefits and costs. The traditional Chinese way of thinking – ethnicity inheriting and patriarchal mind – as the main source of direct benefits and costs, is much less heeded by people with better education and economic condition, especially younger generations in major city areas. For example, Lee [1999] describes how the traditional patriarchal mind in China has been less observed since recent revolution and reform eras (1980s), and Zuo [2009] explains how family patriarchy and women's positions have evolved in modern China. Supported by the logic and evidences above, we assume that direct benefits and costs will shrink in magnitude with economic development and better educational quality, making the direct part less weighted in parents' individual and family utilities. This effect is equivalent to an increase on the indirect payoff, which already happens to be the expected result as analyzed.

4.6 A simple Intra-household Bargaining Model

Consider the following model for a mixed couple's behavior in choosing the ethnicity of a newborn child: Each spouse $i \in \{m, f\}$ with ethnicity $e \in \{H, M\}$ derives utility from the choice of the ethnicity of their child:

$$u_e^i = \alpha_e^i N + \gamma_e^i (1 - N)$$

where $N = 1$ if the assigned ethnicity of the child is a minority and $N = 0$ if the assigned ethnicity of the child is Han. $\alpha_e^i(\gamma_e^i)$ represents the derived utility of having a child with minority (Han) ethnicity for each individual with their specific gender and ethnicity.

The utility derived above shows the net payoff for parents in response to the ethnicity of their children. As explained above, these utilities can be separated into two components, indirect (I) and direct (D).

[19] Chinese Youth Daily. 2009-07-17.

$$\alpha_e^i = I_M + D_e^i(M)$$

and

$$\gamma_e^i = I_H + D_e^i(H)$$

Where I_M (I_H) is the indirect benefit of having a minority (Han) child: this variable of indirect benefit is not indexed with different genders or ethnicities of parents; therefore it is identical for both male and female parents and both Han and minority parents. This is because indirect benefits are derived from preferential government policies, and the minority (Han) child's material well-being should not differ across parents' genders or ethnicities. $D_e^i(M)$ and $D_e^i(H)$ are the direct benefits of having a minority and a Han child. The direct benefit is related to the patriarchal social norm of choosing the father's ethnicity for the children, and also the pride of having one's own ethnicity inherited. We restate related two assumptions: (1) if a couple breaks the social norm, the husband will encounter a larger social stigma than the wife does, and (2) minority people have a stronger incentive to have their ethnicity inherited than the Han. Below is the algebraic interpretation of these assumptions.

$$D_H^m(M) - D_M^f(M) < 0$$

$$D_M^f(H) - D_H^m(H) < 0$$

$$D_M^m(M) - D_H^f(M) > 0$$

$$D_H^f(H) - D_M^m(H) > 0$$

Following Chiappori [1988] and Chiappori [1992], we assume taht the household maximizes a collective utility function, a weighted average of two family members' utilities. The household then decides on the newborn child's ethnicity to maximize the joint utility function:

$$N = \arg\max_N (\beta u_e^m + (1-\beta) u_{-e}^f)$$

where $\beta \in [0,1]$ is the bargaining power of the male and $1-\beta$ is that of the female. $N \in \{0,1\}$ is the solution to the maximization problem.

4.6.1 Comparative Statistics

We examine the model by breaking down the joint utility function and discussing its comparative statistics. In Section 5 we made three explicit assumptions:

1. Women's relative bargaining power increases with economic development and better educational quality.
2. The indirect payoff for minority children increases with the economic development and higher educational quality.
3. The direct payoff shrinks in magnitude with the development of the economy and better educational quality, making the direct payoff part less weighted in parents' individual and family utilities.

Therefore, with two exogenous factors $ECON$ and EDU capturing the development of the economy and education, the above assumptions can be illustrated as follows:

$$\frac{\partial \beta}{\partial ECON} < 0, \frac{\partial \beta}{\partial EDU} < 0$$

$$\frac{\partial I_M}{\partial ECON} > 0, \frac{\partial I_M}{\partial EDU} > 0$$

(1) Han father, minority mother (H-M family)

The family utility function for a family with a Han father and a minority mother is given as

$$U = \beta u_H^m + (1 - \beta) u_M^f$$

where the Han father's utility is

$$u_H^m = \alpha_H^m N + \gamma_H^m (1 - N)$$

and the minority mother's utility is

$$u_M^f = \alpha_M^f N + \gamma_M^f (1 - N)$$

If the assigned ethnicity of the child is the minority (same as the mother's), then $N = 1$, family utility is:

$$U_1 = \beta\alpha_H^m + (1-\beta)\alpha_M^f$$

and if the assigned ethnicity of the child is Han (same as the father's), then $N = 0$, family utility is:

$$U_0 = \beta\gamma_H^m + (1-\beta)\gamma_M^f$$

thus the premium on choosing to assign the minority ethnicity to the child is:

$$P = \beta(\alpha_H^m - \gamma_H^m) + (1-\beta)(\alpha_M^f - \gamma_M^f)$$

Separating the payoff into indirect and direct, the full expression for the premium is:

$$P = \beta(I_M + D_H^m(M) - I_H - D_H^m(H)) + (1-\beta)(I_M + D_M^f(M) - I_H - D_M^f(H))$$

The premium can be separated into a indirect benefit difference between having a minority child and a Han child, and the sum of the direct benefit differences between having a minority child and a Han child for the father and the mother, weighted by their bargaining powers:

$$P = I_M - I_H + \beta(D_H^m(M) - D_H^m(H)) + (1-\beta)(D_M^f(M) - D_M^f(H))$$

We can then discuss the following comparative statics derived from the model:

$$\frac{\partial P}{\partial I_M} = 1 > 0$$

$$\frac{\partial P}{\partial I_H} = -1 < 0$$

Both parents react similarly to changes in indirect benefits, the premium will increase (or decrease) at a constant rate with the increase in the indirect benefit of having a minority (or Han) child.

$$\frac{\partial P}{\partial D_H^m(M)} = \beta > 0$$

$$\frac{\partial P}{\partial D_H^m(H)} = -\beta < 0$$

$$\frac{\partial P}{\partial D_M^f(M)} = 1 - \beta > 0$$

$$\frac{\partial P}{\partial D_M^f(H)} = \beta - 1 < 0$$

The above results show that if the direct payoff of a parent with a minority (Han) child increases, then the family premium of having a minority child will increase (decrease), in proportion to the bargaining power of that parent.

$$\frac{\partial P}{\partial \beta} = (D_H^m(M) - D_M^f(M)) + (D_M^f(H) - D_H^m(H)) < 0$$

This inequality is supported by the assumptions of aforementioned model. This assumption ensures that if we only look at the direct payoff, a Han father will prefer to have a Han child and a minority mother will prefer to have a minority child. If there is a change in relative bargaining power, then the family premium will change in the direction that favors the side with a larger increase in bargaining power.

Then we can combine the results with the assumptions from Section 5, where all assumptions lead to the following conclusion:

$$\frac{\partial P}{\partial ECON} > 0$$

and

$$\frac{\partial P}{\partial EDU} > 0$$

Therefore the model predicts that H-M families are more likely to have their children assigned as minorities with the economic development and better educational quality.

(2) Minority father, Han mother (M-H family)

The set-up of the family utility function for a family with a minority father and a Han mother is symmetric to what we had in the previous analysis of a Han father and a minority mother. Therefore here we directly give the comparative statistics and discuss.

$$\frac{\partial P}{\partial D_M^m(M)} = \beta > 0$$

$$\frac{\partial P}{\partial D_M^m(H)} = -\beta < 0$$

$$\frac{\partial P}{\partial D_H^f(M)} = 1 - \beta > 0$$

$$\frac{\partial P}{\partial D_H^f(H)} = \beta - 1 < 0$$

$$\frac{\partial P}{\partial I_M} = 1 > 0$$

$$\frac{\partial P}{\partial I_H} = -1 < 0$$

$$\frac{\partial P}{\partial \beta} = (D_M^m(M) - D_H^f(M)) + (D_H^f(H) - D_M^m(H)) > 0$$

The only difference between an M-H family and an H-M family is that the father will prefer to have a minority child and the mother will prefer to have a Han child, leading to a change in the sign of the derivative of the premium of having a minority child with respect to the male's bargaining power. However, it is still the case that if there is a change in relative bargaining power, then the family premium will change in the direction that favors the side that has a larger increase in bargaining power. Therefore, the effect of the economic development and education quality on family decisions is ambiguous for M-H families. On the one hand, the development of economic and better educational quality increases the indirect payoff for parents from assigning their children as minorities, which makes families more likely to assign their children as minorities. However on the other hand it also increases Han mother's relative bargaining power, which makes families more likely to assign their children as Han.

4.7 Measures

4.7.1 Data

Household data were obtained from the Chinese census. China has been conducting a nationwide census almost every ten years and a population survey (1%) between each census. We use the 1-percent samples of the 1982, 1990, and 2000 censuses and the 2005 population survey.

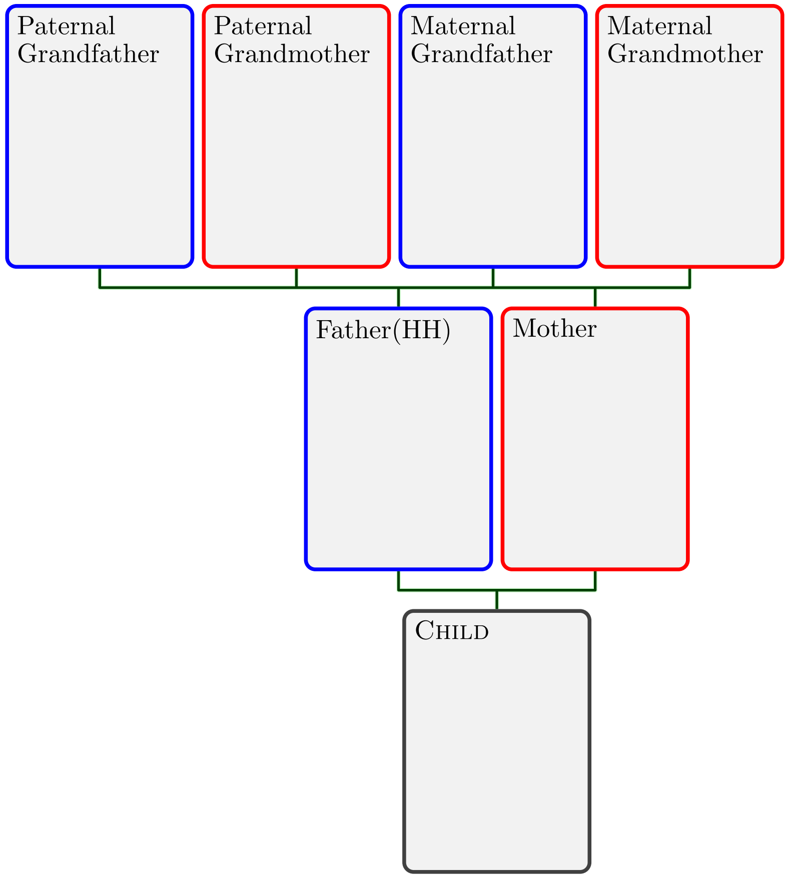
We gauge the data to only look at the husband-wife-children structure of households where 1)One parent is of a minority ethnicity,the other is Han, and 2)one of the parents is the household head (HH). The ethnicity of parents can be identified by the head–spouse–child label in the censuses and by the gender of the head and spouse. We only look at families with one parent as the HH for the following reasons. First, the head-spouse-child structure is the most common in the data. Second, the data do not distinguish parents from parents-in-law, which makes it difficult to examine the parental relationship of the HH. Third, the data lists persons in the family according to "the relation with the HH", which makes it difficult to examine the parental relationship of the grandchildren of the HH. For example, if a household head man lives with his wife, parents and children, then we will look at the decision on the ethnicity of the household head's children made by the household head and his wife rather than the decision on the household head's ethnicity made by his parents. If a household head woman lives with her husband, children, and grandchildren, we will still examine the decision on the ethnicity of the household head's children made by the household head and her husband, rather than the decision on her grandchildren's ethnicity made by her children. We provide two examples to illustrate this issue using the data in Figure 1.1 and Figure 1.2.

As shown in Figure 1.1, since the father is the HH, the data do not distinguish between paternal and maternal grandparents. They are all listed as "the father/mother of the HH". We cannot study the decision-making on the ethnicity of the HH, because we do not know who his parents are. However we can study the decision-making regarding the child's ethnicity made by the HH and the mother.

As shown in Figure 1.2, when a grandmother is the HH, the data does not distinguish between the child and cousin. They are all listed as "the grandson/granddaughter of the HH". We cannot study the decision-making on the ethnicity of the child/cousin because we do not know who their parents are (the father and the uncle are all listed as "the son of the HH"), while we can study the decision-making on the ethnicity of the father/uncle made by the grandfather and HH.

After gauging, the head-spouse-child triad in our data always consists of the head of the household, his wife (or her husband), and their children. It is always the household head and their spouse who make decisions choosing the ethnicity for their child. Our final sample of mixed marriages had around 240,000

Figure 4.1: Father as the Household Head



children, including 130,000 from Han-minority families and 110,000 from minority-Han families.

We also gather the GDP data at the provincial and prefecture levels for the corresponding years from the National Bureau of Statistics of China, as well as the data of universities and colleges[20] of China (Table 4).[21]

4.7.2 Hypotheses and Predictions

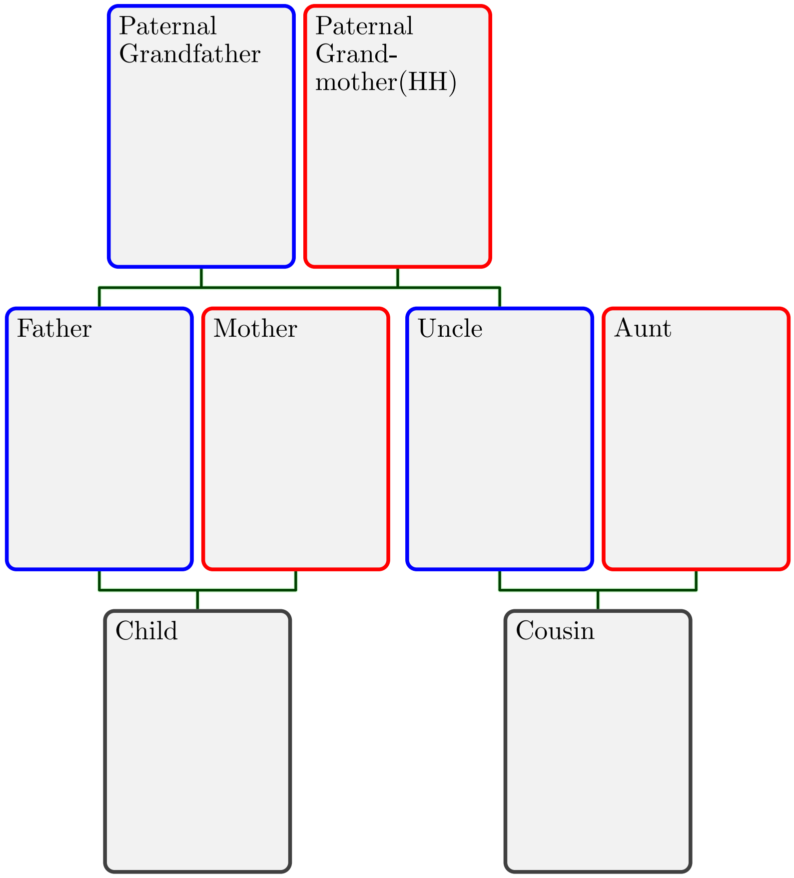
First, we summarize the hypotheses made in Section 5:

1. The indirect payoff for having minority children increases with the economic development and better educational quality.

[20]We select Project 211 schools as the indicator of top schools in the data. Project 211 was a project of national key universities and colleges initiated in 1995 by China. Receiving additional funds, degree programs and policy favors, project 211 institutions that make up about 6 percent of national schools take on the responsibility of training four-fifths of doctoral students, two-thirds of graduate students, half of students from abroad and one-third of undergraduates. They hold 96% of the key laboratories and consume 70% of research funding.

[21]Ministry of Education, China, 2019

Figure 4.2: Grandmother as the Household Head



2. With economics development and better educational quality, the direct payoff will shrink in magnitude, making the direct part less weighted in parents' individual and family utilities. This is equivalent to an increase in the indirect payoff of the utility functions.

3. Women's relative bargaining power increases with economic development.

Although the first two suggest an increase in the incentive of having minority children for families with the development of the economy and better educational quality, there will be different predictions of ethnicity choices for different types of families (H-M family or M-H family) considering the third assumption. For H-M families, all three lead to the prediction that families will be more likely to choose the minority ethnicity for their children, because the minority mother, who has increased bargaining power, would be psychologically in favor of having minority children.In M-H families, it is the Han mother who favors Han children who have increased bargain power. The increased bargaining power of Han mothers shifts the decision of the family bargaining problem toward choosing more Han children, which can offset the impact of economic development and better educational quality that favor minority children. This would make the prediction of

Table 4.4: Universities and Colleges of China

Province	Universities and Colleges	Top Universities and Colleges
Jiangsu	167	11
Guangdong	151	4
Shandong	145	3
Henan	134	1
Hubei	129	7
Hunan	124	4
Hebei	121	1
Anhui	119	3
Liaoning	115	4
Sichuan	109	5
Zhejiang	107	1
Jiangxi	100	1
Shaanxi	93	8
Beijing	92	26
Fujian	89	2
Heilongjiang	81	4
Shanxi	80	1
Yunnan	77	1
Guangxi	74	1
Guizhou	70	1
Chongqing	65	2
Shanghai	64	10
Jilin	62	3
Tianjin	57	3
Inner Mongolia	53	1
Gansu	49	1
Xinjiang	47	2
Hainan	19	1
Ningxia	19	1
Qinghai	12	1
Tibet	7	1

the M-H families ambiguous. Thus we do not have a clear prediction regarding the effect from the economics development and better educational quality on the incentive to choose ethnicities for children in M-H families. The changes, if any, in M-H families' decisions will be determined by the relative magnitude between the increased bargaining power of a Han mother and the increased indirect benefit from having minority children.

According to the data, on average 47% of the children in H-M families are minorities, while 94% of children in the M-H families are minorities. Note that indirect benefits make no difference between the two types of families. Hence, this gap should be generated solely by the difference in direct payoffs due to gender and ethnicity differences among parents. That is, minority fathers and Han mothers have stronger incentives to have their children in the minority, compared with Han fathers and minority mothers. Moreover, the propensity to have minority children has been increasing significantly in H-M families since 1980, while it remains almost the same for M-H families. Table 5 shows the propensity of having minority children and its trend. There has been an increase in H-M families at the individual level, and there has been little change for M-H families.

Table 4.5: Minority Children Shares compared to 1970-74

	H-M Families	M-H Families
1975-79	0.017***	-0.004*
	(0.005)	(0.002)
1980-84	0.048***	0.006
	(0.008)	(0.005)
1985-90	0.089***	-0.007
	(0.011)	(0.003)
1990+	0.109***	-0.002
	(0.015)	(0.005)

Significance: ***,1%, **,5%, *,10%

4.7.3 Empirical Evidence

The model predicts a positive relationship between economic development and education quality and the propensity to choose minority ethnicity for children. We separate the data into H-M families and M-H families.

Main Specification:

$$CM_{i,p,t} = \beta_1 ECON_{r,t} + \beta_2 ECON_{r,t} \times EDU_r + birthyear_t + pref_p + ethn_g + X_{i,p,t} + \epsilon_{i,p,t}$$

The dependent variable $CM_{i,p,t}$ is a binary indicator of child i with a Han father and a minority mother of ethnic group g (or a minority father of ethnic group g and and a Han mother) in prefecture p (in province r), and birth year t having a minority ethnicity. This is directly provided in the data as censuses consistently report ethnicity for each individual.

$ECON_{r,t}$ is the measure of economic development, the log GDP of province r in year t, adjusted for inflation. The coefficient of interest β_1 measures the interaction between economic development and ethnicity choice.

EDU_r measures the level of education, the number of universities and colleges in province r (Table

4). Because of its time-invariance,[22] rather than EDU_r, we are interested in the cross factor of economic development and education quality $ECON_{r,t} \times EDU_r$. Its coefficient β_2 captures the potential change in the effect of economic development from different education levels.

We include $birthyear_t$, $pref_p$ and $ethn_g$ as year fixed effects, prefecture fixed effects and ethnicity fixed effects, since some certain year of cohorts, people in specific regions or people of certain minority groups may have special preferences for having minority (or Han) children (Jia and Persson [2021]).

$X_{i,p,t}$ is the set of other individual and prefecture controls including measures of preferential policies, such as the roll-out of the one child policy, extra fertility of minorities and extra exam scores for minorities. The family planning policies became salient in the 1980s when they became a binding one-child policy. However, minority people are treated flexibly in such a way that in some regions, families with at least one minority parent are allowed to have more than one child. We use the data from Jia and Persson [2021] and the official data from the National Health Commission of China to measure the roll-out of the one child policy and extra fertility of minorities. Extra exam scores for minorities is to capture the educational benefits for minorities. Following in Jia and Persson [2021], we use the administrative data from the 2000 National College Entrance Exam (Gaokao), where the extra scores are normalized to a percentage benefit relative to the cutoff score for four-year universities in each province. This is necessary because each province has its own cutoff score in the same exam, and some provinces even have their own exams. For example, the cutoff score for four-year universities in Beijing in 2000 was 593 out of 750,the extra score granted to minorities was 10, and the percentage benefit was $10/593 = 1.69\%$. This measure is only cross-sectional for provinces and is not time-varying in our regressions.

Table 4.6: Economic Development, Education and Ethnicity Choice, H-M families

	(1)	(2)	(3)
$ECON$	0.070***	0.051**	0.050**
	(0.008)	(0.019)	(0.015)
$ECON_{r,t} \times EDU_r$		0.005**	0.005**
		(0.002)	(0.002)
Year FE	Y	Y	Y
Prefecture FE	Y	Y	Y
Ethnicity FE			Y

Significance: ***,1%, **,5%, *,10%

Table 6 shows the empirical results for H-M families. The significant positive results of the coefficients

[22] Most universities and colleges were founded either before the establishment of P.R.China (1949) or around the first two decades of P.R.China (1950-1970) based on government's plan. There is little change on the numbers of universities and colleges during the period of our population data (1980s - 2010s).

Table 4.7: Economic Development, Education and Ethnicity Choice, M-H family

	(1)	(2)	(3)
$ECON$	0.012	0.014	0.013
	(0.073)	(0.031)	(0.030)
$ECON_{r,t} \times EDU_r$		0.008	0.008
		(0.005)	(0.005)
Year FE	Y	Y	Y
Prefecture FE	Y	Y	Y
Ethnicity FE			Y

Significance: ***,1%, **,5%, *,10%

of interest confirm the prediction that economic development increases the propensity to choose minority ethnicity for children, especially in areas with better educational quality. As explained in the predictions, the economic development and better educational quality increase both the indirect payoff for parents having minority children and the relative bargaining power of the minority mother; these two forces work jointly, making families choose to assign minority ethnicity to their children. This explains the positive effect of economic development on choosing minority ethnicity for children; the effect is greater in regions with better educational quality. On the other hand, no significant result was obtained from M-H family data (Table 7), mainly because of the lack of change in the dependent variables. The previous discussion has provided a plausible explanation, which is that the increased bargaining power of Han mothers offsets the impact of economic development and better educational quality that favor minority children, making M-H families' decisions less responsive to economic development. Another argument here is that because of the strong preference of having his minority ethnicity inherited and following the patriarchal social norm of the minority father, and the weak willingness of having her Han ethnicity inherited from the Han mother, the benefits and costs and bargaining power of most M-H families are naturally unresponsive to changes in economic conditions, compared to those of H-M families. In other words, a relatively small level of material incentive from economic development will not be sufficient to generate a significant change on their choice of ethnicity for the M-H family.

We further explore the behavior of M-H families by examining the data in more details. We separate the data of the M-H families based on the gender of their children. The proposition here is to test whether families with new-born boys will behave differently from families with new-born girls, since the gender of a child can create differences in parents' perception of the benefits and costs regarding the ethnicity of the child, especially the direct benefits and costs that are related to ethnic inheritance and patriarchal minds. As an extension of Chinese patriarchal culture, the meaning of ethic inheritance or cultural inheritance is more significant when the child is a boy. In our model, this means that when Han mothers gain increased relative bargaining power from economic development and better educational quality, it is more likely for them to convert this advantage into their favored result in the bargaining problem (i.e., convincing their minority husband to assign a Han identity to the new-born child) when the new-born child is a girl. Our empirical findings confirm this hypothesis. To tease out the potential influence of existing children on parents' decisions for the new-born child, we limited the data to only look at M-H families with their first child. As shown in Tables 8 and 9, while no significant effect has been found in M-H families with a boy, a significant negative effect of economic development with improved education quality has been found for M-H families with a girl on their decision to assign the new-born girl a minority identity. That is, when the economy develops with improved education quality, it is more likely for M-H families to assign a Han identity to their new-born child only when the child is a girl, because the potential social stigma and the incentive of ethnic inheritance is less intensive for the minority father. Therefore the increased bargaining power of Han mothers out-weighs the indirect benefits of having minority children, making families more likely to choose minority children.

Table 4.8: Economic Development, Education and Ethnicity Choice, M-H family with a boy

	(1)	(2)	(3)
$ECON$	0.010	0.007	0.004
	(0.094)	(0.126)	(0.130)
$ECON_{r,t} \times EDU_r$		0.003	0.003
		(0.005)	(0.005)
Year FE	Y	Y	Y
Prefecture FE	Y	Y	Y
Ethnicity FE			Y

Significance: ***,1%, **,5%, *,10%

Table 4.9: Economic Development, Education and Ethnicity Choice, M-H family with a girl

	(1)	(2)	(3)
$ECON$	-0.022**	-0.015**	-0.017**
	(0.007)	(0.009)	(0.009)
$ECON_{r,t} \times EDU_r$		-0.004**	-0.004**
		(0.001)	(0.001)
Year FE	Y	Y	Y
Prefecture FE	Y	Y	Y
Ethnicity FE			Y

Significance: ***,1%, **,5%, *,10%

4.8 Conclusion

The minority ethnicity choice problem in China is understudied in the economics literature. In this study, we provide theoretical and empirical analyses of the effect of economic development on ethnicity choices for children in China's inter-ethnic marriages. We proposed and empirically tested the prediction based on an intra-household bargaining model in which economic development increases the propensity to choose minority ethnicity for children in families with Han fathers and minority mothers, especially in areas with higher educational foundations. This explains for the change in minority ethnic population in the past and provides potential insights into guiding future policies. For example, considering the differences in the reactions to ethnicity-related policies from families of different ethnicity combinations (H-H, H-M, M-H and M-M), policy makers should design policies at the household level rather than at the individual level.

In future work, we hope to examine our model with micro-level data that carries more detailed individual economic, educational, and cultural measures, which can provide a more precise description of indirect and direct payoffs. In an extension to the topic, one may also look at the effect of economic development on the inter-ethnic marriage market, and therefore its consequence on the choice of ethnicity for children.

Chapter 5

Conclusion

In this dissertation, we explored various dimensions of identity expression, from cultural identity expression in social networks to social hierarchies in animal populations and ethnicity choices in the context of China's inter-ethnic marriages. Through the application of game theory and rigorous mathematical models, we have uncovered interesting patterns and dynamics that govern these expressions of identity.

In our first analysis, we employed game theory to model cultural identity expression in social networks, taking into account the delicate interplay between conformity and uniqueness. Through our innovative network framework, we highlighted the influence of network structures and social environments on the expression of cultural identities. Introducing metrics that provided novel insights into cultural identity dispersion, diversity, and connectivity strengthens our understanding of the intricacies of cultural identity expression. Future research should extend our framework to explore other motives such as self-esteem and examine more complex network structures and player settings.

The second study was centered around the classic Hawk-Dove game, which provided insight into the formation of hierarchical social structures given cognitive ability limitations. This model highlighted the possible mechanisms underlying the diverse forms of social hierarchies observed in nature and suggested a framework to understand how species leverage cognitive abilities in social interactions. We encourage further research to delve deeper into the dynamics of the Hawk-Dove game and cognitive ability limitations in relation to other social hierarchy structures.

Finally, in the context of inter-ethnic marriages in China, we explored the impact of economic development and education quality on ethnicity choices for children. Our intra-household bargaining model provided theoretical and empirical evidence that economic development promotes the propensity to choose minority ethnicity, particularly in regions with a robust educational foundation. This study underscores the significance of designing ethnicity-related policies at the household level, considering the varying reactions from families of different ethnicity combinations. Future research could enrich this line of inquiry by utilizing micro-level data to capture a detailed snapshot of individual economic, educational, and cultural factors.

Overall, this dissertation adds to the expanding field of identity studies, suggesting that identity is not a static or homogeneous concept, but a fluid and dynamic construct that can both greatly affect and be influenced by a variety of socio-economic factors and individual preferences. We recommend that future studies continue to adopt interdisciplinary approaches, merging insights from game theory, economics, sociology, and cognitive science, to more comprehensively understand the nuances of identity formation and expression.

In conclusion, the rich tapestry of identity is interwoven with a multitude of factors, ranging from personal motives to cognitive abilities and socio-economic developments. The knowledge we have uncovered in this dissertation represents an important stepping stone for future identity studies, and we hope that our findings inspire further scholarly inquiry into this fascinating field.

Appendices

Appendices of Chapter 1

Game of cultural identity expression with two players and two identities

In the game depicted in Example 1, each player i has four pure strategies available: $e_i \in (0,0)$, $(0,1)$, $(1,0)$, $(1,1)$. The payoff function is given by $u_i = -\|e_i - \bar{e}\| - ks_i$, where $-\|e_i - \bar{e}\|$ is the disutility derived from deviating from the social average, and ks_i is the disutility derived from being the identical to the other player.

It's worth noting that in a game of cultural identity expression involving two players, exactly one of the disutilities will be zero for players in any strategy profile. This is because the two players either have the same identity expression, which aligns the social average with their expressions and thereby eliminates the cost of deviating from the social average, or they have different identity expressions, in which case players do not incur any cost from being identical to the other player.

Game of cultural identity expression, with two players and two identities

		Player B			
		(0,0)	(0,1)	(1,0)	(1,1)
Player A	(0,0)	$-k, -k$	$-\frac{1}{2}, -\frac{1}{2}$	$-\frac{1}{2}, -\frac{1}{2}$	$-\frac{\sqrt{2}}{2}, -\frac{\sqrt{2}}{2}$
	(0,1)	$-\frac{1}{2}, -\frac{1}{2}$	$-k, -k$	$-\frac{\sqrt{2}}{2}, -\frac{\sqrt{2}}{2}$	$-\frac{1}{2}, -\frac{1}{2}$
	(1,0)	$-\frac{1}{2}, -\frac{1}{2}$	$-\frac{\sqrt{2}}{2}, -\frac{\sqrt{2}}{2}$	$-k, -k$	$-\frac{1}{2}, -\frac{1}{2}$
	(1,1)	$-\frac{\sqrt{2}}{2}, -\frac{\sqrt{2}}{2}$	$-\frac{1}{2}, -\frac{1}{2}$	$-\frac{1}{2}, -\frac{1}{2}$	$-k, -k$

1. If $k < \frac{1}{2}$, then the best responses of players to the other's strategies are:

    - Best response to $(0,0)$ is $(0,0)$
    - Best response to $(0,1)$ is $(0,1)$
    - Best response to $(1,0)$ is $(1,0)$
    - Best response to $(1,1)$ is $(1,1)$

So $((0,0),(0,0))$, $((0,1),(0,1))$, $((1,0),(1,0))$ and $((1,1),(1,1))$ are NEs

2. If $k > \frac{1}{2}$, then the best responses of players to the other's strategies are:

   - Best responses to $(0,0)$ are $(0,1)$ and $(1,0)$
   - Best responses to $(0,1)$ are $(0,0)$ and $(1,1)$
   - Best responses to $(1,0)$ are $(0,0)$ and $(1,1)$
   - Best responses to $(1,1)$ are $(0,1)$ and $(1,0)$

   So $((1,0),(0,0))$, $((1,0),(1,1))$,$((0,0),(0,1))$, $((0,0),(1,0))$, $((0,1),(0,0))$, $((0,1),(1,1))$, $((1,1),(1,0))$, $((1,1),(0,1))$ are NEs.

3. If $k = \frac{1}{2}$, all best response conditions in previous two cases are true, so all NEs in previous two cases are NEs.

Game of expressing of cultural identity with two players and two identities with self-esteem motives

In the game depicted in example 2, each player now has their personal values: $v_A = (1,0)$, $v_B = (0,1)$, which are used in deriving the utility related with the newly-added self-esteem motives. Recall with the self-esteem motive, the utility is now:

$$u_i = -\alpha \|e_i - v_i\| - \beta \|e_i - \bar{e}\| - \gamma s_i$$

Each agent chooses their strategy e_i from the strategy set $\{(0,0),(0,1),(1,0),(1,1)\}$, so there are 16 possible strategy profiles. Substituting strategies into the utility function gives us the individual payoff under each strategy profile:

$$u_A((0,0),(0,0)) = -\alpha\|(0,0)-(1,0)\| - \beta\|(0,0)-(0,0)\| - \gamma(1) = -\alpha - \gamma$$

$$u_B((0,0),(0,0)) = -\alpha\|(0,0)-(0,1)\| - \beta\|(0,0)-(0,0)\| - \gamma(1) = -\alpha - \gamma$$

$$u_A((0,1),(0,0)) = -\alpha\|(0,1)-(1,0)\| - \beta\|(0,1)-(0,\frac{1}{2})\| - \gamma(0) = -\sqrt{2}\alpha - \frac{1}{2}\beta$$

$$u_B((0,1),(0,0)) = -\alpha\|(0,0)-(0,1)\| - \beta\|(0,0)-(0,\frac{1}{2})\| - \gamma(0) = -\alpha - \frac{1}{2}\beta$$

$$u_A((1,0),(0,0)) = -\alpha\|(1,0)-(1,0)\| - \beta\|(1,0)-(\frac{1}{2},0)\| - \gamma(0) = -\frac{1}{2}\beta$$

$$u_B((1,0),(0,0)) = -\alpha\|(0,0)-(0,1)\| - \beta\|(0,0)-(\frac{1}{2},0)\| - \gamma(0) = -\alpha - \frac{1}{2}\beta$$

$$u_A((1,1),(0,0)) = -\alpha\|(1,1)-(1,0)\| - \beta\|(1,1)-(\frac{1}{2},\frac{1}{2})\| - \gamma(0) = -\alpha - \frac{\sqrt{2}}{2}\beta$$

$$u_B((1,1),(0,0)) = -\alpha\|(0,0)-(0,1)\| - \beta\|(0,0)-(\frac{1}{2},\frac{1}{2})\| - \gamma(0) = -\alpha - \frac{\sqrt{2}}{2}\beta$$

$$u_A((0,0),(0,1)) = -\alpha\|(0,0)-(1,0)\| - \beta\|(0,0)-(0,\frac{1}{2})\| - \gamma(0) = -\alpha - \frac{1}{2}\beta$$

$$u_B((0,0),(0,1)) = -\alpha\|(0,1)-(0,1)\| - \beta\|(0,1)-(0,\frac{1}{2})\| - \gamma(0) = -\frac{1}{2}\beta$$

$$u_A((0,1),(0,1)) = -\alpha\|(0,1)-(1,0)\| - \beta\|(0,1)-(0,1)\| - \gamma(1) = -\sqrt{2}\alpha - \gamma$$

$$u_B((0,1),(0,1)) = -\alpha\|(0,1)-(0,1)\| - \beta\|(0,1)-(0,1)\| - \gamma(1) = -\gamma$$

$$u_A((1,0),(0,1)) = -\alpha\|(1,0)-(1,0)\| - \beta\|(1,0)-(\frac{1}{2},\frac{1}{2})\| - \gamma(0) = -\frac{\sqrt{2}}{2}\beta$$

$$u_B((1,0),(0,1)) = -\alpha\|(0,1)-(0,1)\| - \beta\|(0,1)-(\frac{1}{2},\frac{1}{2})\| - \gamma(0) = -\frac{\sqrt{2}}{2}\beta$$

$$u_A((1,1),(0,1)) = -\alpha\|(1,1)-(1,0)\| - \beta\|(1,1)-(\frac{1}{2},1)\| - \gamma(0) = -\alpha - \frac{1}{2}\beta$$

$$u_B((1,1),(0,1)) = -\alpha\|(0,1)-(0,1)\| - \beta\|(0,1)-(\frac{1}{2},1)\| - \gamma(0) = -\frac{1}{2}\beta$$

$$u_A((0,0),(1,0)) = -\alpha\|(0,0)-(1,0)\| - \beta\|(0,0)-(\frac{1}{2},0)\| - \gamma(0) = -\alpha - \frac{1}{2}\beta$$

$$u_B((0,0),(1,0)) = -\alpha\|(1,0)-(0,1)\| - \beta\|(1,0)-(\frac{1}{2},0)\| - \gamma(0) = -\sqrt{2}\alpha - \frac{1}{2}\beta$$

$$u_A((0,1),(1,0)) = -\alpha\|(0,1)-(1,0)\| - \beta\|(0,1)-(\frac{1}{2},\frac{1}{2})\| - \gamma(0) = -\sqrt{2}\alpha - \frac{\sqrt{2}}{2}\beta$$

$$u_B((0,1),(1,0)) = -\alpha\|(1,0)-(0,1)\| - \beta\|(1,0)-(\frac{1}{2},\frac{1}{2})\| - \gamma(0) = -\sqrt{2}\alpha - \frac{\sqrt{2}}{2}\beta$$

$$u_A((1,0),(1,0)) = -\alpha\|(1,0)-(1,0)\| - \beta\|(1,0)-(1,0)\| - \gamma(1) = -\gamma$$
$$u_B((1,0),(1,0)) = -\alpha\|(1,0)-(0,1)\| - \beta\|(1,0)-(1,0)\| - \gamma(1) = -\sqrt{2}\alpha - \gamma$$
$$u_A((1,1),(1,0)) = -\alpha\|(1,1)-(1,0)\| - \beta\|(1,1)-(1,\frac{1}{2})\| - \gamma(0) = -\alpha - \frac{1}{2}\beta$$
$$u_B((1,1),(1,0)) = -\alpha\|(1,0)-(0,1)\| - \beta\|(1,0)-(1,\frac{1}{2})\| - \gamma(0) = -\sqrt{2}\alpha - \frac{1}{2}\beta$$
$$u_A((0,0),(1,1)) = -\alpha\|(0,0)-(1,0)\| - \beta\|(0,0)-(\frac{1}{2},\frac{1}{2})\| - \gamma(0) = -\alpha - \frac{\sqrt{2}}{2}\beta$$
$$u_B((0,0),(1,1)) = -\alpha\|(1,1)-(0,1)\| - \beta\|(1,1)-(\frac{1}{2},\frac{1}{2})\| - \gamma(0) = -\alpha - \frac{\sqrt{2}}{2}\beta$$
$$u_A((0,1),(1,1)) = -\alpha\|(0,1)-(1,0)\| - \beta\|(0,1)-(\frac{1}{2},1)\| - \gamma(0) = -\sqrt{2}\alpha - \frac{1}{2}\beta$$
$$u_B((0,1),(1,1)) = -\alpha\|(1,1)-(0,1)\| - \beta\|(1,1)-(\frac{1}{2},1)\| - \gamma(0) = -\alpha - \frac{1}{2}\beta$$
$$u_A((1,0),(1,1)) = -\alpha\|(1,0)-(1,0)\| - \beta\|(1,0)-(1,\frac{1}{2})\| - \gamma(0) = -\frac{1}{2}\beta$$
$$u_B((1,0),(1,1)) = -\alpha\|(1,1)-(0,1)\| - \beta\|(1,1)-(1,\frac{1}{2})\| - \gamma(0) = -\alpha - \frac{1}{2}\beta$$
$$u_A((1,1),(1,1)) = -\alpha\|(1,1)-(1,0)\| - \beta\|(1,1)-(1,1)\| - \gamma(1) = -\alpha - \gamma$$
$$u_B((1,1),(1,1)) = -\alpha\|(1,1)-(0,1)\| - \beta\|(1,1)-(1,1)\| - \gamma(1) = -\alpha - \gamma$$

The calculation gives us the game table:

Game of expressing cultural identity, two players and two identities with self-esteem motives

		Player B			
		(0,0)	(0,1)	(1,0)	(1,1)
Player A	(0,0)	$-\alpha-\gamma, -\alpha-\gamma$	$-\alpha-\frac{1}{2}\beta, -\frac{1}{2}\beta$	$-\alpha-\frac{1}{2}\beta, -\sqrt{2}\alpha-\frac{1}{2}\beta$	$-\alpha-\frac{\sqrt{2}}{2}\beta, -\alpha-\frac{\sqrt{2}}{2}\beta$
	(0,1)	$-\sqrt{2}\alpha-\frac{1}{2}\beta, -\alpha-\frac{1}{2}\beta$	$-\sqrt{2}\alpha-\gamma, -\gamma$	$-\sqrt{2}\alpha-\frac{\sqrt{2}}{2}\beta, -\sqrt{2}\alpha-\frac{\sqrt{2}}{2}\beta$	$-\sqrt{2}\alpha-\frac{1}{2}\beta, -\alpha-\frac{1}{2}\beta$
	(1,0)	$-\frac{1}{2}\beta, -\alpha-\frac{1}{2}\beta$	$-\frac{\sqrt{2}}{2}\beta, -\frac{\sqrt{2}}{2}\beta$	$-\gamma, -\sqrt{2}\alpha-\gamma$	$-\frac{1}{2}\beta, -\alpha-\frac{1}{2}\beta$
	(1,1)	$-\alpha-\frac{\sqrt{2}}{2}\beta, -\alpha-\frac{\sqrt{2}}{2}\beta$	$-\alpha-\frac{1}{2}\beta, -\frac{1}{2}\beta$	$-\alpha-\frac{1}{2}\beta, -\sqrt{2}\alpha-\frac{1}{2}\beta$	$-\alpha-\gamma, -\alpha-\gamma$

To identify the pure NEs of the game, we will examine the best responses (BR) of players.

For player A:

1. If player B plays $(0,0)$, player A's BR is to play $(0,0)$ if $\alpha+\gamma < \frac{1}{2}\beta$, to play $(1,0)$ if $\alpha+\gamma > \frac{1}{2}\beta$, and to play $(0,0)$ or $(1,0)$ if $\alpha+\gamma = \frac{1}{2}\beta$.

2. If player B plays $(0,1)$, player A's BR is to play $(0,0)$ or $(1,1)$ if $\alpha < \frac{\sqrt{2}-1}{2}\beta$ and $(\sqrt{2}-1)\alpha > \frac{1}{2}\beta - \gamma$, to play $(1,0)$ if $\alpha > \frac{\sqrt{2}-1}{2}\beta$ and $\sqrt{2}\alpha+\gamma > \frac{\sqrt{2}}{2}\beta$, to play $(0,1)$ if $\alpha > \frac{\sqrt{2}-1}{2}\beta$ and $\sqrt{2}\alpha+\gamma < \frac{\sqrt{2}}{2}\beta$.

3. If player B plays $(1,0)$, player A's BR is to play $(0,0)$ or $(1,1)$ if $\alpha+\frac{1}{2}\beta < \gamma$, to play $(1,0)$ if $\alpha+\frac{1}{2}\beta > \gamma$, and to play $(0,0)$ or $(1,1)$ or $(1,0)$ if $\alpha+\frac{1}{2}\beta = \gamma$.

4. If player B plays $(1,1)$, player A's BR is to play $(1,0)$ if $\alpha+\gamma > \frac{1}{2}\beta$, to play $(1,1)$ if $\alpha+\gamma < \frac{1}{2}\beta$, and to play $(1,0)$ or $(1,1)$ if $\alpha+\gamma = \frac{1}{2}\beta$.

For player B:

1. If player A plays $(0,0)$, player B's BR is to play $(0,0)$ if $\alpha+\gamma < \frac{1}{2}\beta$, to play $(0,1)$ if $\alpha+\gamma > \frac{1}{2}\beta$, and to play $(0,0)$ or $(1,0)$ if $\alpha+\gamma = \frac{1}{2}\beta$.

2. If player A plays $(0,1)$, player B's BR is to play $(0,0)$ or $(1,1)$ if $\alpha+\frac{1}{2}\beta < \gamma$, to play $(0,1)$ if $\alpha+\frac{1}{2}\beta > \gamma$, and to play $(0,0)$ or $(1,1)$ or $(0,1)$ if $\alpha+\frac{1}{2}\beta = \gamma$.

3. If player A plays $(1,0)$, player B's BR is to play $(0,0)$ or $(1,1)$ if $\alpha < \frac{\sqrt{2}-1}{2}\beta$ and $(\sqrt{2}-1)\alpha > \frac{1}{2}\beta-\gamma$, to play $(0,1)$ if If $\alpha > \frac{\sqrt{2}-1}{2}\beta$ and $\sqrt{2}\alpha+\gamma > \frac{\sqrt{2}}{2}\beta$, to play $(1,0)$ if $\alpha > \frac{\sqrt{2}-1}{2}\beta$ and $\sqrt{2}\alpha+\gamma < \frac{\sqrt{2}}{2}\beta$.

4. If player A plays $(1,1)$, player B's BR is to play $(0,1)$ if $\alpha+\gamma > \frac{1}{2}\beta$, to play $(1,1)$ if $\alpha+\gamma < \frac{1}{2}\beta$, and to play $(0,1)$ or $(1,1)$ if $\alpha+\gamma = \frac{1}{2}\beta$.

Combine the BRs from player A and player B, we can get:

1. $((0,0),(0,0))$ and $((1,1),(1,1))$ are strategy profiles where players playing BR to each other's strategy if $\alpha+\gamma \leq \frac{1}{2}\beta$. So if $\alpha+\gamma \leq \frac{1}{2}\beta$, then ((0,0),(0,0)) and ((1,1),(1,1)) are NEs. One example here can be when $\alpha = 1$, $\beta = 8$, and $\gamma = 2$.

2. $((1,0),(0,0))$, $((1,0),(1,1))$,$((0,0),(0,1))$ and $((1,1),(0,1))$ are strategy profiles where players playing BR to each other's strategy if $\alpha \leq \frac{\sqrt{2}-1}{2}\beta$, $\alpha+\gamma \geq \frac{1}{2}\beta$ and $(\sqrt{2}-1)\alpha \geq \frac{1}{2}\beta-\gamma$. So if $\alpha \leq \frac{\sqrt{2}-1}{2}\beta$, $\alpha+\gamma \geq \frac{1}{2}\beta$ and $(\sqrt{2}-1)\alpha \geq \frac{1}{2}\beta-\gamma$, then ((1,0),(0,0)), ((1,0),(1,1)),((0,0),(0,1)) and ((1,1),(0,1)) are NEs. One example here can be when $\alpha = 2$, $\beta = 10$, and $\gamma = 5$.

3. $((1,0),(0,1))$ is a strategy profiles where players playing BR to each other's strategy if $\alpha \geq \frac{\sqrt{2}-1}{2}\beta$ and $\sqrt{2}\alpha+\gamma \geq \frac{\sqrt{2}}{2}\beta$. So if $\alpha \geq \frac{\sqrt{2}-1}{2}\beta$ and $\sqrt{2}\alpha+\gamma \geq \frac{\sqrt{2}}{2}\beta$, then ((1,0),(0,1)) is a NE. One example here can be when $\alpha = 2$, $\beta = 2$, and $\gamma = 2$.

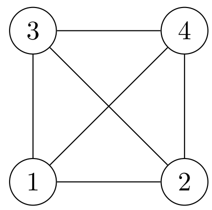
4. $((0,1),(0,1))$ and $(1,0),(1,0)$ are strategy profiles where players playing BR to each other's strategy if $\alpha+\frac{1}{2}\beta > \gamma$, $\alpha > \frac{\sqrt{2}-1}{2}\beta$ and $\sqrt{2}\alpha+\gamma < \frac{\sqrt{2}}{2}\beta$. So if $\alpha+\frac{1}{2}\beta > \gamma$, $\alpha > \frac{\sqrt{2}-1}{2}\beta$ and $\sqrt{2}\alpha+\gamma < \frac{\sqrt{2}}{2}\beta$ then $((0,1),(0,1))$ and $(1,0),(1,0)$ are NEs. One example here can be when $\alpha = 2$, $\beta = 4$, and $\gamma = 2$.

5. No matter what values of α,β, and γ are, Player A is not playing their best response at strategy profiles $((0,1),(0,0))$,$((1,1),(0,0))$,$((0,1),(1,0))$,$((0,0),(1,1))$ and $((0,1),(1,1))$. These strategy profiles cannot be NEs.

6. No matter what values of α,β, and γ are, Player B is not playing their best response at strategy profiles $((0,0),(1,0))$,$((0,0),(1,1))$,$((0,1),(1,0))$,$((1,1),(0,0))$ and $((1,1),(1,0))$. These strategy profiles cannot be NEs.

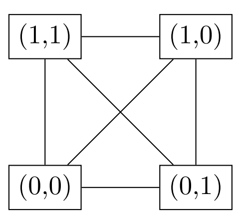
List of NEs of four player networks

Complete graph

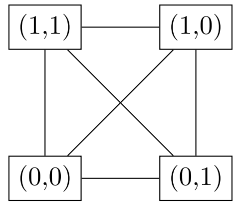


The complete graph is the most connected network structure, where every player is directly connected to every other player. In this case, every player can observe the strategies of all other players, and therefore the opportunities for coordination are high. The level of social interaction of this network is $l = 3$. The NEs for different values of the parameter k are as follows:

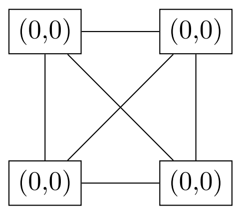
1. When $k = 1$, strategy profiles where all four players choosing different strategies are Nash equilibria. Each player selects a different strategy that is equidistant from the average of all strategies, receiving a payoff of $\frac{\sqrt{2}}{2}$. There are 24 different combinations of strategy profiles that could arise in this game, which all have a dispersion of $D = \frac{\sqrt{2}}{2}$ and 4 traits. An example of such combinations is:



2. When $k = 0.5$, all four players choosing different strategies are still Nash equilibria. The relative decreasing in the uniqueness motive is not enough to support any new equilibrium yet. resulting in the same Nash equilibrium with a dispersion of $D = \frac{\sqrt{2}}{2}$ as in the previous case. This suggests that the relative strength of the motive to conform and the motive to be unique has little impact on the outcomes in a complete graph when k is between 0.5 and 1.

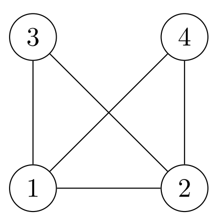


3. When $k = 0$, only NEs are when all four players choose the same strategy, resulting in a Nash equilibrium with a dispersion of $D = 0$. In this case, all players select the same strategy that matches the average of all strategies. This suggests that, without any incentive to differentiate from others, players tend to converge to a single strategy in a complete graph. There four ways to form this NE with one trait. Below is one example.



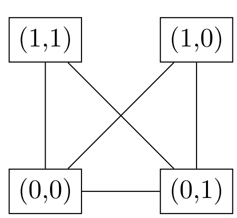
5-edge graph

The 5-edge graph has two players connected to three neighbors, and two players connected to two neighbors. The maximum number of links is three.

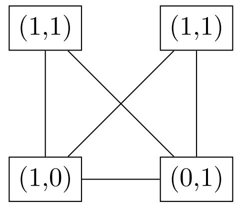


1. When k=1, there are two different possible Nash equilibria.

   (a) The first equilibrium is where all four players choose different strategies, resulting in a dispersion of $D = 0.7071$ (with 24 Combinations). This is same as the NEs in the complete graph.

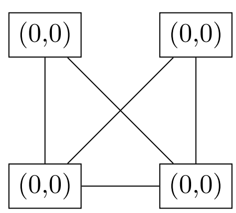


(b) The second equilibrium is where players with two neighbors choose the same strategy, while one player with three neighbors chooses an strategy that shares one of the identities from the two's. And the other player with three neighbors chooses the other strategy that shares one of the identities from the two's. There are 8 combinations of this type of equilibrium with a dispersion of $D = 0.3$.



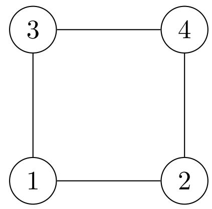
2. When $k = 0.5$, there is no equilibrium. Agents will always have incentives to deviate to another strategy, given any other's strategies. As a result, the system in this network will continually change between multiple strategy profiles, with no steady states serving as the Nash Equilibrium (NE). This dynamic implies that under certain conditions, such as when the relative strength of uniqueness over conformity is equal to 0.5, the cultural identity expressions within the population may never stabilize, leading to an ever-shifting landscape of identity expressions. This finding highlights the importance of considering the impact of parameters such as k on the overall stability of the system when examining the dynamics of cultural identity expression in multicultural societies.

3. When k=0, all four players choosing the same strategy is still the Nash equilibrium with a dispersion of $D = 0$.



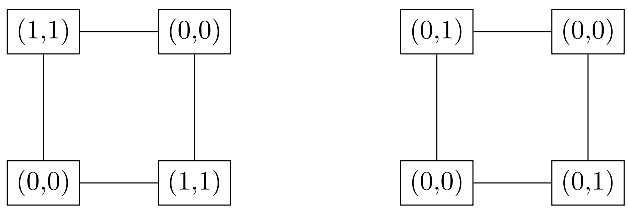
4-edge cycle or ring

The 4-edge cycle or ring is a network structure where players are connected in a closed cycle, forming a ring-like structure. This structure differs from the previous two structures in terms of the maximum links connected to a node, which is two compared to three in the previous two examples. We discussed the maximum links connected to a node as it captures the level of social interaction of a network structure. The reduced level of social interaction can lead to different dynamics in terms of cultural identity expression. As individuals have fewer connections, their identity expression decisions may be more influenced by their immediate neighbors, leading to a potentially different balance between conformity and uniqueness. This can, in turn, affect the Nash Equilibria and the overall distribution of cultural identity expressions within the population.

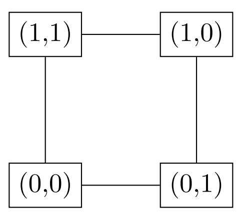


1. When k=1, there are three different types of NEs:

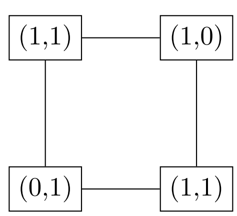
   (a) NEs contain two types of strategies (number of traits is two) which players choose strategies in an A-B-A-B pattern. There are 4 different combinations if A and B does not share any identity expression (with D=0.7071), and 8 combinations if they share one (D=0.5)

   (b) NEs contain four types of strategies where all players choose different strategies in an A-B-C-D pattern. (24 combinations with D=0.7071)

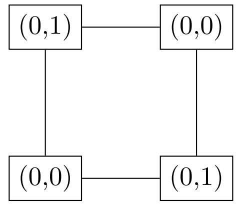
   

   (c) NEs contain three types of strategies where players choose strategies in an A-B-A-C pattern. (8 combinations with D=0.3)

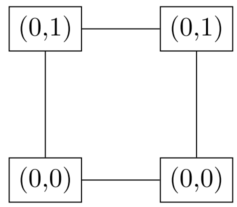
   

2. When k=0.5:

   (a) Players choose strategies in an A-B-A-B pattern. (8 combinations with D=0.5)

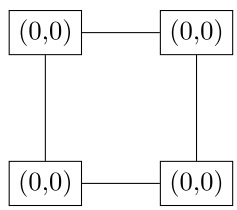


(b) Players choose strategies in an A-A-B-B pattern.(8 combinations with D=0.5)

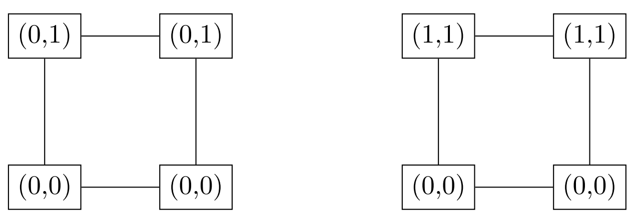


3. When k=0:

(a) All four players choose the same strategy. D=0

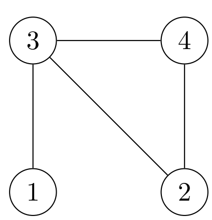


(b) Players choose strategies in an A-A-B-B pattern. (4 combinations with D=0.7071, 8 combinations with D=0.5)

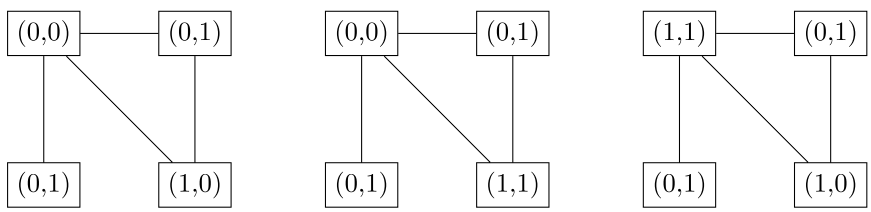


4-edge "bowtie"

In bowtie networks, One central player is connected to three neighbors, and two of those three neighbors are connected to each other.



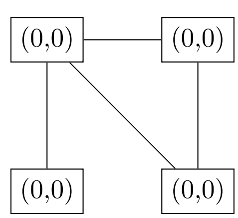
1. When k=1: Strategy profiles where everyone plays a different strategy (A-B-C-D profile, D=0.7071), are NEs. Strategy profiles in which the player who is only connected to the central player (the player connected to all others) chooses a strategy that shares one identity with the central player's strategy, while the other two players, who are connected to each other and also connected to the central player, choosing another strategy that also shares one identity with the central player's strategy, are also NEs. In such NEs, the number of strategies is three, with Dispersion $D = 0.6583$. Another Each player shares one common cultural identity trait with the central player while still maintaining some level of uniqueness in their strategy. Another type of three-trait NE also exists, with a difference where one of the two players, who are connected to each other and also connected to the central player, chooses the strategy that does not share any identity type with the central player's strategy. In such NEs, the number of strategies is three, with Dispersion $D = 0.3$



2. When $k = 0.5$, both the A-B-C-D profile, where everyone plays a different strategy (D=0.7071), and the A-B-B-C 3-trait strategy profiles, with $D = 0.6583$, can still be NE. The $D = 0,3$ 3-trait strategy profile is no longer NE.

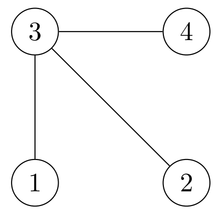
   In the A-B-C-D profile, individuals express greater uniqueness in their cultural identity, as each player chooses a different strategy. This results in a higher dispersion value and more traits, reflecting a more diverse set of cultural identity expressions within the population. On the other hand, the A-B-B-C strategy profiles exhibit a lower dispersion value and less traits, indicating a higher level of conformity to a shared identity.

3. When $k = 0$, the only type of NE is still all player playing a same strategy.



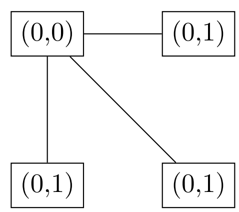
Star-like structure

A star-like structure is where one central player is connected to all other players, and non-central players are not connected.

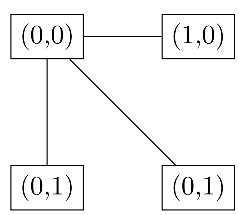


1. When k=1, there are two types of NEs:

   (a) Central player picks one strategy (e.g., (0,0)), and the other three players pick the same adjacent strategy (e.g., (0,1)). D= 0.375

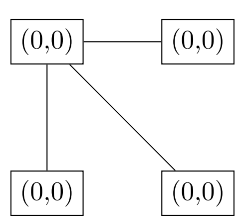
   

   (b) Central player picks one strategy (e.g., (0,0)), two of the other players pick the same adjacent strategy (e.g., (0,1)), and the remaining player picks the other adjacent strategy (e.g., (1,0)). D=0.6583

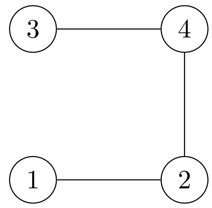
2. When k=0.5, Two types of strategy profiles as NEs when $k = 1$ are still equilibria. Similar to the case in the complete graph, this suggests that the relative strength of the motive to conform and the motive to be unique has little impact on the outcomes in a star-like graph when k is between 0.5 and 1.

3. When $k = 0$, the only type of NE is still all player playing a same strategy.



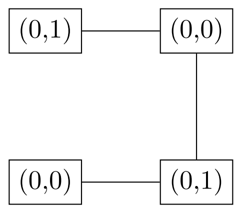
Line structure

In a line structure, two players at the ends have only one neighbor while the middle two players have two neighbors, the level of social interaction of a line structure is 2.

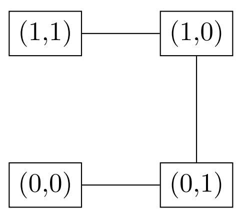


1. When k=1, there are three types of NE:

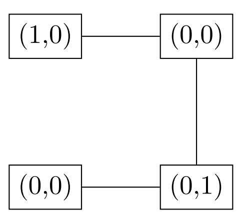
   (a) Players choose strategies in an A-B-A-B pattern. There are 8 combinations with D=0.5.

   (b) Players choose strategies in an A-B-C-D pattern. There are 24 combinations with D=0.7071.

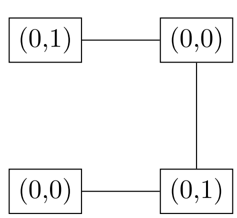
   

   (c) Players choose strategies in an A-B-A-C pattern. 8 combinations with D=0.6361.

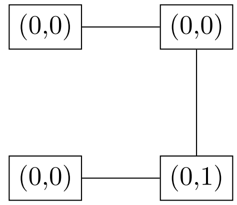
   

2. k=0.5

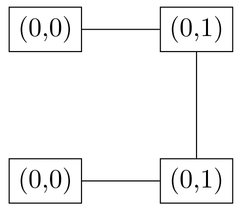
   (a) Players choose strategies in an A-B-A-B pattern. 8 combinations with D=0.5.

(b) Players choose strategies in an A-B-A-A pattern. 8 combinations with D=0.375.

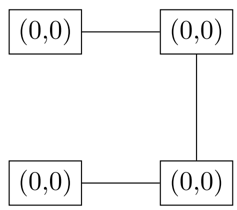


(c) Players choose strategies in an A-B-B-A pattern. 8 combinations with D=0.5.

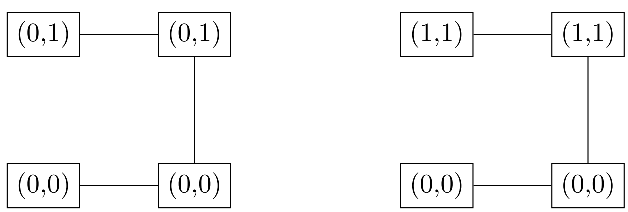


3. k=0

(a) Players choose strategies in an A-A-A-A pattern. 4 combinations D=0.



(b) Players choose strategies in an A-A-B-B pattern. 8 combinations with D=0.5 and 4 combinations with D=0.7071.



Appendix of Chapter 2: Computational method to find the optimal social structure

1. Set N = given population, m = given memory ability.
2. Create the memory profile matrix base and the strategy profile matrix base, they are N-by-N null matrix.
3. Digitize the strategies (we use: hawk = 3, dove = 1, mix = 2), to be used in the strategy profile matrix.
4. Generate an arbitrary memory profile matrix under the given memory ability.
5. Generate an arbitrary strategy profile matrix at equilibrium (the off-diagonal pairs must sum to 4, meaning players must play $H - D$, $D - H$, or $M - M$ at equilibrium).
6. Check whether the strategy profile can be supported by the memory profile. The strategy profile can be supported by the memory profile if the agents play the same strategy against all non-memorized opponents:
   (a) Locate all 0-value entries in the first row in the memory profile matrix. This reflects all non-memorized opponents for the first agent.
   (b) Find all corresponding entries in the strategy profile matrix to the entries found in (a).
   (c) If all entries found in (b) have the same value, then this agent's strategy profile can be supported by its memory profile.
   (d) Repeat (a) to (c) for every agents. The strategy profile matrix is supported by the memory profile matrix if all agents' strategy profiles can be supported by their memory profiles.
7. If the strategy profile can be supported by the memory profile, then it is an equilibrium. Count the number of clashes by counting entries with value=2 (strategy M) in the strategy profile matrix. Divide by 2 will give us the number of pairs that play $M - M$ (i.e. clash pairs).
8. Repeat 5-7 for all possible strategy profile matrices at equilibrium.
9. Repeat 4-8 for all possible memory profile matrices under the given memory ability.
10. The social structure that induces the least number of clashes is the optimal social structure. If there are multiple, compare their memory profile matrices. The one with more zeroes (fewer ones) is the superior one in terms of fitness, because of lower memory usage.

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